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| 1 | Title page | -- | Date for application |
| 2 | Table of Contents | i - xiv | Changes to application to reflect revisions |
| 3 | Application | Appl-1 (Sections 5) | Owner's Signature |
| 4 | Application | Appl-1 (Section 6 and 7) | Legal location (Sections, T/R); revised acres |
| 5 | Application | Appl-2 (Section 11) | Name of person signing form |
| 6 | Application | Appl. Attachment 1 – Section A6 | Datum/Latitude/Longitude |
| 7 | Application | Appl. Attachment 1-6a | Latitude/Longitude of revised boundary table |
| 8 | Application | Appl. Attachment 1 Section A-7 | Revised NTEA acreage |
| 9 | Application | -- | Figure Appl. 1-1 |
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| 107 | Chapter T | T-7 | Section T.2.1.2.5 [revised ft2 & pore vol amts.] |
| 108 | Chapter T | T-8 | Section T.2.2 |
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| 131 | Chapter V | V-1 | Certification signature (different signer) |
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| 133 | Appendix 1 | -- | New well completion report for Well #445 |
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| 137 | Appendix 5 | -- | Revised Figures 1-1 and 1-2 |
| 138 | Appendix 6 | -- | Revised Water Users Survey spreadsheet |
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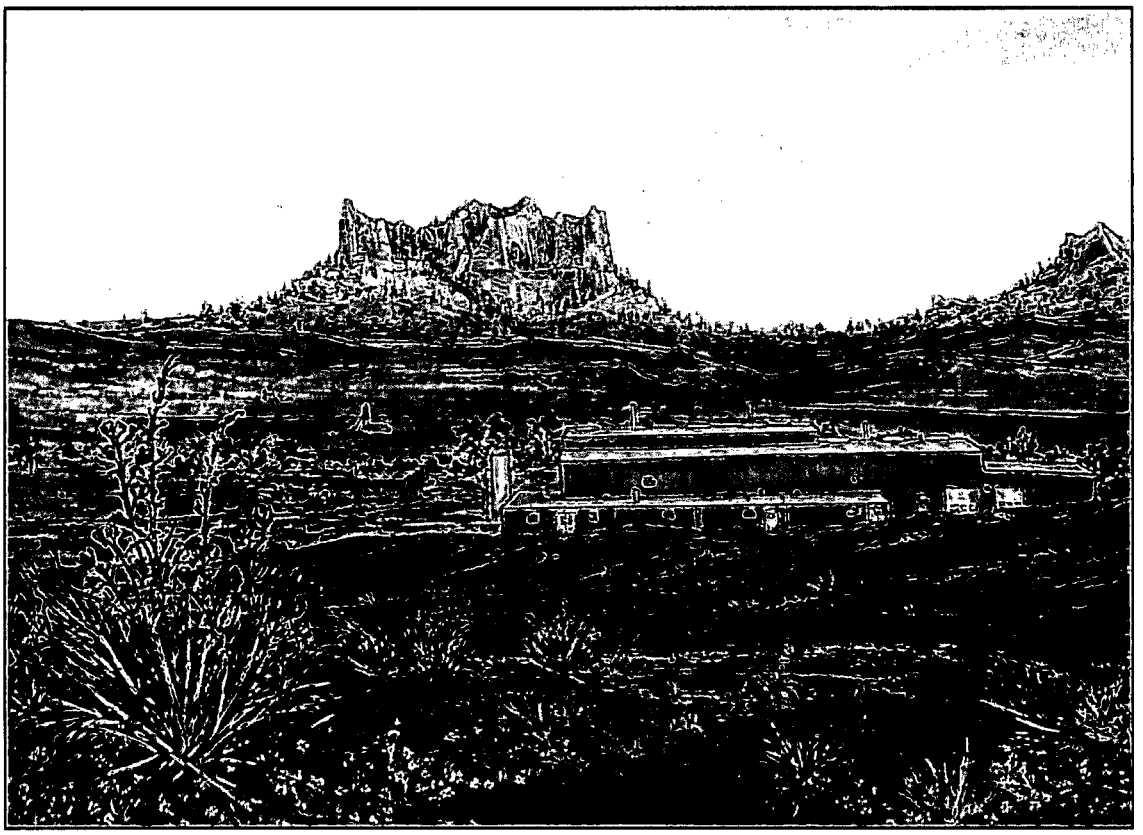
| 139 | Appendix 10 | -- | New: Swift Fox Survey Protocol |
| | | | |

# Application for

# Nebraska Department of Environmental Quality (NDEQ)

# Class III Underground Injection Control (UIC) Permit

## Volume I – Application

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**January 2010 (Revised)**

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Appendix 3 Mineralogical and Particles Size Distribution Analyses
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| FOR AGENCY USE ONLY | APPLICATION NUMBER | | |
|---|---|---|---|
| | N E | | |
| | DATE RECEIVED | | |
| | | | |
| | YEAR | MO. | DAY |

**NEBRASKA DEPARTMENT OF ENVIRONMENTAL QUALITY**
**APPLICATION FOR A CLASS III UNDERGROUND INJECTION CONTROL (UIC) PERMIT APPLICATION**

**This application is required in accordance to Title 122, Chapter 7, Section 001.** This application must be submitted at least 180 days prior to any testing, drilling, or planned construction at the application site. Every item on this application must be completed. **An incomplete application will be returned.** If you have questions while filling out this application please refer to Title 122, Chapter 11 or call **(402) 471-4982** and someone will assist you.

1. **Did you include the $25,000.00 non-refundable permit fee Made payable to the State of Nebraska?** **Yes**

2. **Describe the activities conducted at the facility and nature of the business (Attach if necessary):**

CBR currently operates a commercial in-situ leach uranium mine located in Dawes County, Nebraska. The existing facility is operated under a Class III UIC Permit issued by the NDEQ (Permit Number NE0122611) which became effective on April 23, 1990.

Crow Butte Resources, Inc. (CBR) is submitting this permit application to the Nebraska Department of Environmental Quality (NDEQ) to allow development of additional uranium in-situ leach mining resources located near the current mining operations in Dawes County, Nebraska. The proposed new development area, referred to as the North Trend Expansion Area (NTEA), will be used as a satellite facility to the existing main plant. The North Trend Expansion Area will be developed by constructing independent wellfields and mining support facilities while utilizing existing processing equipment to the greatest extent possible for uranium recovery. Additional information about the facilities is presented in Chapters A and B of Supplemental Information for this application.

3. **List up to 4 Standard Industrial Classification (SIC) codes which best reflect the facility or process.**

| | | | |
|---|---|---|---|
| **1094** | **NAICS 212291** | | |

4.

| | | | |
|---|---|---|---|
| **Name of Facility:** | **Crow Butte Operation** | | |
| Operator's Name: | **Crow Butte Resources, Inc. d/b/a Cameco Resource** | | |
| Street Address: | **86 Crow Butte Road** | City/ zip: | **Crawford 69339** |
| Telephone Number: | **308-665-2215** | County: | **Dawes** |
| Ownership Status: | (i.e. President, Partner, Stockholder) | **Subsidiary of Cameco U.S Holdings, Inc.** | |
| Entity Status: | (i.e. Federal, State, Private, Other) | **Private** | |

5.

| | | | |
|---|---|---|---|
| **Owner's Name:** | **Cameco Resources** | | |
| Mailing Address: | **141 Union Blvd. Suite 330** | City/zip: | **Lakewood 80228** |
| Telephone Number: | **720-879-5140** | County: | **Jefferson** |
| Ownership Status: | (i.e. President, Partner, Stockholder) | **Subsidiary of Cameco U.S. Holdings, Inc.** | |
| Entity Status: | (i.e. Federal, State, Private, Other) | **Private** | |
| Owner's Signature: | | | |

6. **Legal Location of the Injection well including county:** County: **Dawes**
(i.e. NW ¼ of the SE ¼ of Section 27, Township 14 North, Range 1 East)
**Section 21, 22, 27, 28 and 34 of Township 32 North, Range 52 West**

7. **Is the facility located on Indian lands, historic and/or archaeological sites?** **Yes**
**If yes, please list them below (Attach if necessary):**

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| See Attachment |
| --- |
| |
| |
| |
| |

8. **List all environmental permits, construction approval, or any other relevant permit, received or applied for from the Department or any other federal, state, or local regulatory agency for this site (Attach if necessary):**

| See Section B.4 of Chapter B of Supplemental Information |
| --- |
| |
| |
| |
| |
| |
| |

9. **Proposed Operating Data:**

**9a.** Average and maximum daily volume of fluid to be injected:

Average 6,246,720 gallons Maximum 6,480,000 gallons

**9b.** Average and maximum injection pressure:

Average 96.4 p.s.i. Maximum 100 p.s.i.

10. **The zone of endangering influence:** (Refer to Title 122, Chapter 14) **One-fourth Mile**

**Attach all calculations and assumptions used in calculations.**

11. **Name of person completing this form:** Thomas Young

Telephone number: (720) 879-5534

Signature:

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**ATTACHMENT 1**

**Attachment 1 provides additional information as to the datum on topography maps presented in the application and supporting documents, and to questions 1.0 through 11.0 of the application, as needed. Otherwise, additional information, as noted, is presented in the Supplemental Information section of this application.**

### A.6 Datum Referenced in Figure Appl. 1-1 of this application and all other topographic maps used in the application.

The datum on topography maps presented in the application is North American Datum 1927 (NAD 1927), and the geographic coordinate reference system (projection) is:

NAD_1927_StatePlane_Nebraska_North_FIPS_2601 US_Foot.

The longitude and latitude for the site boundary vertices are presented in Application Attachment 6a. (based on NAD 1927):

The latitude and longitude for the centroid of the processing assets (Satellite Facility and Evaporation Ponds) is: 42.724112/-103.416047.

### A.7 Is the facility located on Indian lands, historic and/or archaeological sites?

The North Trend Expansion Area, as well as the current Crow Butte permit area, is not located on Indian Land.

An intensive pedestrian cultural resource inventory (approximately 1,165 acres) was completed for Crow Butte Resources, Inc., in support of a Nuclear Regulatory Commission (NRC) license amendment application for the North Trend Expansion Area. A systematic cultural resource survey of the North Trend Expansion Area documented six cultural resources (Späth 2007). None of the historic, archaeological, and cultural resources within this area were recommended as eligible for the National Register of Historic Places (NRHP); therefore, none of them were considered historic properties. The proposed North Trend Expansion Area will have no effect on historic properties, and no further cultural resource work was recommended. A more detailed discussion of the assessment for historic, archaeological, and cultural resources within and near the North Trend Expansion Area is presented in Section I.3 of Chapter I of this application. The cultural resource inventory report will be submitted as a separate, confidential document to the Nebraska Department of Environmental Quality (NDEQ) at the time of submittal of this Underground Injection Control (UIC) application.

### A.10 The Zone of Endangering Influence (refer to Title 122, Chapter 4)

As per paragraph 001.02 of Chapter 14 of Title 122, the Zone of Endangering Influence (ZOEI) for the North Trend Expansion Area will be a fixed radius of 0.25 mile around the project boundary. Because a net withdrawal of fluid from the mining zone is being proposed, the calculation called for in 40 Code of Federal Regulations (CFR) 146.6(a) and Title 122, Chapter 14, Section 001.01 does not give meaningful results when calculating a zone of endangering influence (i.e., it produces a negative number). As a result, CBR is using a fixed radius of 0.25 mile as provided for in the regulations. As per paragraph 002 of Chapter 14, Title 122, the Area of Review (AOR) includes the ZOEI and a 2-mile radius around the permit boundary extending beyond the ZOEI, for a total AOR of 2.25 miles. (**Figure Appl.1-1**).

| Application Attachment 1-6a Latitude and Longitude for Site Boundary Vertices | | | | | |
|---|---|---|---|---|---|
| **No.** | **Latitude** | **Longitude** | **No.** | **Latitude** | **Longitude** |
| 1 | 42.70511248850 | -103.41174490900 | 52 | 42.71072552450 | -103.42221332800 |
| 2 | 42.70507620050 | -103.41264700400 | 53 | 42.71316897680 | -103.42283706700 |
| 3 | 42.69964811690 | -103.41278977000 | 54 | 42.71340241680 | -103.42289390400 |
| 4 | 42.69965298670 | -103.41285062700 | 55 | 42.71422035610 | -103.42309943700 |
| 5 | 42.69965464930 | -103.41286327700 | 56 | 42.71503695010 | -103.42331458000 |
| 6 | 42.69965794970 | -103.41291457400 | 57 | 42.71585213800 | -103.42353931800 |
| 7 | 42.69966264240 | -103.41306397100 | 58 | 42.71666585910 | -103.42377363300 |
| 8 | 42.69966004160 | -103.41321346200 | 59 | 42.71706248470 | -103.42389147500 |
| 9 | 42.69965015870 | -103.41336239300 | 60 | 42.71713419330 | -103.42391205900 |
| 10 | 42.69963303630 | -103.41351011200 | 61 | 42.71755036540 | -103.42403740600 |
| 11 | 42.69960875030 | -103.41365597500 | 62 | 42.71796490720 | -103.42417231800 |
| 12 | 42.69957740610 | -103.41379934300 | 63 | 42.71837770010 | -103.42431676000 |
| 13 | 42.69953914120 | -103.41393958800 | 64 | 42.71878862450 | -103.42447068800 |
| 14 | 42.69949412240 | -103.41407609900 | 65 | 42.71919756100 | -103.42463405800 |
| 15 | 42.69944414870 | -103.41420447600 | 66 | 42.71960439380 | -103.42480682400 |
| 16 | 42.69943170160 | -103.41423378600 | 67 | 42.71997418750 | -103.42497285900 |
| 17 | 42.69933490420 | -103.41445056900 | 68 | 42.72100727930 | -103.42551280400 |
| 18 | 42.69923197870 | -103.41466210000 | 69 | 42.72206208840 | -103.42607447400 |
| 19 | 42.69912308060 | -103.41486806000 | 70 | 42.72311423960 | -103.42664525000 |
| 20 | 42.69905223750 | -103.41499351000 | 71 | 42.72416369040 | -103.42722510700 |
| 21 | 42.69906444790 | -103.41571890100 | 72 | 42.72521039700 | -103.42781402400 |
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| 24 | 42.69914485500 | -103.41793603300 | 75 | 42.72610899830 | -103.42833152700 |
| 25 | 42.69917095950 | -103.41841815500 | 76 | 42.72621401420 | -103.42838108100 |
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| 27 | 42.69920994540 | -103.41871737400 | 78 | 42.72643008080 | -103.42845175500 |
| 28 | 42.69924807170 | -103.41894491300 | 79 | 42.72654020710 | -103.42847257100 |
| 29 | 42.69926115130 | -103.41901409300 | 80 | 42.72665110180 | -103.42848357400 |
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| 40 | 42.70024289160 | -103.41955822500 | 91 | 42.73008360880 | -103.42731611400 |
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| 51 | 42.71060193700 | -103.42218655900 | 102 | 42.73465453840 | -103.42490076600 |

| Application Attachment 1-6a Latitude and Longitude for Site Boundary Vertices | | | | | |
|---|---|---|---|---|---|
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| 109 | 42.73520580350 | -103.42437378800 | 162 | 42.72760115610 | -103.40874688700 |
| 110 | 42.73527796020 | -103.42428850000 | 163 | 42.72714710420 | -103.40868792000 |
| 111 | 42.73534515440 | -103.42419605500 | 164 | 42.72688448540 | -103.40865829700 |
| 112 | 42.73540700180 | -103.42409697900 | 165 | 42.72490854210 | -103.40848133600 |
| 113 | 42.73546314940 | -103.42399184300 | 166 | 42.72332530610 | -103.40834289100 |
| 114 | 42.73551327320 | -103.42388124900 | 167 | 42.72313418540 | -103.40833220200 |
| 115 | 42.73555708760 | -103.42376582700 | 168 | 42.72236120110 | -103.40829508200 |
| 116 | 42.73559434220 | -103.42364624300 | 169 | 42.72158799400 | -103.40826775200 |
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| 120 | 42.73567407040 | -103.42314023100 | 173 | 42.71848576440 | -103.40824323800 |
| 121 | 42.73567628010 | -103.42304230500 | 174 | 42.71720215290 | -103.40825384900 |
| 122 | 42.73568404090 | -103.42234139600 | 175 | 42.71658116390 | -103.40827373400 |
| 123 | 42.73568613640 | -103.42154030600 | 176 | 42.71559805170 | -103.40831319400 |
| 124 | 42.73568100810 | -103.42073924200 | 177 | 42.71461517830 | -103.40836242400 |
| 125 | 42.73566865530 | -103.41993832200 | 178 | 42.71370072830 | -103.40841701700 |
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| 130 | 42.73557387840 | -103.41705225100 | 183 | 42.70906816050 | -103.40883557100 |
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| 136 | 42.73536337830 | -103.41403002400 | 189 | 42.70847998370 | -103.40908472000 |
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| 150 | 42.73204399930 | -103.41006849900 | 203 | 42.70651558580 | -103.41062547800 |
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| 152 | 42.73126737160 | -103.40971744200 | 205 | 42.70610612250 | -103.41072968800 |
| 153 | 42.73087576110 | -103.40955587400 | 206 | 42.70589963670 | -103.41076728100 |
| 154 | 42.73048211470 | -103.40940368100 | 207 | 42.70587836300 | -103.41077059400 |
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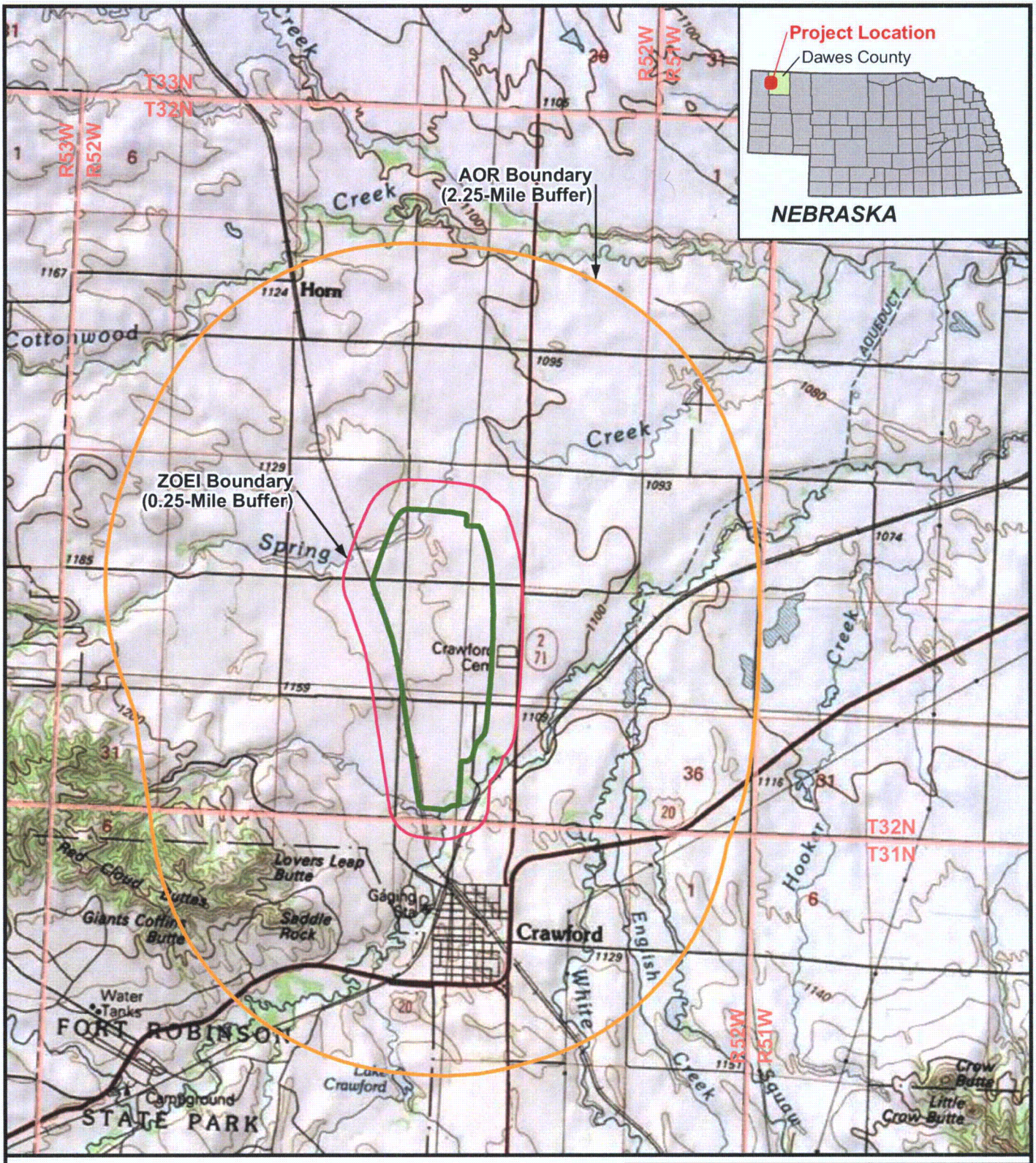
| Application Attachment 1-6a Latitude and Longitude for Site Boundary Vertices | | | | | |
|---|---|---|---|---|---|
| **No.** | **Latitude** | **Longitude** | **No.** | **Latitude** | **Longitude** |
| 209 | 42.70578209600 | -103.41081293100 | 215 | 42.70533126240 | -103.41122769400 |
| 210 | 42.70569758930 | -103.41086101600 | 216 | 42.70527248480 | -103.41132303100 |
| 211 | 42.70561616750 | -103.41091805200 | 217 | 42.70521948030 | -103.41142439800 |
| 212 | 42.70553834490 | -103.41098367700 | 218 | 42.70517258230 | -103.41153115400 |
| 213 | 42.70546461380 | -103.41105748000 | 219 | 42.70513359890 | -103.41163803300 |
| 214 | 42.70539544040 | -103.41113899000 | 220 | 42.70513001150 | -103.41165891300 |




## Legend

- Proposed North Trend Expansion Area (NTEA)
- Zone of Endangering Influence (ZOEI)
- Area of Review (AOR)

NOTE: Both buffer distances are relative to the boundary of the proposed North Trend Expansion Area.

0 3,000 6,000 Feet

N
W E

CROW BUTTE RESOURCES, INC.

FIGURE Appl.1-1
PROJECT LOCATION MAP
ZOEI AND AOR

PROJECT: CO001322.0001 MAPPED: JC CHECKED: J.CEARLEY

FILE: K:\CO001322_UIC\A_1-1.mxd @ 11/10/09

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# CHAPTER A. DESCRIPTION OF OPERATOR'S EXPERTISE

*A detailed description of the operator's technological expertise to construct and operate the facility and to conduct the necessary well closure, plugging, or abandonment, reclamation, and aquifer restoration.*

Over the 20-year period during which Crow Butte Resources, Inc. (CBR) has been involved with the research and development (R&D) and subsequent commercial mining phases at Crow Butte, CBR has developed substantial expertise regarding in-situ mining operations and pertaining to the protection of groundwater resources during these operations. The permits obtained for the project (**Table B.4-1 of Chapter B**) are indicative of CBR's technical expertise regarding construction and operation of the Crow Butte facility, and demonstrate CBR's ability to conduct necessary well closure, plugging, abandonment, reclamation, and aquifer restoration associated with the project.

## A.1 Solution Mining Method and Recovery Process

The in-situ leaching (ISL) process for uranium recovery consists of an oxidation step and a dissolution step. Gaseous oxygen or hydrogen peroxide is used to oxidize the uranium, and carbonate species is used for dissolution. The uranium bearing solution that results from the leaching of uranium underground is recovered from the wellfield and the uranium extracted in the process plant. The plant process uses the following steps:

- Loading of uranium complexes onto ion exchange resin;
- Reconstitution of the solution by the addition of bicarbonate and oxygen;
- Elution of the uranium complexes from the resin;
- Precipitation of uranium from the rich eluate (pregnant lixiviant);
- Drying and packaging of the uranium.

### A.1.1 Advantages of ISL Uranium Mining

ISL uranium mining is a proven technology that has been successfully demonstrated commercially in Wyoming, Texas, and at the Crow Butte Project in Nebraska. ISL mining of uranium is environmentally superior to conventional open pit and underground uranium mining as evidenced by the following:

1. ISL mining results in significantly less surface disturbance as mine pits, waste dumps, haul roads, and tailings ponds are not needed
2. ISL mining requires much less water demand than conventional mining and milling, avoiding the water usage associated with pit dewatering, conventional milling, and tailings transport
3. The lack of heavy equipment, haul roads, waste dumps, etc. result in very little air quality degradation at ISL mines

4. Fewer employees are needed at ISL mines, thereby reducing transportation and socioeconomic concerns
5. Aquifers are not excavated, but remain intact during and after ISL mining
6. Tailings ponds are not used, thereby eliminating a major groundwater pollution concern. State of the art lined evaporation ponds and/or deep disposal wells are used to manage liquid waste streams
7. ISL uranium mining results in leaving the majority of other contaminants (e.g., heavy metals) where they naturally occur instead of moving them to waste dumps and tailings ponds where their presence is of more environmental concern.

### A.1.2 Ore Amenability to the ISL Mining Method

Based on similar regional deposition, the North Trend Expansion Area (NTEA) ore body is expected to be similar mineralogically and geochemically to that of the current Crow Butte Permit Area. The ore bodies in the two areas are within the same geologic unit (Basal Chadron Sandstone) and have the same mineralization source. The sites are separated by only a few miles, and the cause of mineral deposition in the two areas appears to be similar.

Amenability of the uranium deposits in the Basal Chadron Sandstone in the Crow Butte Project area to ISL mining was demonstrated initially through core studies at the original Crow Butte Study Area (CSA) where mining currently is being conducted. Results of the core studies were confirmed in the Research and Development (R&D) phase at the Crow Butte site using bicarbonate/carbonate leaching solutions with oxygen. Reports concerning the results of the R&D activities, including restoration of affected groundwater, were previously submitted to the Nebraska Department of Environmental Quality (NDEQ) and the U.S. Nuclear Regulatory Commission (NRC). Similar to the CSA currently being mined by ISL, the NTEA exhibits the following conditions:

- For containment of solution, the Basal Chadron Sandstone ore body is relatively horizontal (within the permit boundary) and is underlain and overlain by very low permeability strata
- The Basal Chadron Sandstone ore body is below the static water table and has sufficient permeability to achieve solution flow
- The permeability, porosity, and hydrology of the Basal Chadron Sandstone is favorable to the ISL process
- A pumping test was conducted that verifies the favorable hydrologic conditions in the Basal Chadron Sandstone at the site
- The uranium ore is similar to that of the current Crow Butte ISL operation and, therefore, is mineralogically suitable for solution mining

The information and experience gained during the past R&D programs formed the basis for the commercial uranium ISL mining operations. CBR believes that the current commercial project, including successful uranium recovery and restoration (e.g., groundwater in Mine Unit 1), demonstrates that the leach solution is compatible with the ore and such a program can be

implemented in a profitable manner with minimal short-term environmental impacts and with no significant risk to public health and safety.

## A.2 Operating Plans, Design Throughput, and Production

The current Crow Butte Central Plant is licensed under Nuclear Regulatory Commission (NRC) License SUA-1534 for a process flow rate of 9,000 gallons per minute (gpm), excluding restoration flow, and a maximum production flow of 9000 gpm. Total annual production is limited to 2 million pounds of yellowcake. On October 16, 2006, CBR submitted a request to the NRC for a license amendment to increase the plant throughput from 5,000 to 9,000 gpm. The NRC issued the requested license amendment on November 30, 2007.

The current extraction plant is permitted for a maximum total flow rate of 11,000 gpm (including restoration flow) and a maximum production flow of 9,660 gpm under Class III UIC Permit Number NE0122611. On October 20, 2006 CBR submitted a request to the NDEQ for a permit modification to increase the maximum total flow from 5,500 gpm to 11,000 gpm. The NDEQ issued the permit modification on August 16, 2007.

The uranium-bearing solution extracted from the subsurface of the Crow Butte License Area is transported via pipeline to the Crow Butte Central Plant for elution, drying, and packaging. This cycle will continue until the ore zone is depleted or leach of the uranium is no longer economically viable.

Uranium extracted from the NTEA wellfield will be processed in a satellite facility located within the expansion area. The North Trend Satellite Facility will operate at a flow rate of 4,500 gpm with an expected annual production rate of 500,000 to 600,000 pounds $U_3O_8$. Total reserves for the North Trend Expansion Area are not developed at this time. However, CBR has estimated recoverable resources at North Trend to be approximately 2,000,000 pounds $U_3O_8$.

The uranium extracted from the North Trend Expansion Area will be loaded onto ion exchange resin in the Satellite Plant, which will then be transported by tanker truck to the main plant for elution, precipitation, drying and packaging. Barren resin will be returned to the North Trend Satellite Plant by tanker truck. A more detailed discussion of the North Trend operations can be found in Chapter M – Injection Procedures.

### A.2.1 Operating Schedules

#### *A.2.1.1 Current Production Area*

Sufficient reserves in the current permit area have been estimated to allow mining operations to continue until the end of 2014. Completion of groundwater restoration in the current permit area is scheduled for 2023. The locations of the current license area and mine units are shown in **Figure A.2-1**. Status of the current mine unit operations is shown in **Table A.2-1**. Projected production and restoration schedules for the current production area are shown in **Figure A.2-2**.

Additional mine unit plans are developed approximately 1 year prior to the planned commencement of new mining operations. For the current production area, planning and construction are underway for Mine Units 10 and 11.

### *A.2.1.2 North Trend Expansion Area*

The proposed North Trend Mine Unit map and mine schedule are shown in **Figure A.2-3** and **Figure A.2-4**, respectively. The NTEA will be subdivided into an appropriate number of mine units. Each mine unit will contain a number of wellhouses where injection and recovery solutions from the satellite plant building are distributed to the individual wells. The injection and production manifold piping from the satellite process facility to the wellfield houses will be either polyvinyl chloride (PVC) or high-density polyethylene (HDPE) with butt-welded joints or an equivalent. In the wellfield house, injection pressure will be monitored on the injection trunk lines. Oxidizer will be added to the injection stream and all injection lines off of the injection manifold will be equipped with totalizing flowmeters, which will be monitored in the satellite Control Room. The NTEA Area wellfields will be designed in a manner consistent with the existing CBR wellfields.

A more detailed discussion of the wellfield design and operation and satellite process description is presented in Chapter M – Injection Procedures.

**Table A.2-1 Current Crow Butte Production Area Mine Unit Status**

| Mine Unit | Production Initiated | Current Status |
|---|---|---|
| Mine Unit 1 | April 1991 | Groundwater Restored; Reclamation underway |
| Mine Unit 2 | March 1992 | Groundwater Restoration |
| Mine Unit 3 | January 1993 | Groundwater Restoration |
| Mine Unit 4 | March 1994 | Groundwater Restoration |
| Mine Unit 5 | January 1996 | Groundwater Restoration |
| Mine Unit 6 | March 1998 | Production |
| Mine Unit 7 | July 1999 | Production |
| Mine Unit 8 | July 2002 | Production |
| Mine Unit 9 | October 2003 | Production |
| Mine Unit 10 | August 2007 | Production |
| Mine Unit 11 | Pending | Under Construction |

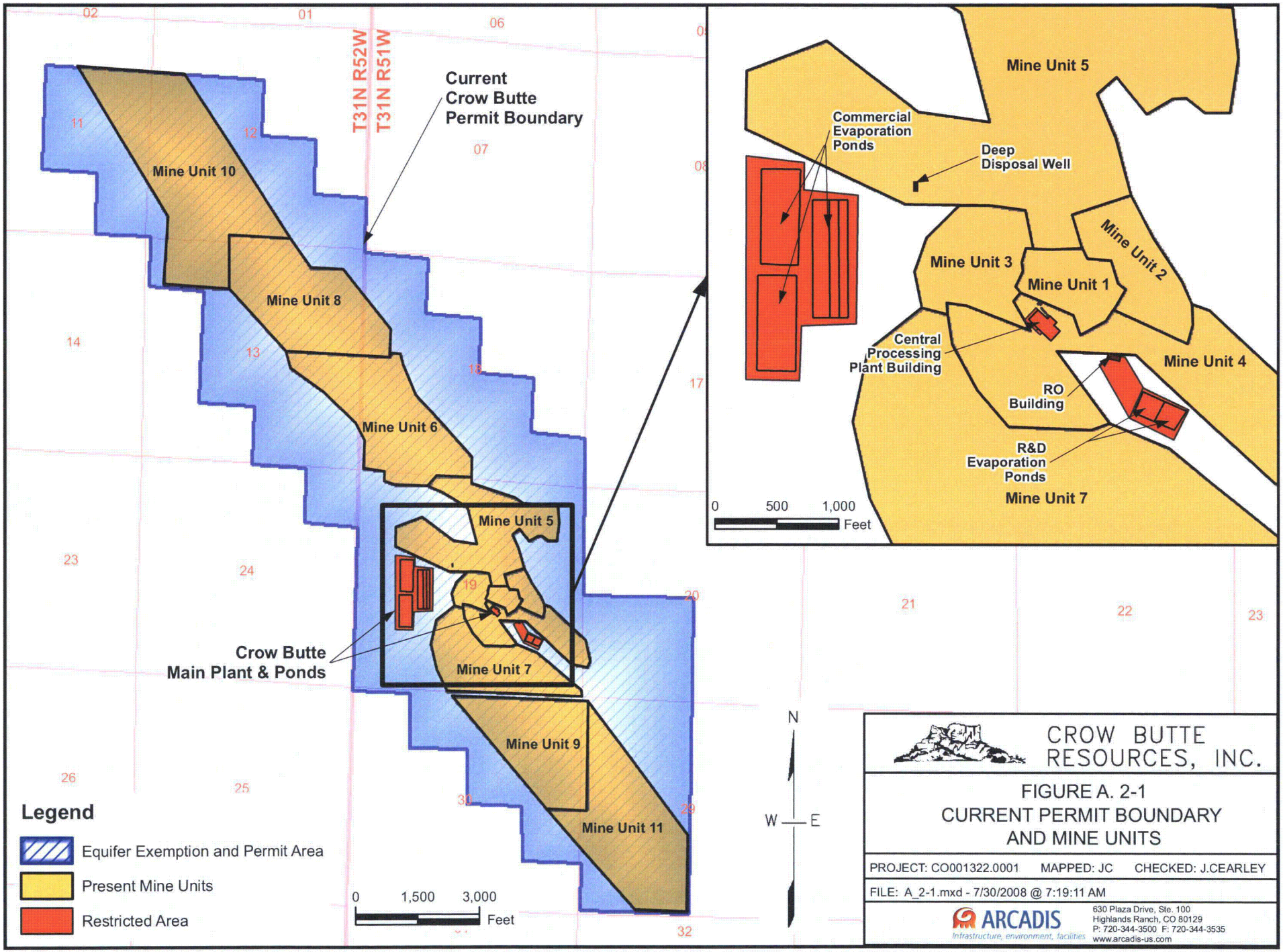
T31N R52W
T31N R51W
Current
Crow Butte
Permit Boundary
Mine Unit 10
Mine Unit 8
Mine Unit 6
Mine Unit 5
Mine Unit 7
Mine Unit 9
Mine Unit 11
Crow Butte
Main Plant & Ponds
Legend
Equifer Exemption and Permit Area
Present Mine Units
Restricted Area
0 1,500 3,000
Feet
Commercial
Evaporation
Ponds
Deep
Disposal Well
Mine Unit 5
Mine Unit 3
Mine Unit 1
Mine Unit 2
Mine Unit 4
Central
Processing
Plant Building
RO
Building
R&D
Evaporation
Ponds
Mine Unit 7
0 500 1,000
Feet
N
W E
CROW BUTTE
RESOURCES, INC.
FIGURE A. 2-1
CURRENT PERMIT BOUNDARY
AND MINE UNITS
PROJECT: CO001322.0001 MAPPED: JC CHECKED: J.CEARLEY
FILE: A_2-1.mxd - 7/30/2008 @ 7:19:11 AM
ARCADIS
Infrastructure, environment, facilities
630 Plaza Drive, Ste. 100
Highlands Ranch, CO 80129
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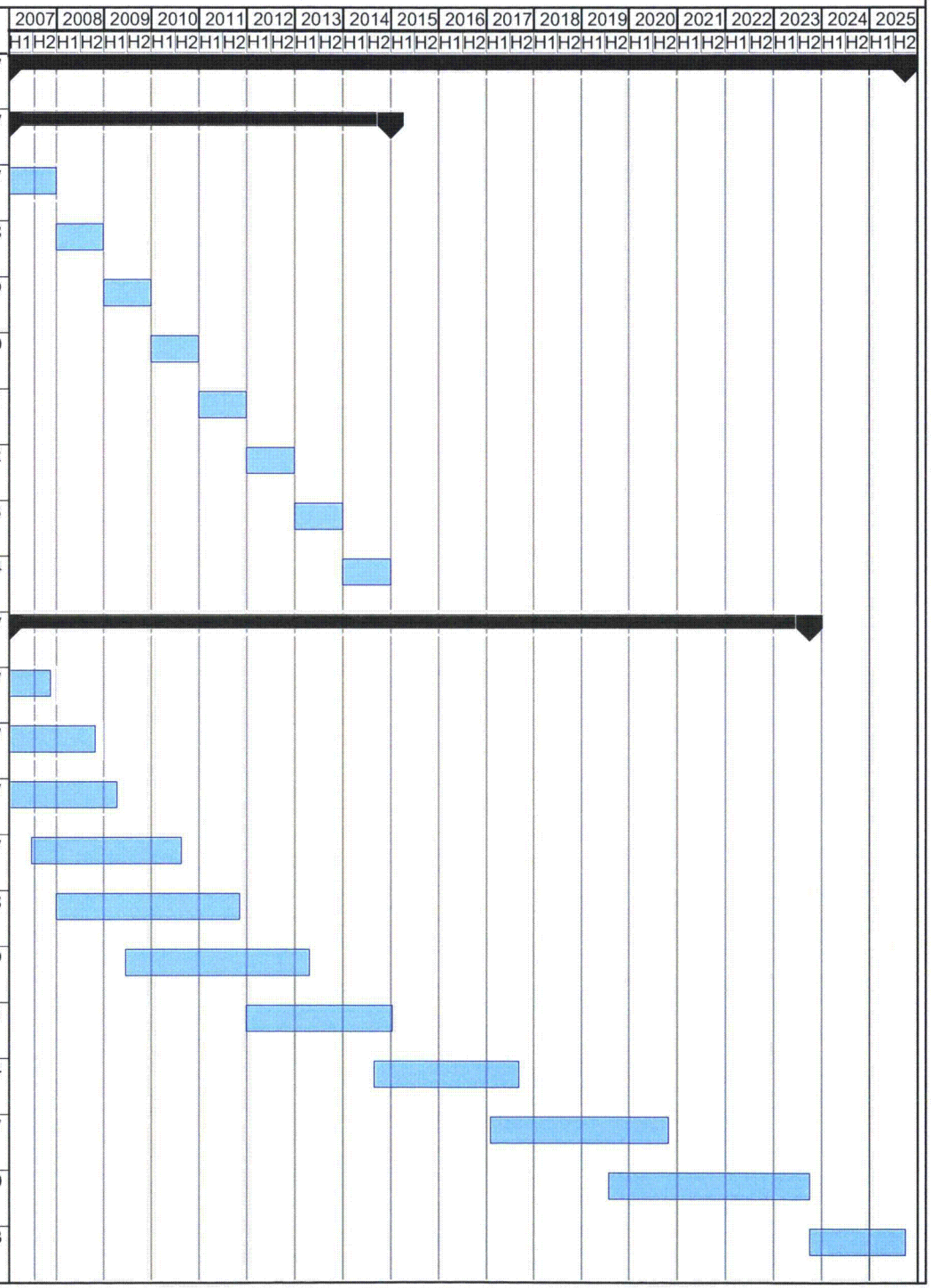
Figure A. 2-2 Current Production Area Mine Unit Schedule

| ID | Task Name | Start |
|---|---|---|
| 1 | **Current Production Area** | **Mon 1/1/07** |
| 2 | **Current Production Area** | **Mon 1/1/07** |
| 3 | Year 2007 at 800,000 lbs | Mon 1/1/07 |
| 4 | Year 2008 at 800,000 lbs | Tue 1/1/08 |
| 5 | Year 2009 at 800,000 lbs | Thu 1/1/09 |
| 6 | Year 2010 at 800,000 lbs | Fri 1/1/10 |
| 7 | Year 2011 at 800,000 lbs | Sat 1/1/11 |
| 8 | Year 2012 at 700,000 lbs | Mon 1/2/12 |
| 9 | Year 2013 at 600,000 lbs | Tue 1/1/13 |
| 10 | Year 2014 at 500,000 lbs | Wed 1/1/14 |
| 11 | **Groundwater Restoration** | **Mon 1/1/07** |
| 12 | MU2 | Mon 1/1/07 |
| 13 | MU3 | Mon 1/1/07 |
| 14 | MU4 | Mon 1/1/07 |
| 15 | MU5 | Tue 6/26/07 |
| 16 | MU6 | Tue 1/1/08 |
| 17 | MU7 | Fri 6/19/09 |
| 18 | MU8 | Fri 12/30/11 |
| 19 | MU9 | Wed 8/27/14 |
| 20 | MU10 | Thu 2/2/17 |
| 21 | MU11 | Fri 8/2/19 |
| 22 | Final Site Reclamation | Tue 10/3/23 |



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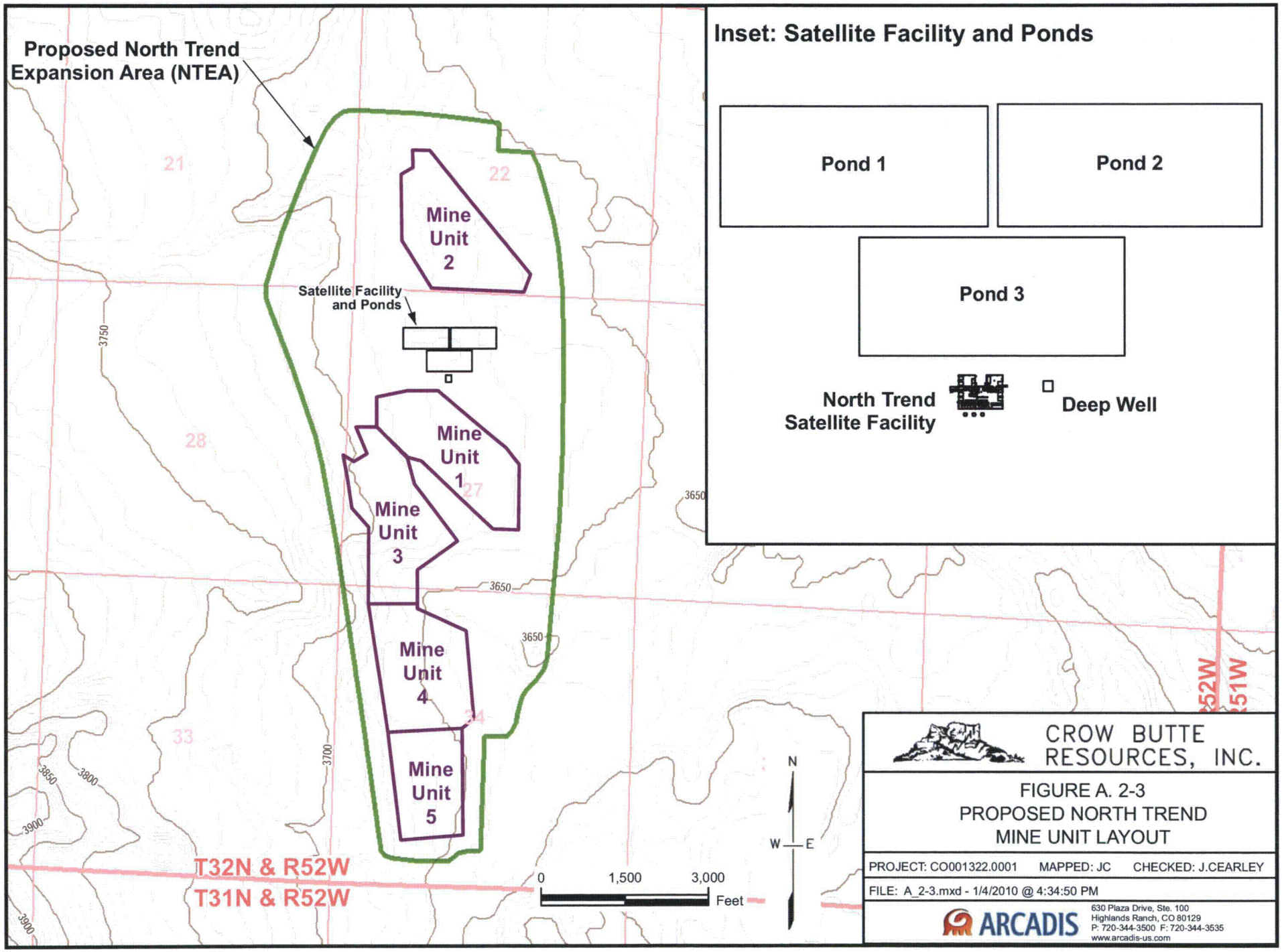
Proposed North Trend Expansion Area (NTEA)
Inset: Satellite Facility and Ponds
Pond 1
Pond 2
Pond 3
North Trend Satellite Facility
Deep Well
Mine Unit 2
Satellite Facility and Ponds
Mine Unit 1
Mine Unit 3
Mine Unit 4
Mine Unit 5
21
22
28
27
33
34
3750
3650
3700
3850
3800
3900
T32N & R52W
T31N & R52W
0
1,500
3,000
Feet
N
W
E
CROW BUTTE RESOURCES, INC.
FIGURE A. 2-3
PROPOSED NORTH TREND
MINE UNIT LAYOUT
PROJECT: CO001322.0001
MAPPED: JC
CHECKED: J.CEARLEY
FILE: A_2-3.mxd - 1/4/2010 @ 4:34:50 PM
ARCADIS
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Highlands Ranch, CO 80129
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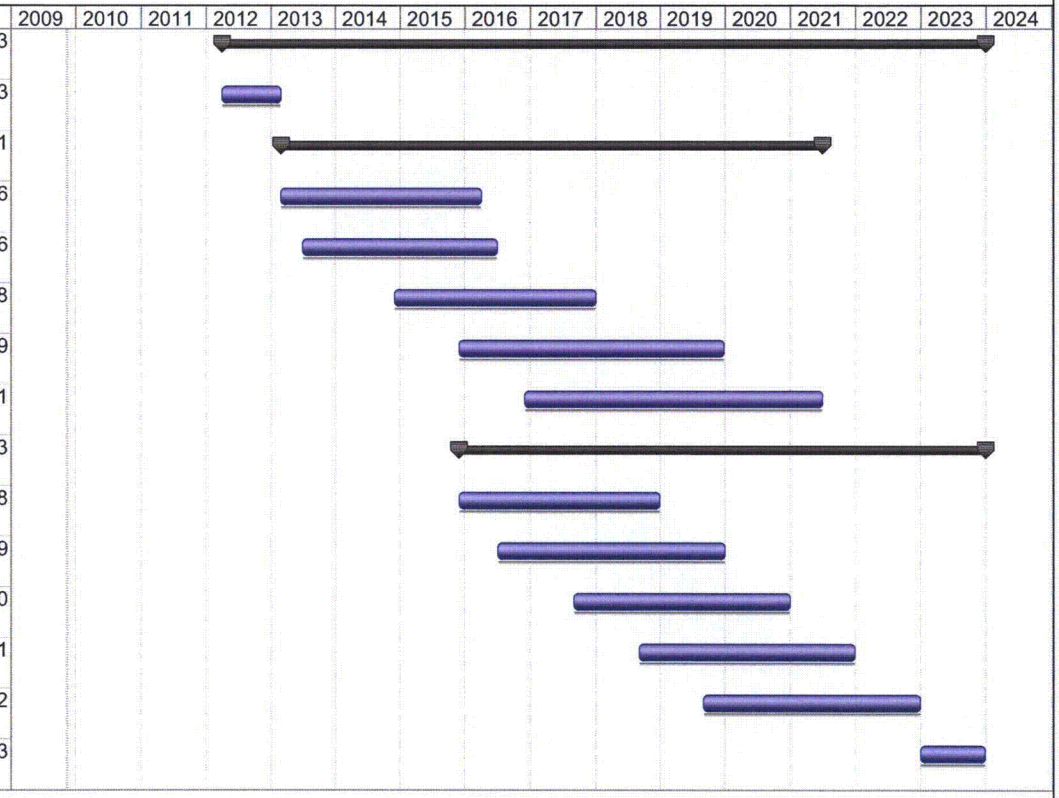
Figure A. 2-4 North Trend Expansion Area Mine Unit Schedule

| ID | Task Name | Start | Finish |
|---|---|---|---|
| 1 | North Trend Production and Restoration | Mon 4/2/12 | Sun 12/31/23 |
| 2 | North Trend Facility Construction | Mon 4/2/12 | Fri 3/1/13 |
| 3 | North Trend Production | Fri 3/1/13 | Thu 7/1/21 |
| 4 | Mine Unit NT-1 | Fri 3/1/13 | Fri 4/1/16 |
| 5 | Mine Unit NT-2 | Mon 7/1/13 | Tue 6/28/16 |
| 6 | Mine Unit NT-3 | Mon 12/1/14 | Mon 1/1/18 |
| 7 | Mine Unit NT-4 | Tue 12/1/15 | Fri 12/27/19 |
| 8 | Mine Unit NT-5 | Thu 12/1/16 | Thu 7/1/21 |
| 9 | Groundwater Restoration | Tue 12/1/15 | Sun 12/31/23 |
| 10 | Mine Unit NT-1 | Tue 12/1/15 | Mon 12/31/18 |
| 11 | Mine Unit NT-2 | Fri 7/1/16 | Tue 12/31/19 |
| 12 | Mine Unit NT-3 | Fri 9/1/17 | Thu 12/31/20 |
| 13 | Mine Unit NT-4 | Mon 9/3/18 | Fri 12/31/21 |
| 14 | Mine Unit NT-5 | Mon 9/2/19 | Sat 12/31/22 |
| 15 | Final Site Reclamation | Mon 1/2/23 | Fri 12/29/23 |



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# CHAPTER B. DESCRIPTION OF RELATED UIC PROJECTS

*A description of all related underground injection projects, other than that for which a permit is being applied for, in which the operator is or has been involved as an operator. The description shall include but not be limited to the following items:*

*B1: The name of each project.*

*B2: The location of each project by county, state, and country.*

*B3 Nature of the project.*

*B4 All regulatory aspects of the project including permits, compliance issues, and permitting agency. (Refer to Title 122, Chapter 11, Section 006.06)*

## B.1 Name of Project

There is one related underground injection project in which Crow Butte Resources, Inc. (CBR) is involved as the operator other than that for which this Class III Underground Injection Control (UIC) Permit Application is made. This project involves a Class I UIC Permit for the disposal of wastewater in a deep disposal well and a Class III UIC Permit for in-situ leach uranium mining at the Crow Butte Uranium Project. A permit application will be submitted in the near future for a Class I UIC permit application for a deep disposal well to be located on the North Trend Expansion Area (NTEA).

## B.2 Location of Project

The Crow Butte Project is located in northwestern Nebraska in Dawes County approximately 4.2 miles southeast of Crawford, Nebraska, USA. (**Figure B.2-1**). CBR operates an in-situ mining operation to recover uranium from the basal sandstone of the Chadron Formation. The Crow Butte Project Area is located in Sections 11, 12, 13, and 24 of Township 31 North, Range 52 West and Sections 18, 19, 20, 29, and 30 of Township 31 North, Range 51 West. The permit area consists of approximately 3,380 acres. The NTEA Class III UIC Permit area is shown in **Figure A.2-3 of Chapter A**, and the location of the NTEA in relation to the current production area is shown in **Figure B.2-1**.

## B.3 Nature of Project

The Crow Butte Uranium Project is an in-situ leach uranium mining project. In-situ mining entails the extraction of uranium-enriched groundwater (leachate) from the mineralized zone, processing of the leachate to recover the uranium, and then mixing of the process stream with a complexing agent and oxidant with re-injection of the stream back into the mineralized zone to repeat the process. A small amount of bleed water (approximately 0.5 to 1.5 percent of the total mining flow) is generated during the in-situ mining process. This bleed water and a small volume of process water and waste water generated by groundwater restoration activities is disposed by injection via the existing Class I disposal well to the Morrison Formation, which is approximately 2,700 feet below the lowest underground source of drinking water (USDW).

The Crow Butte Project Research and Development Facility commenced operations in 1986. Following successful restoration of the R&D Project, commercial operations were initiated in 1991. In 2007, CBR registered Cameco Resources as a trade name with the Nebraska Secretary of State, with Crow Butte Resources, Inc. operating under the Cameco Resources trade name. The name of the facility was then referred to as the Crow Butte Operation, with the operator's and owner's name being Crow Butte Resources, Inc. d/b/a Cameco Resources. The project continues to produce uranium.

## B.4 Regulatory Aspects of Project

Applicable permits received (or applied for if denied) for the Crow Butte Uranium Project are listed in **Table B.4-1**. All the permits apply to the Crow Butte Project located in Dawes County, Nebraska, USA.

A listing of any citations and notices of violations issued to the Crow Butte Uranium Project or a lawsuit concerning the project in which CBR was a party is presented in **Table B.4-2**.

**Table B.4-1 List of Relevant Permits for the Crow Butte Project Including North Trend Expansion Area**

| ISSUING AGENCY | PERMIT DESCRIPTION |
|---|---|
| Nebraska Department of Environmental Quality<br>PO Box 98922<br>Lincoln, Nebraska 68509-8922 | Underground Injection Control Class III Authorization NE0122611<br>Approved: April 24, 1990<br>Amended to increase flow on August 16, 2007 |
| | Aquifer Exemption<br>Approval Effective: March 23, 1984<br>*Aquifer Exemption for North Trend Expansion Area<br>Submitted: August 15, 2007<br>Approval: Petition denied due to deficiencies |
| | Underground Injection Control Class I Authorization NE0206369<br>Approved: September 9, 1994<br>Replaced: July 2, 2004 |
| | Underground Injection Control Class I Authorization NE0210457<br>Approved: July 2, 2004 |
| | National Pollutant Discharge Elimination System Permit NE0130613<br>Approved: September 30, 1994 |
| | Mineral Exploration Permit NE0209317<br>Approved: June 3, 2003<br>Replaced July 16, 2007 |
| | Mineral Exploration Permit NE0210679<br>Approved: July 16, 2007 |
| | Mineral Exploration Permit NE0210678<br>Approved: July 16, 2007 |
| | Mineral Exploration Permit NE0210680<br>Approved: July 18, 2007 |
| | Underground Injection Control Class V Authorization NE0207388<br>Approved: November 6, 2000 |
| | Evaporation Pond Design<br>Approved: July 21, 1988 |
| | Construction Stormwater NPDES General Permit NER 100000<br>Authorization #NER105203<br>Approved December 19, 2006 |
| Nebraska Department of Natural Resources<br>301 Centennial Mall South<br>Lincoln, Nebraska 68509-4676 | Industrial Groundwater Permit<br>Approved: August 7, 1991 |
| Nebraska Department of Health and Human Services Regulation and Licensure<br>PO Box 95007<br>Lincoln, Nebraska 68509-5007 | Class IV Public Water Supply Permit NE3121024<br>Approved: April 12, 2002 |

**Table B.4-1 List of Relevant Permits for the Crow Butte Project Including North Trend Expansion Area**

| ISSUING AGENCY | PERMIT DESCRIPTION |
|---|---|
| U.S. Nuclear Regulatory Commission<br>Washington, DC 20555 | *Source Material License<br>SUA – 1534<br>Amendment for New Satellite Facility: North Trend Expansion Area<br>Submitted: May 30, 2007<br>NRC Approval: Pending<br><br>Source Material License<br>SUA – 1534<br>License Renewal request by CBR<br>Submitted: November 27, 2007<br>NRC Approval: Pending<br><br>Source Materials License<br>SUA – 1534<br>Amendment to Increase Flow<br>Issued: November 30, 2007<br><br>Source Materials License<br>SUA-1534<br>Issued: December 29, 1989<br>Renewed: February 28, 1998 |
| U.S. Environmental Protection Agency<br>1200 Pennsylvania Ave, NW,<br>Washington, DC 20460 | Aquifer Exemption<br>Approval Effective: June 22, 1990 |

Note: All entries apply to the current Crow Butte Project except where noted with an *, which apply to the North Trend Expansion Area.

**Table B.4-2 List of Citations, Notices of Violation, or Lawsuits Relevant to the Crow Butte Uranium Project**

| Issuing Agency | Notice of Violation Date | Violation Description | Resolution |
|---|---|---|---|
| U.S. Nuclear Regulatory Commission | 6 June 1991 | Pond construction soils placed at moisture content below requirements | Level IV violation. Closed |
| Nebraska Department of Environmental Control | April 15, 1992 | Surface release from well PR003 | NDEC fine of $3,500. Closed |
| U.S. Nuclear Regulatory Commission | January 14, 1993 | Lack of SOPs for construction, testing, operation and maintenance of pipelines | 2 Level IV violations. Closed |
| Nebraska Department of Environmental Quality | November 30, 1993 | Trunk line release at Mine Unit 3 | NDEQ fine of $5000. Closed |
| U.S. Nuclear Regulatory Commission | April 27, 1995 | Failure to assign TLDs to plant personnel at all times | Level IV violation. Closed |
| U.S. Nuclear Regulatory | April 11, 1996 | Failure to establish SOPs | Level IV violation. |

**Table B.4-2 List of Citations, Notices of Violation, or Lawsuits Relevant to the Crow Butte Uranium Project**

| Issuing Agency | Notice of Violation Date | Violation Description | Resolution |
|---|---|---|---|
| Commission | | for all monitoring activities and maintain in certain areas | Closed |
| U.S. Nuclear Regulatory Commission | February 5, 1998 | Failure to provide and document special radiation protection training the supervisors | Level IV violation. Closed |
| U.S. Nuclear Regulatory Commission | February 11, 1999 | CRSO did not review and approve two SOPs | Level IV violation. Closed |
| Nebraska Department of Environmental Quality | April 6, 1999 | Surface release from well I-710 | Proposed NDEQ fine of $10,000; resolved through Supplemental Environmental Project (SEP). Closed |
| U.S. Nuclear Regulatory Commission | September 23, 1999 | Failure to incorporate radiation safety steps in dryer SOP | Level IV violation. Closed |
| Nebraska Department of Environmental Quality | December 4, 2000 | Surface release from well I-1274 | NOV issued. Closed |
| Nebraska Department of Environmental Quality | June 7, 2006 | Recycling Chadron Formation well development water | NOV issued. Closed NDEQ fine of $25,000 $50,000 to AG Environmental Protection Fund |
| Nebraska Department of Environmental Quality | May 30, 2008 | Failure to conduct 5 year MIT's on 42 injection/production wells | NOV issued. Closed |
| Nebraska Department of Environmental Quality | July 22, 2008 | Wellhead injection manifold pressure exceeding 100 psig | NOV issued. Closed |

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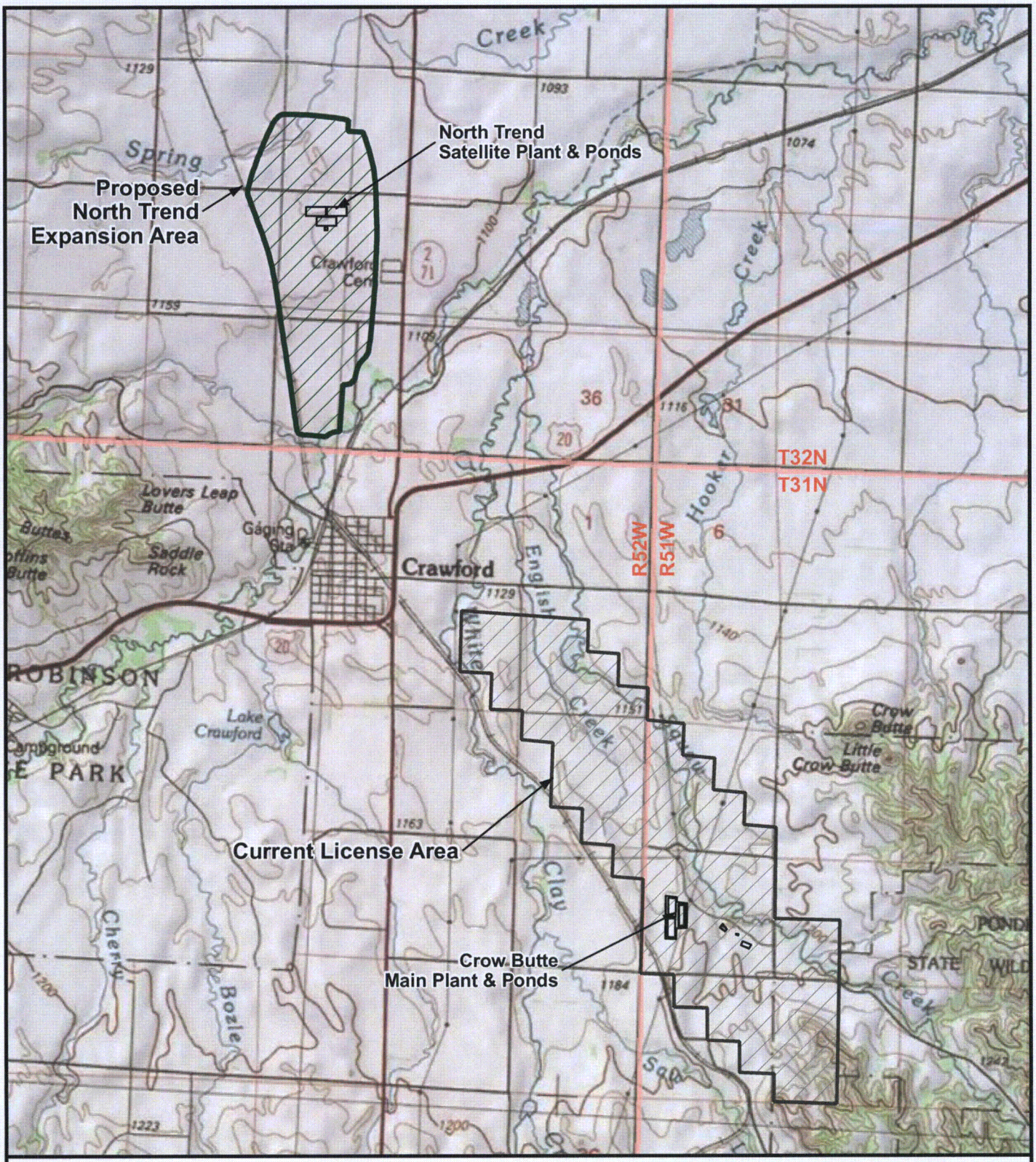


## Legend

- Plants_and_Ponds
- Proposed North Trend Expansion Area
- Current License Area

0 0.5 1 Miles

N
W E

CROW BUTTE RESOURCES, INC.

FIGURE B.2-1
CURRENT LICENSE AREA BOUNDARY
& PROPOSED NORTH TREND BOUNDARY

PROJECT: CO001322.0001 MAPPED: JC CHECKED: J.CEARLEY

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# CHAPTER C. MAPS OF WELLS, SURFACE FEATURES AND MAJOR STRUCTURES IN AREA OF REVIEW

*A scaled map of the entire property on which the injection is proposed. The map should include but not be limited to the following items: (Refer to Title 122, Chapter 11, Section 006.09)*

- *C1. The area of review around the permit area for injection wells (a minimum of 2.25 miles beyond the zone of endangering influence).*
- *C2. All other injection wells (i.e. septic systems, heat pump returns).*
- *C3. All water wells (i.e. irrigation, drinking, monitoring, abandoned).*
- *C4. All surface features (i.e. water bodies, quarries, springs).*
- *C5. All major structures (i.e. buildings, streets, property lines).*
- *C6. All underground features (i.e. utilities, mines, faults).*

*All the information on the map should be verified by an inspection conducted by the applicant.*

## C.1 Area of Review

As shown on **Figure C.1-1**, the Crow Butte Project is located southeast of the City of Crawford in northwestern Nebraska. **Figure C.1-1** shows all private water wells, oil and gas test hole locations, surface features (e.g., water bodies, sand and concrete aggregate/gravel quarries), proposed major structures at the North Trend Expansion Area (NTEA) (i.e., satellite facilities, impoundments, deep disposal well and mining areas), White River Fault, current monitor wells at the NTEA, and other general information about the Area of Review (AOR). **Figure C.2-1** presents the location of groundwater wells within the City of Crawford. More detailed maps of the proposed features at the NTEA and existing features at the current production area can be seen in **Figures A.2-1 and A.2-3** of Chapter A. A detailed layout of the NTEA satellite facility is presented in **Figure N.2-1**. The zone of endangering influence (ZOEI) boundary is depicted in **Figure Appl.1-1** of the Application.

**Figure C.1-3,** an aerial photo, shows the locations of rural residences and associated lands within the AOR as well as the City of Crawford. This aerial photo also depicts agriculture activities in the AOR. More detailed information about land use in the AOR is shown in **Figures I.1-1** and **I.5-1** of Chapter I, and is discussed in Section I.1 of Chapter I.

The layouts for a typical wellfield and associated monitor wells are shown in **Figures M.1-1** and **M.1-2** of Chapter M, respectively. The precise locations of injection/recovery wells for the first wellfield cannot be provided until review and approval of the Aquifer Exemption Petition and the proposed provisions of the UIC Class III permit application by the Nebraska Department of Environmental Quality (NDEQ). Following this approval by the NDEQ, final selection and design of injection/production and monitor well locations will be provided to the NDEQ.

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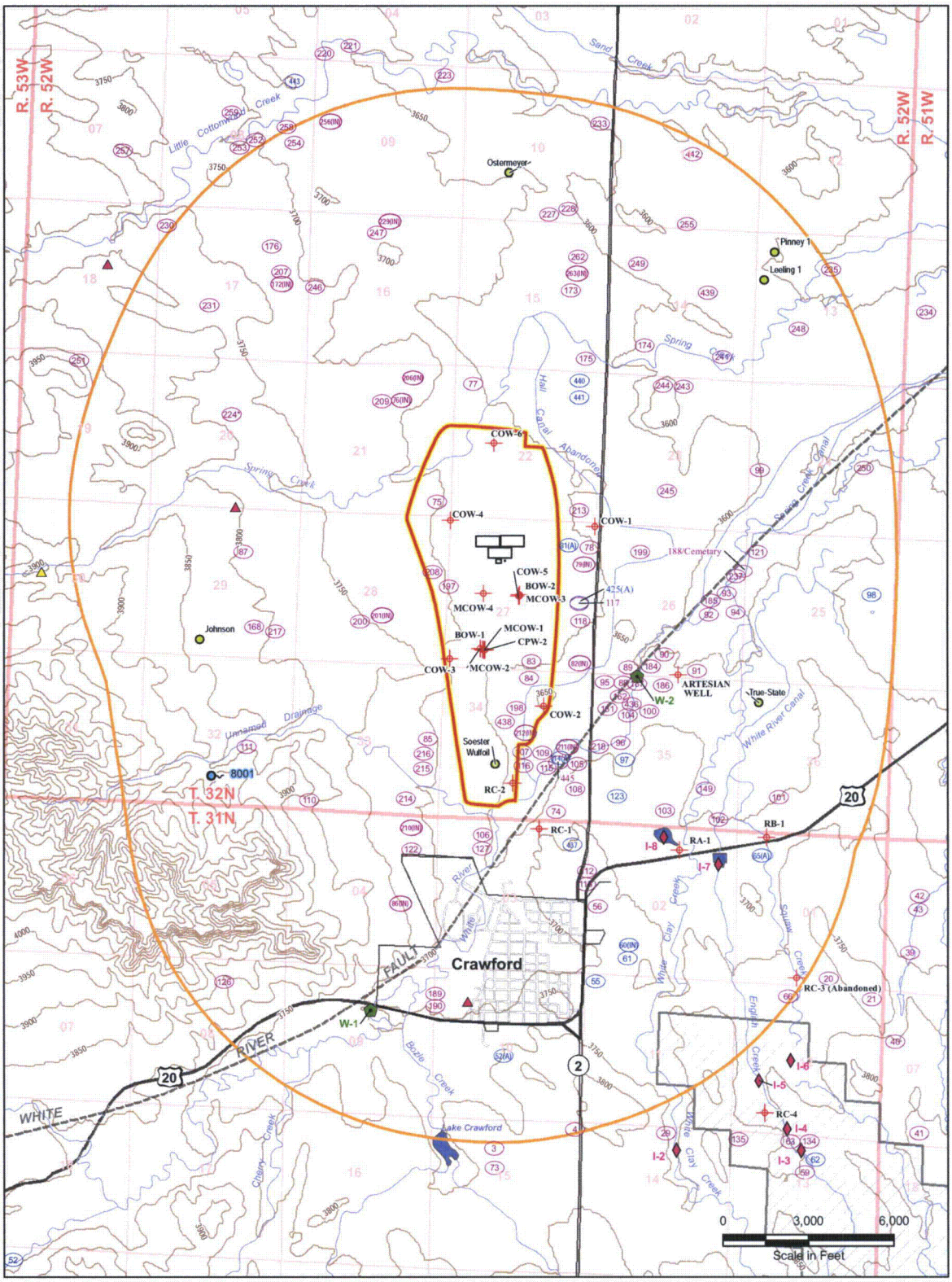


## LEGEND

- Monitoring Well
- Oil/Gas Deep Exploration Well
- Concrete Aggregate Pit
- Sand & Grave Pit
- Brule Water Well (Active)
- Brule Water Well (Abandoned)
- Brule Water Well (Inactive)
- Chadron Water Well (Active)
- Chadron Water Well (Abandoned)
- Chadron Water Well (Inactive)
- Surface Water Monitor
- Water Impoundment
- Spring
- Elevation Contours (in Feet)
- Facilities (Ponds, Satellite Facilities, Deep Well)
- Class III Permit Boundary
- Proposed North Trend Expansion Area (NTEA)
- 2.25-Mile Buffer of Proposed NTEA Boundary
- Lakes
- Streams

N
W — E

* Location of well 224 is approximated.

CROW BUTTE RESOURCES, INC.

FIGURE C.1-1
MAJOR SURFACE FEATURES/STRUCTURES WITHIN AOR
AS PER TITLE 122, CHAPTER 11, SECTION 006.09

PROJECT: CO001322 MAPPED: JC CHECKED: MS

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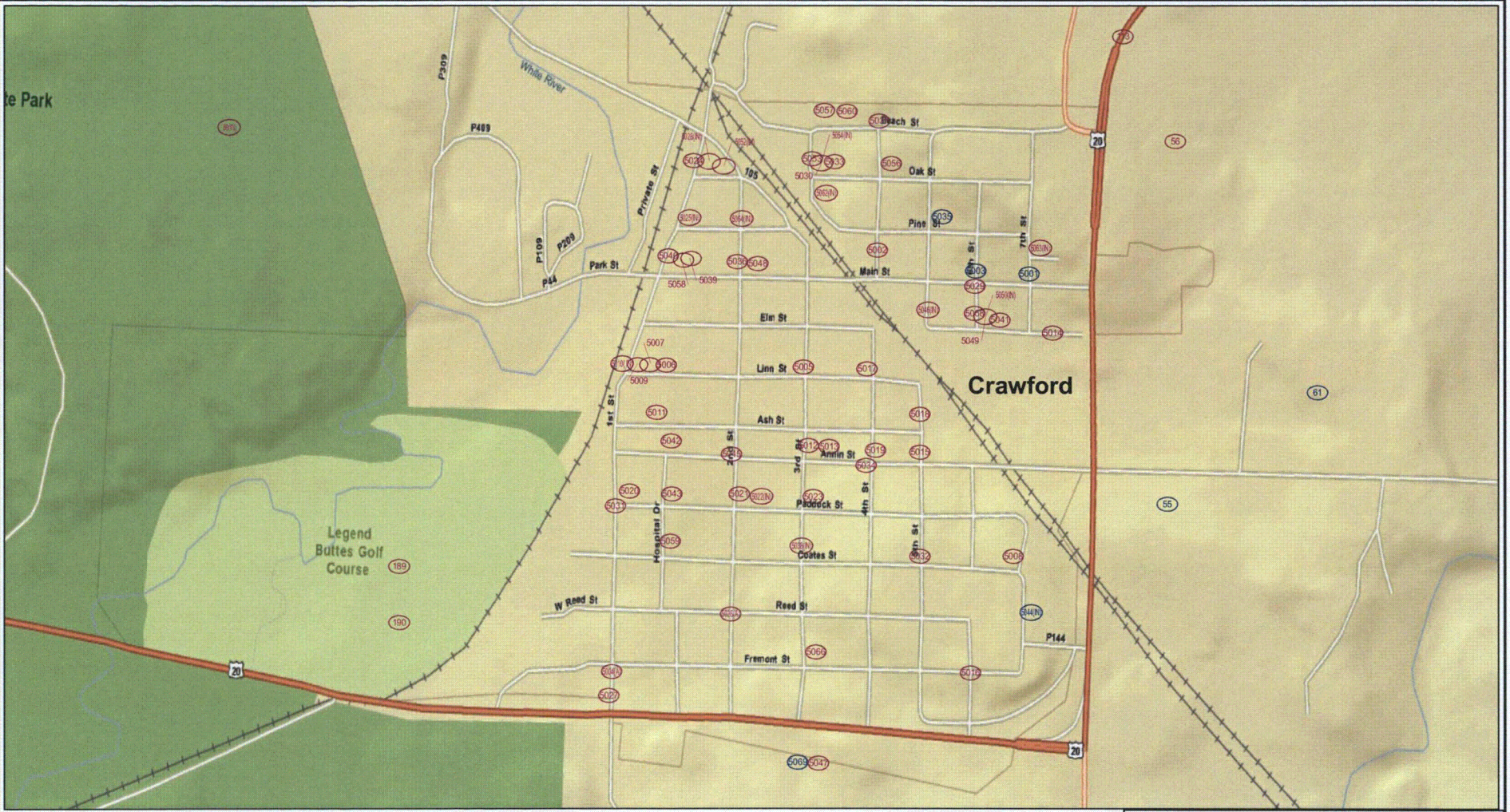


## LEGEND

- Brule Water Well (Active)
- Brule Water Well (Inactive)
- Brule Water Well (Abandoned)
- Chadron Water Well (Active)
- Chadron Water Well (Inactive)

## NOTES

1. Locations of some wells are approximate and are based on available information.
2. Background street map is from ESRI ArcGIS Online Services, 2008.

0 500 1,000
Scale in Feet

CROW BUTTE RESOURCES, INC.

FIGURE C.1-2
LOCATION OF GROUNDWATER WELLS WITHIN CITY OF CRAWFORD

PROJECT: CO001322 MAPPED: JC CHECKED: MS

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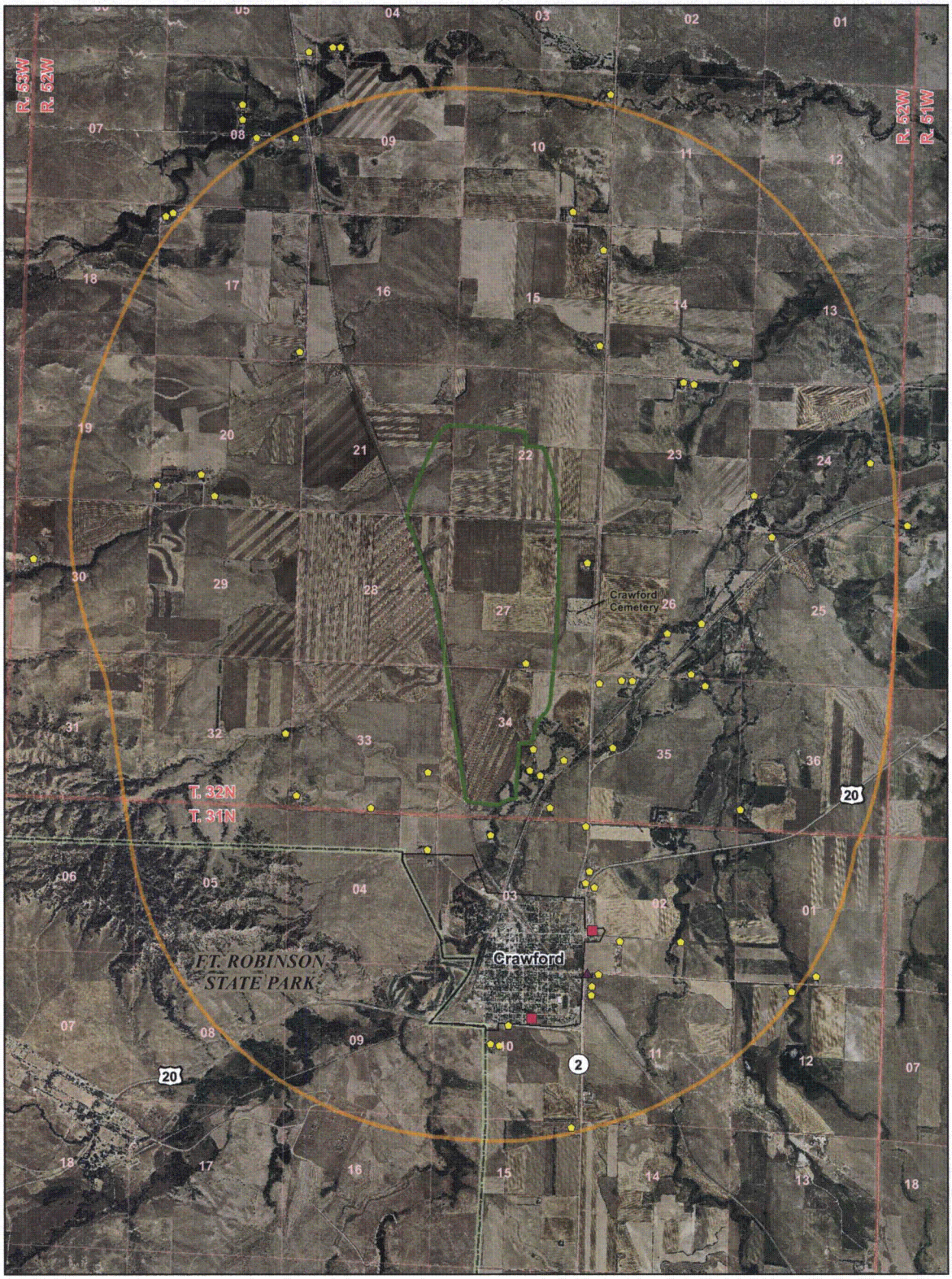


**LEGEND**

- Commercial
- Motel
- Rural Residence
- City Limit of Crawford
- Boundary of Fort Robinson
- Proposed North Trend Expansion Area (NTEA)
- 2.25-Mile Buffer of Proposed NTEA Boundary

0 3,000 6,000
Scale in Feet

N
W E

CROW BUTTE RESOURCES, INC.

FIGURE C.1-3
AERIAL PHOTO DEPICTING LOCATION OF RURAL RESIDENCES AND OTHER LAND FEATURES IN THE AREA OF REVIEW

PROJECT: CO001322 MAPPED: JC CHECKED: MS

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# CHAPTER D. WELLS PENETRATING INJECTION ZONE IN AOR

*A tabulation of all available data on all wells within the area of review which penetrate the injection zone. Data should include but not be limited to each well's type, construction, date drilled, location, depth, water level, and plugging or completion records (Title 122, Chapter 11, Section 006.10).*

## D.1 Oil and Gas Exploration Test Holes

A total of 6 abandoned oil and gas exploration test holes were identified in the designated Area of Review (AOR), with only one identified in the North Trend Expansion Area (NTEA) (NOGC 2008). This latter well, referred to as the Soester-Wulf Oil, is located in Section 34, T32N, R52W, and was drilled to a total depth of 2,006 feet (**Figure D.1-1**). There are currently no active oil and gas exploration activities with the NTEA or the associated AOR. The last test hole in the AOR was drilled in 1977, with the others being drilled and abandoned between 1928 and 1976.

The locations of the six abandoned oil and gas exploration test holes within the AOR are shown in **Figure D.1-1**. A tabulation of all available data on all oil and gas exploration test holes within the NTEA and associated AOR, which have penetrated the injection zone are shown in **Table D.1-1.**

## D.2 Inactive, Active and Abandoned Water Wells

**Tables D.2-1** and **D.2-2** lists the wells currently known to be completed in the Basal Chadron Sandstone Formation (injection zone) within the AOR for the NTEA. More detailed information is presented in **Chapter G** and associated **Appendix 6. Tables D.2-1** and **D.2-2** do not include the injection, recovery, restoration or monitor wells that penetrate the injection zone and are located within that portion of the current CBR production area that is located within the southeast corner of the AOR of the NTEA.

**Table D.2-1** provides a list of 12 private water wells located within the AOR that are completed in the injection zone. Seven of the wells in **Table D.2-1** (Wells, 55, 60, 97, 123, RC-1, 5035 and 5044) are designated for agriculture use, two listed as domestic/agricultural (Well 61 and Well 98), two designated as Other Use (i.e., yard and garden watering) (Well 5001 and Well 5003), and two listed as domestic (Well 5069). Eleven of the 12 wells are designated as active, with the other 1 is designated as inactive. All but 1 of the 12 wells in Table D.2-1 was drilled between 1962 and 1982, with Well # 5069 being drilled in March 2007. The locations of these wells are shown in **Figures C.1-1** and **C.1-2** of **Chapter C**.

As noted in **Table D.1-2**, there is only 1 well (Well 5069) completed in the Basal Chadron Sandstone with available well completion records. A search of the Nebraska Department of Natural Resources (NDNR) groundwater well database (NDNR 2009) did not result in locating any well completion records for 11 of the 12 wells listed in **Table D.2-1**. The reason for this is that completion information for older wells is not available on this database site, but information for more recently drilled wells, such as Well 5069, is available. Under current Nebraska law, domestic or livestock wells completed prior to September 09, 1993, do not have to be registered

(NRS 2008). Therefore, there is little public information available for the pre-1993 completed wells. However, efforts were made by CBR to gather available information on such wells completed in the injection zone of the AOR of the NTEA through interviews with land owners and local drillers, with this information presented in **Appendix 6**. Based on the information available and collected to date, the only known private water supply wells completed in the Basal Chadron Sandstone Formation in the NTEA and associated AOR are presented in **Table D.2-1**.

**Table D.2-2** presents a list of eight CBR Monitor wells (COW-1, COW-2, COW-3, COW-4, COW-5, COW-6, CPW-2 and RC-2) that are completed in the injection zone. All of these wells except COW-1 are completed within the NTEA boundary. Monitor well COW-1 is located approximately 1,300 feet outside of the permit boundary. With the exception of RC-2, the wells were installed in 2004 in support of Pumping Test #6. Well completion reports for these wells are presented in **Appendix 1**. RC-2 was previously used by Wyoming Fuel Company (WFC) as a baseline monitor well in association with the current production area. It was used in Pumping Test #6 in the NTEA as an observation well. The well is currently not being used, but it may be used again in the future in operations as an observation or monitor well. Four additional active monitor wells in the NTEA are screened in the Upper/Middle Chadron (MCOW-1, MCOW-2, MCOW-3, and MCOW-4).

**Table D.2-3** lists 4 private water wells (52, 65, 81, and 114), one City of Crawford water well (425), and two CBR project wells (RC-3, CPW-1) that were plugged and abandoned from 2004 to 2008. A replacement well for well 114 was installed on October 18, 2008 (well #445). Private well abandonment is regulated by the Nebraska Department of Health and Human Services (NDHHS), with requirements being found in the NDHHS regulation Title 178. As per Title 178, Chapter 12 (012.10), once these wells are abandoned, a notice of private well decommissioning must be submitted to the Nebraska Department of Natural Resources (NDNR) on the NDNR's Notice of Abandonment form, as per NDHHS requirements. The wells to be plugged are discussed further in Chapter S – Corrective Action Plan.

All inactive, active and abandoned water wells completed in the Brule or Chadron formations within the North Trend Expansion Area and associated AOR are discussed in Section I.1.3.2 of **Chapter I** and Section G.2 of **Chapter G** (see **Table G.2-1 and** associated **Appendix 6** for a complete tabulation and **Figures C.1-1** and **C.1-2** for the location of groundwater wells within 2.25 miles of the NTEA.).

## D.3 Abandonment Documentation

### D.3.1 Oil and Gas Test Holes

Based on data provided by the Nebraska Oil and Gas Commission (NOGC), Plugging Affidavits were available for 5 of the 6 abandoned exploration test holes (NOGCC 2008). The Pinney 1 Test Hole (API Well No.260450503400) did not have a plugging affidavit, but it did have well information that indicated the test hole was abandoned in 1930. This well information and available plugging affidavits for the remaining test holes are presented in **Appendix 2**.

### D.3.2 Private Water Wells and Monitor Wells

Affidavits of abandonment for all of the wells in **Table D.2-3** are provided in **Appendix 2**.

## D.4 References

Nebraska Department of Natural Resources (NDNR) 2008. Department of Natural Resources *Registered Groundwater Wells Data Retrieval.* Located at: http://dnrdata.dnr.ne.gov/wellssql/. Accessed on June 26, 2008.

Nebraska Oil and Gas Conservation Commission (NOGCC). 2008. [Webpage]. Located at: http://www.nogcc.ne.gov/ (Well data and publications). Accessed on April 1, 2008.

Nebraska Revised Statues. (NRS). 2008. Chapter 46: Irrigation and Regulation of Water. Section 46-602: Registration of water wells; forms; replacement; change in ownership; illegal water well; decommissioning required.

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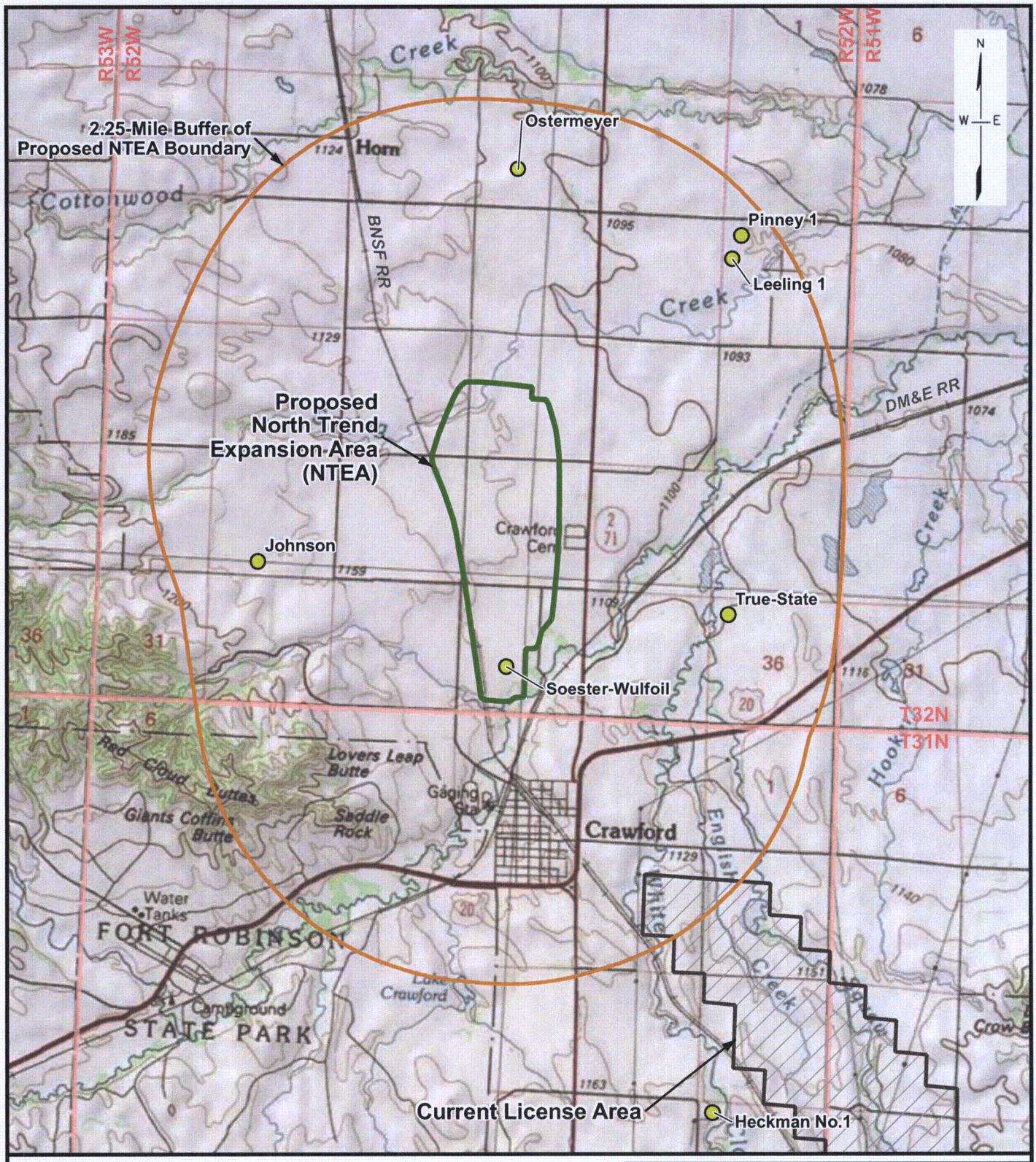


## Legend

- Oil/Gas Deep Exploration Well
- Proposed North Trend Expansion Area (NTEA)
- 2.25-Mile Buffer of Proposed NTEA Boundary
- Current License Area

BNSF RR - Burlington Northern Santa Fe Railroad
DM&E RR - Dakota, Minnesota and Eastern Railroad

Source:
Nebraska Oil and Gas Commission (NOGC). 2008. [Web page]. http://www.nogcc.ne.gov/ (Well data and publications). Accessed on April 01, 2008.

0 0.5 1 Miles

CROW BUTTE RESOURCES, INC.

FIGURE D. 1-1
North Trend Expansion Area
Location of Oil/Gas Test Holes

PROJECT: CO001322.0001 MAPPED: JC CHECKED: J.CEARLEY

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**Table D.1-1 Oil and Gas Exploration Drill Holes for North Trend Area of Review**

| API Well Number | Operator | Well Name | Location | Well Type | Total Depth (ft) | Well Status | Spud Date | Date Plugged & Abandoned | Plugging Affidavit |
|---|---|---|---|---|---|---|---|---|---|
| 260450503400 | Wm. Erbe | Pinney 1 | T32N R52W Sec. 13 Lat: 42.753678527 Long: -103.3822222 | DH Exploration | 3188 | DA | 9/02/1928 | 05/02/1928 | No[a] |
| 260450503500 | Amerada Petroleum Corp. | Ostermeyer | T32N R52W Sec. 10 Lat: 42.760296342 Long:-103.4174203 | DH Exploration | 5110 | DA | 9/01/1945 | 12/30/1945 | Yes (See Appendix 2) |
| 260452100200 | Gable Drilling Co. – Joe Josephson | Johnson | T32N R52W Sec. 29 Lat: 42.714008491 Long: -103.4554364 | DH Exploration | 3400 | DA | 01/28/1969 | 02/03/1969 | Yes (See Appendix 2) |
| 260452103700 | True Oil Company | True-State | T32N R52W Sec. 36 Lat: 42.710003762 Long: -103.3818733 | DH Exploration | 5123 | DA | 09/02/1972 | 09/29/1972 | Yes (See Appendix 2) |
| 260452104100 | Kansas-Nebraska | Leeling 1 | T32N R52W Sec. 13 Lat: 42.750955507 Long: -103.3834312 | DH Exploration | 2181 | DA | 02/24/1976 | 02/09/1976 | Yes (See Appendix 2) |
| 260452105000 | Wulf Oil Corporation | Soester-Wulf Oil | T32N R52W Sec. 34 Lat: 42.703058483 Long: -103.4161225 | DH Exploration | 2006 | DA | 08/29/1977 | 09/03/1977 | Yes (See Appendix 2) |

DH – Drill Hole
DA – Dry and Abandoned
[a]Well information stating year of abandonment presented in Appendix 2.
Source: Nebraska Oil and Gas Conservation Commission (NOGCC 2008).

**Table D.2-1 Private Water Wells Located in Area of Review and Completed in the Injection Zone**

| Well No. | 55 | 60 | 61 | 97 | 98 | 123 | RC-1[a] |
|---|---|---|---|---|---|---|---|
| Well Type | Agricultural | Agricultural | Domestic/ Agricultural | Agricultural | Domestic/ Agriculture | Agricultural | Agricultural |
| Construction | 320 feet plastic casing | 312 feet steel casing | 280 feet plastic casing | 380 feet plastic casing | 100 feet plastic casing | 280 feet plastic casing | 330 feet Yellowstone casing |
| Date Drilled | -- | 1962 | 1980 | ~1976 | 1981 | 1979 | 1982 |
| Location | T31N R52W Sec 11 | T31N R52W Sec 2 | T31N R52W Sec 2 | T32N R52W Sec 35 | T32N R52W Sec 25 | T32N R52W Sec 35 | T31N R52W Sec 3 |
| Total Depth (feet) | 320 | 312 | 280 | 380 | 100 | 280 | 70 |
| Water Level | Artesian Flow | Artesian Flow | Artesian Flow | Artesian Flow to Surface | Artesian Flow | Artesian Flow to Surface | 3685.77[b] |
| Well Status | Active | Inactive | Active | Active | Active | Active | Active |
| Completion Records | No | No | No | No | No | No | No |

| Well Number | 5001 | 5003 | 5035 | 5044 | 5069 |
|---|---|---|---|---|---|
| Well Type | Other [water lawn] | Other [some lawn & garden watering] | Agricultural | Agricultural | Domestic |
| Construction | Plastic Casing | Steel | Plastic | Steel | PVC |
| Date Drilled | 1/1972 | 1/1964 | 1/1980 | ~1/1965 | 3/30/2007 |
| Location | 31N 52W 3 | 31N 52W 3 | 31N 52W 3 | 31N 52W 3 | 31N 52W 10 SWNE 42°40' 38.00" 103° 24' 46.00" |
| Total Depth (feet) | 280 | 280 | 285 | 400 | 360 [casing 0 to 300 ft] |
| Water Level | -- | -- | -- | 17.9 | 30 |
| Well Status | Active | Active | Active | Inactive [no pump] | Active |
| Completion Records | No | No | No | No | Yes (See Appendix 1) |

[a]Former WFC monitor well; now privately owned.

[b]Groundwater elevations are in feet above mean sea level (ft-amsl). Groundwater elevations based on pressure readings (psi). Measurements taken in 3/04/08 – 03/17/08, 03/17/08, 03/28/08, 04/04/08 and 04/16/08. Measurement readings in table are an average for these 5 sampling periods per each well.

-- Denotes unknown.

**Table D.2-2 CBR North Trend Expansion Area Monitor Wells in the Area of Review Completed in the Injection Zone**

| Well Number | RC-2 [a] | COW-1 | COW-2 | COW-3 |
|---|---|---|---|---|
| Well Type | Basal Chadron Observation Well Not Used | Basal Chadron Observation well | Basal Chadron Observation well | Basal Chadron Observation well |
| Construction | 572 feet Yellowstone casing | 529 feet PVC | 569 feet PVC | 589 feet PVC |
| Date Drilled | 1982 | 6/30/2004 | 7/06/2004 | 6/28/2004 |
| Location | T32N R52W Sec 34 | T32N R52W Sec 27 | T32N R52W Sec 34 | T32N R52W Sec 27 |
| Total Depth (feet) | 630 | 580 | 620 | 670 |
| Water Level | 3701.18[b] | 3707.22[b] | 3706.75[b] | 3517.72[b] |
| Well Status | Active | Active | Active | Active |
| Completion Records | No | Yes (See Appendix 1) | Yes (See Appendix 1) | Yes (See Appendix 1) |

| Well Number | COW-4 | COW-5 | COW-6 | CPW-2 |
|---|---|---|---|---|
| Well Type | Basal Chadron Observation well | Basal Chadron Pumping Well | Basal Chadron Monitor Well | Basal Chadron Observation well |
| Construction | 579 feet PVC | 659 feet PVC | 449 feet PVC | 609 feet PVC |
| Date Drilled | 7/01/2004 | 12/15/2004 | 2/11/2008 | 7/15/2004 |
| Location | T32N R52W Sec 27 | T32N R52W Sec 27 | T32N R52W Sec 22 | T32N R52W Sec 27 |
| Total Depth (feet) | 670 | 740 | 510 | 710 |
| Water Level | 3714.19[b] | 3711.30[b] | 3719.50[b] | 3718.00[b] |
| Well Status | Active | Active | Active | Active |
| Completion Records | Yes (See Appendix 1) | Yes (See Appendix 1) | Yes (See Appendix 1) | Yes (See Appendix 1) |

[a]RC-2 was a previously drilled well (1982) and was used as an observation well during Pumping Test #6; the well is currently not being used, but may be used in future operations as an observation or monitor well.

[b]Groundwater elevations are in feet above mean sea level (ft-amsl). Groundwater elevations based on pressure readings (psi). Measurements taken in 3/04/08 – 03/17/08, 03/17/08, 03/28/08, 04/04/08 and 04/16/08. Measurement readings in table are an average for these 5 sampling periods per each well.

--Denotes unknown.

**Table D.2-3 Wells Abandoned, or to be Abandoned, in the Area of Review in Support of Class UIC Permit Application**

| Well Number | 65 | 81 | RC-3 | CPW-1[a] | 425[b] | 52 | 114 |
|---|---|---|---|---|---|---|---|
| Well Type | Agricultural | Agricultural | WFC Monitor Well | Basal Chadron Observation well | Agricultural | Agricultural | Agricultural |
| Construction | 260 feet plastic casing | 530 feet of 2-inch PVC casing with 15 feet of 6-inch galvanized piping at top | 260 feet Yellowstone casing | Well not completed | ~700 feet Steel | 420 feet steel casing | 50 feet plastic casing |
| Date Drilled | 1980 | 1985 | 1982 | 2004 | ~1983 | 1956 | 1970s |
| Location | T31N R52W Sec 1 | T32N R52W Sec 27 | T31N R52W Sec 1 | T32N R52W Sec 27 | T32N R52W Sec 27 | T31N R52W Sec 10 | T32N 52W Sec 34 |
| Total Depth (feet) | 260 | 530 | 293 | 650 | ~700 feet | 420 | 470 |
| Water Level | Artesian Flow | Artesian Flow | Artesian Flow | Artesian Flow | 4.8 feet | Artesian Flow | Estimated 15 feet |
| | Abandoned [5/19/2008] | Abandoned [ 12/20/2005] | Abandoned [5/20/2008] | Abandoned [12/22/2004] | Abandoned [8/30/2008] | Abandoned [11/16/2008] | Abandoned [10/18/2008] |
| Plugging and Abandonment Records | Yes (See Appendix 2) | Yes (See Appendix 2) | Yes (See Appendix 2) | Yes (See Appendix 2) | Yes (see Appendix 2) | Yes (see Appendix 2) | Yes (See Appendix 2) |

[a]CPW-1 was abandoned due to casing problems and replaced with CPW-2.
[b]Well # 425 was located at cemetery owned by City of Crawford near the eastern NTEA boundary.

# CHAPTER E. GEOLOGY AND SEISMOLOGY

*Discussion of the regional geological setting and geological structure of the local area including faults if known or suspected. Discussion of the regional and local seismology and associated risk.*

**Note: All figures referenced in this section are located in the following Chapter F. The Chapter F figures are numbered to correspond with the section numbers of Chapter E.**

## E.1 Regional Setting

The Crow Butte Project is in Dawes County in northwestern Nebraska. Crawford is the principal city in the area and lies approximately 4 miles northwest of the current Crow Butte Nuclear Regulatory Commission (NRC)-licensed and Nebraska Department of Environmental Quality (NDEQ)-permitted area. The proposed North Trend Expansion Area lies approximately 5.5 miles northwest of the current operations.

Crawford is 25 miles west of Chadron, Nebraska and 70 miles north of Scottsbluff, Nebraska. Crawford is 21 miles south of the South Dakota state line and 33 miles east of the Wyoming state line. The topography consists of low rolling hills dominated by the Pine Ridge south and west of the project area.

## E.2 Regional and North Trend Area Geology

**Table E.2-1** summarizes the regional stratigraphic section for northwest Nebraska. **Figure F.2.1** of Chapter F represents a geologic map of bedrock in northwest Nebraska. The bedrock map depicts the occurrence in northwest Nebraska of the Miocene Ogallala Group, Miocene Arikaree Group, the Eocene-Oligocene White River Group, and Upper Cretaceous strata belonging to the Montana Group and Colorado Group. The Upper Cretaceous Pierre Shale, the unconformably overlying White River Group, and the Arikaree Group outcrop in the vicinity of the City of Crawford and the North Trend Expansion Area (NTEA) (**Figure F.2-1** of Chapter F, see inset).

The Crow Butte area is located near the northern limits of the High Plains section of the Great Plains physiographic province. Topography of the Crow Butte area includes gently sloping, rolling hills with outlying, broad ridges which are dissected by intermittent and perennial streams. The most prominent physiographic feature in the region is the Pine Ridge Escarpment, which rises roughly 300 to 900 feet above the basal plain. The escarpment bounds three sides of the Crawford Basin. Colluvial and alluvial deposits originating from this escarpment cover the permit area. The elevation of the Crow Butte Project area ranges from 3,600 to 4,400 feet above mean sea level (amsl).

The local stratigraphy within the NTEA consists of the following geological units in descending order: alluvial sediments, Brule Formation, Chadron Formation, Basal Chadron Sandstone, and Pierre Shale. The Basal Chadron Sandstone represents the production zone and target of solution mining in the NTEA. The general stratigraphic section for the NTEA is summarized in **Table E.2-2**. Revised nomenclature for stratigraphic units within the White River Group is discussed in detail in Section E.3. **Figure F.2-2** of Chapter F illustrates the locations of four north-south and

east-west cross-sections through the NTEA depicted on **Figures F.2-3a** through **F.2-3d** of Chapter F.

Though a thick (approx. 1,200 to 1,500 feet), regionally extensive stratigraphic section of sedimentary units underlies the Pierre Shale, those units are not relevant to this permit application. The absence of sandstone units for more than 1,000 feet below the top of the Pierre Shale precludes the need for monitoring zones below the surface of the Pierre Shale. Discussion in this report is limited to those formations immediately above and below the Basal Chadron Sandstone (Petrotek 2004; Wyoming Fuel Company 1983).

Hansley et al. (1989) conducted detailed geochemical analysis of the Crow Butte uranium ore to assess both ore genesis and composition. The Crow Butte deposits, including those at the NTEA, are roll-type deposits with coffinite being the predominant uranium mineral species present. The origin of the uranium is in-situ rhyolitic ash material within the Basal Chadron Sandstone. Coffinite is associated with pyrite and high silica activity due to dissolution of the rhyolitic ash favored formation of coffinite over uraninite in most parts of this sandstone. In addition, smectite is present in the samples examined, with the most common minerals in the sandstone being quartz, plagioclase, K-feldspar, coffinite, pyrite, marcasite, calcite, illite/spectite smectite, and tyuyamunite. The heavy mineral portion of the samples contained several minerals including those above as well as garnet, magnetite, marcasite, and illmenite. Vanadium was detected in the samples primarily as an amorphous species presumed to have originated from the in-situ ash. Hansley, et al. (1989) state that at least some uranium and vanadium remain bound to amorphous volcanic material and/or smectite rather than as discrete mineral phases.

Petrographic data obtained and examined by Hansley et al. (1989) suggest that uranium mineralization occurred before lithification of the Basal Chadron Sandstone. Hansley states: "*Dissolution of abundant rhyolitic volcanic ash produced U- and Si- rich groundwaters that were channeled through permeable sandstone as at the base of the Chadron by relatively impermeable overlying and underlying beds. The precipitation of early authigenic pyrite created a reducing environment favorable for precipitation and accumulation of U in the basal sandstone. The U has remained in a reduced state, as evidenced by the fact that the unoxidized minerals, coffinite and uraninite, comprise the bulk of the ore.*"

Based on similar regional deposition, the NTEA ore body is expected to be similar mineralogically and geochemically to that of the Commercial Study Area CSA. The ore bodies in the two areas are within the same geologic unit (the Basal Chadron Sandstone) and have the same mineralization source. The sites are separated by only a few miles, and the cause of mineral deposition in the two areas appears to be similar. Neither site is anticipated to be significantly affected by recharge or other processes. The groundwater characteristics of the NTEA mineralized zone are discussed in detail in Chapter G.

## E.3 Stratigraphy

The general stratigraphy for northwest Nebraska is shown in **Table E.2-1**. The regional stratigraphy consists of pre-Cambrian basement rocks that are overlain by a thick Phanerozoic stratigraphic sequence. This section provides a detailed description of the stratigraphy of the NTEA based on an extensive review of existing site-specific drilling logs and published

literature. Geological units are described from stratigraphically youngest to stratigraphically oldest. Revised nomenclature for these stratigraphic units is discussed, where applicable, and referenced throughout this application. To be consistent with historical permitting, the stratigraphic nomenclature used in previous submittals to the NRC and the NDEQ has been preserved.

### E.3.1 Alluvium

Alluvial deposits occur from the surface to the top of the Brule Formation, and vary in thickness depending on topography from 0 to 60 feet (**Figures F.2-3a** through **F.2-3d** of Chapter F). In general, the alluvium consists of reworked Oligocene-Miocene age rock fragments, sand, gravel, and sandy soil horizons that originated from the Gering and Monroe Creek Formations that form the nearby Pine Ridge Escarpment. It may also include weathered portions of the underlying Brule Formation. It should be noted that the alluvium may be water-bearing at some locations.

A review of available geophysical logs revealed that the bottom of the alluvium was indicated by the transition from meandering or "chattering" of the geophysical curves to a consistent curve pattern. Portions of the log "chatter" represent the varying lithology, saturation, and porosity of the alluvial materials. For boring locations where distinct geophysical curve signatures were not observed between the alluvium and underlying Brule Formation, selection of the contact between the overlying and underlying units were based on existing information provided by CBR.

### E.3.2 White River Group

The Eocene-Oligocene White River Group consists of the Basal Chadron Sandstone overlain by the Chadron Formation, which is, in turn, overlain by the Brule Formation (**Table E.2-2**). Strata assigned to this group were deposited within fluvial, lacustrine, and eolian environments (Terry and LaGarry 1998). In northwest Nebraska, it rests unconformably on pedogenically modified Pierre Shale. The bulk of the White River Group is composed of airfall and reworked volcaniclastics derived from sources in Nevada and Utah (Larson and Evanoff 1998; Terry and LaGarry 1998).

The history of stratigraphic nomenclature for the White River Group of Nebraska and South Dakota has had various interpretations as described by Harksen and Macdonald (1969). The following stratigraphic nomenclature represents a preservation of formal and informal members based on nomenclature by Schultz and Stout (1955) with representation of more recent nomenclature (Terry and LaGarry 1998; Terry 1998; LaGarry 1998; Hoganson et al. 1998).

#### *E.3.2.1 Brule Formation*

The Oligocene Brule Formation represents the youngest unit within the White River Group which outcrops throughout most of the Crow Butte area. The unit conformably overlies the Chadron Formation and is unconformably overlain by sandstones of the Arikeree Group (**Figure F.2-1** of Chapter F). The formation was originally subdivided by Swinehart (1985) and later revised by LaGarry (1998) into three members, from youngest to oldest: the "brown siltstone" member, the Whitney Member, and underlying Orella Member (**Table E.2-2**). The "brown siltstone" member consists of pale brown and brown, nodular, cross-bedded eolian volcaniclastic siltstones and sandy siltstones. The contact with the underlying Whitney Member varies from

gradational to a sharp unconformity where the brown siltstone fills valleys and depressions. The Whitney Member consists of pale brown, massive, typically nodular eolian siltstones with occasional thin interbeds of brown and bluish-green sandstone, and volcanic ash. In contrast, the lowest 10 meters consist of white or green laminated fluvial siltstones, sheet sandstones, and channel sandstones. The contact between the Whitney Member and the underlying Orella Member is intertonguing. The Orella Member consists of pale brown, brown, and brownish-orange volcaniclastic overbank clayey siltstones and silty claystones, brown and bluish-green overbank sheet sandstones, and volcanic ash. Occasional thick, fine- to medium-grained, channelized sandstones occur throughout the Orella Member. These sandstones appear to have very limited lateral extent. The overall thickness of the Brule Formation within the NTEA is approximately 50 to 100 feet. The majority of the Brule Formation present at the NTEA consists of the Orella Member, as the entire "brown siltstone" member and most of the Whitney Member have been eroded.

The contact between the Brule Formation and underlying Chadron Formation is sometimes difficult to ascertain, as the contact between the two formations is intertonguing (LaGarry 1998). The contact is recognized regionally as the lithologic change from thinly interbedded and less pedogenically modified brown, orange, and tan volcaniclastic clayey siltstones and sheet sandstones of the Orella Member to pedogenically modified green, red, and pink volcaniclastic silty claystones of the Upper Chadron (Terry and LaGarry 1998). The contact cannot be consistently selected in drill cuttings or electric logs. Typical log responses for the Brule Formation exhibit relatively flat or straight curves representing the shale/clay log signature (**Figure F.3-1** of Chapter F). The gamma ray GR curve represents the shale/clay baseline. The bottom of the Brule Formation is noted where the curves coincide with the established shale/clay baseline or where there is a slight shift in the shale/clay baseline. Where the contact for the base of the Brule Formation was indiscernible on electric logs, the location of the contact was based on picks provided by CBR. **Figures F.2-3a** through **F.2-3d** of Chapter F depict the occurrence of the Brule Formation within the NTEA.

### *E.3.2.2 The Chadron Formation*

The Eocene-Oligocene Chadron Formation is a member of the lower White River Group (**Table E.2-2**). The Chadron Formation conformably overlies the Basal Chadron Sandstone and is conformably overlain by the Brule Formation. From top to bottom, the Chadron Formation historically consists of the following stratigraphic units: Big Cottonwood Creek Member,(herein referred to as theUpper Chadron, and Upper/Middle Chadron to be consistent with historical permitting), Peanut Peak Member (herein referred to as the Middle Chadron to also be consistent with historical permitting), and Basal Chadron Sandstone. The Basal Chadron Sandstone represents the production zone and target of in-situ leach (ISL) mining within the NTEA. **Figures F.2-3a** through **F.2-3d** of Chapter F depict the subsurface geology of the Chadron Formation within the NTEA and southward across a fold structure.

#### E.3.2.2.1 Upper Chadron and Upper/Middle Chadron

The Upper Chadron and Upper/Middle Chadron are composed primarily of volcaniclastic overbank silty claystones interbedded with tabular and lenticular channel sandstones, lacustrine limestones, pedogenic calcretes, marls, volcanic ashes, and gypsum (Terry and LaGarry 1998). Tuffs in the Toadstool Park area that occur in the Upper Chadron were dated by $^{40}Ar/^{39}Ar$

methods as late Eocene (~34 Ma) in age (Terry and LaGarry 1998). Ma is a unit of time equal to one million ($10^6$) years. The lower boundary of this member is an intertonguing contact with the underlying Middle Chadron of the Chadron Formation, or it is a local unconformity where the Upper/Middle Chadron fills valleys and depressions (Terry and LaGarry 1998) (**Table E.2.-2**). The upper boundary is recognized by a lithologic change from pedogenically modified green, red, and pink volcaniclastic silty claystones of the Upper Chadron to thinly interbedded and less pedogenically modified brown, orange, and tan volcaniclastic clayey siltstones and sheet sandstones of the Orella Member of the Brule Formation (Terry and LaGarry 1998) (**Table E.2-2**).

The Upper Chadron is the youngest member of the Chadron Formation (**Table E.2-2**). The upper part of the Upper Chadron is light green-gray bentonitic clay grading downward to green and frequently red clay, though interbedded sandstones also occur. Based on the predominance of fine-grained lithologies that comprise the Upper Chadron, this unit represents a distinct and rapid facies change from the coarse-grained lithologies present in the underlying Upper/Middle and Basal Chadron Sandstone. Geophysical logs indicate a facies change within the unit toward the southeast (**Appendix 4**). Based on available well control data, the Upper Chadron is continuous across the NTEA. An isopach map of the Upper Chadron is shown on **Figure F.3-2** of Chapter F. The Upper Chadron ranges in stratigraphic thickness from about 100 to 250 feet in the NTEA (**Figures F.2-3a** through **F.2-3d** of Chapter **F**). X-ray diffraction analyses of the red clay from the CSA to the south indicate that it is primarily composed of montmorillonite and calcite in that vicinity.

Typical geophysical log responses for the Upper Chadron exhibit curves that are relatively flat or straight which represent the shale/clay log signature (**Figure F.3-1** of Chapter F). The GR curve represents the shale/clay baseline. The top of the Upper Chadron is noted where the curves begin to deviate from the shale/clay baseline.

The Upper/Middle Chadron is directly overlain by the Upper Chadron (**Table E.2-2**). At some locations, the Upper/Middle Chadron is similar in appearance to the channel sandstone of the upper portion of the Basal Chadron Sandstone (described later in this section) and is typically a very fine to fine grained, well-sorted, poorly cemented sandstone. Similar to the Upper Chadron, geophysical logs for the Upper/Middle Chadron indicate a facies change toward the southeast. Extensive review of available data from the NTEA and vicinity strongly indicate that the sandstone is completely absent in the vicinity of the fold structure south of the NTEA. At other locations, particularly at the northern and western portions of the NTEA, occurrence of the sandstone unit is intermittent, but is generally present at most borehole locations (**Figures F.2-3a** through **F.2-3d** and **F.3-3b** of Chapter F). The available data suggest that the Upper/Middle Chadron, where present, typically ranges in thickness from approximately 10 to 100 feet across the NTEA (**Figure F.3-4** of Chapter F).

The gamma ray (GR) curve distinctly marks the top and bottom of the Upper/Middle Chadron (**Figure F.3-1** of Chapter F). The curve responses of the logs are not as nearly as large as those seen in the Basal Chadron Sandstone (described below). The GR shifts distinctly to the right at the lower boundary, indicating a sandstone containing uranium. The GR curve can also shift to the left, indicating sandstone without the presence of uranium. The top of the sandstone unit is marked by a return of the GR to the shale/clay baseline.

For unknown reasons, possibly the continued or renewed uplift of the Black Hills or Chadron Dome, reworked sediment and fluvial deposits of the Upper and Upper/Middle Chadron were concentrated in northwestern Nebraska (Terry and LaGarry 1998). At some locations, initial deposition of the Upper/Middle Chadron occurred within paleovalleys incised into the underlying Middle Chadron (Terry and LaGarry 1998). At other locations (e.g., Toadstool Park), the lower boundary is intertonguing (Terry and LaGarry 1998).

E.3.2.2.2 Middle Chadron

The Middle Chadron is described as a clay-rich interval that grades from brick red to grey in color with interbedded bentonitic clay and sands. Alight green-gray "sticky" clay within this unit serves as an excellent marker bed in drill cuttings and has been observed in virtually all regional test holes both within the NTEA and the CSA to the south. The Middle Chadron unconformably overlies the Basal Chadron Sandstone in South Dakota and Nebraska (Terry 1998) (**Table E.2-2**). As described above, the upper boundary is variable and is overlain either by the Upper/Middle Chadron, where present, or by the Upper Chadron (**Table E.2-2**). The Middle Chadron differs from the overlying Upper/Middle and Upper Chadron in that the Middle Chadron is composed of bluish-green, smectite-rich mudstone and claystone, weathers into hummocky, "haystack-shaped" hills and slopes with a popcorn-like surface, is less variegated in color, and has less silt (Terry 1998). The predominantly clay lithology of the Middle Chadron represents a distinct and rapid facies change from the underlying Basal Chadron Sandstone. The Middle Chadron is the thickest member of the White River Group. Within the NTEA, the unit ranges in stratigraphic thickness from about 200 to 300 feet.

Six core samples were collected by CBR at borehole T-775 in the NTEA from low permeability intervals that occur in the upper, middle, and lower portions of the Middle Chadron from approximately 380 to 600 feet below ground surface (bgs) (**Appendix 3**). X-ray diffraction analyses indicate that all samples were composed primarily of smectite with minor varying amounts of feldspar, quartz, calcite, dolomite, and illite mica. Particle grain size analyses indicate that all six samples were silty claystones or clayey siltstones with a relatively even mixture of silt- and clay-sized particles. Three samples (Samples 1, 7, and 11) were predominantly clay-sized particles ranging from 52 percent to 61 percent clay. Three samples (Samples 3, 5, and 9) were predominantly silt-sized particles ranging from 54 percent to 61 percent silt.

Typical geophysical log responses for the Middle Chadron exhibit curves that are relatively flat or straight, which represent the shale/clay log signature (**Figure F.3-1** of Chapter F). The GR curve represents the shale/clay baseline. The top of the Middle Chadron is noted where the curves break either distinctly to the left or to the right, representing the sandstone of the Upper/Middle Chadron, where present.

E.3.2.2.3 Basal Chadron Sandstone

The Basal Chadron Sandstone is the oldest unit in the White River Group. The lower section is a coarse-grained, arkosic sandstone with frequent interbedded thin silt and clay lenses of varying thickness and continuity that lies on a marked regional unconformity with the underlying Yellow Mounds Paleosol (Terry 1998). The lower contact is easily recognized by a change in color and lithology from the underlying black or bright yellow, pedogenically modified surface of the Pierre Shale (i.e., the Yellow Mounds Paleosol) to white channel sandstone. Occasionally, the

Basal Chadron Sandstone grades upward to fine-grained sandstone containing varying amounts of interstitial clay material and persistent clay interbeds. Vertebrate fossils from the Basal Chadron Sandstone in northwestern Nebraska and South Dakota indicate a late Eocene age (Chadronian) (Clark et al. 1967; LaGarry 1996; Lillegraven 1970; Vondra 1958). The Upper Interior Paleosol, occurring as a persistent "red clay" horizon, typically developed on top of the Basal Chadron Sandstone and typically marks the upper limit of the sandstone interval (**Table E.2-2**).

Out of the approximately 130 geophysical logs that were reviewed, 68 geophysical logs indicate the presence of the Upper Interior Paleosol throughout the NTEA and southward across the fold structure. Occurrences of the Upper Interior Paleosol are noted on geophysical logs presented in Appendix 4 on the basis of driller or geologist notes. **Figure F.2-2** indicates the locations of geophysical logs that were reviewed where the Upper Interior Paleosol was noted on logs. The presence or absence of the unit is also indicated on cross-sections (**Figures 2-3a through 2.3d**). In general, the Upper Interior Paleosol is approximately 20 feet thick throughout most of the NTEA, though thicknesses can vary significantly. Although mud or clay-dominated sediments typically occur directly above the Basal Chadron Sandstone, with the exception of intermittent basal conglomerate of the lower Middle Chadron, the oxidation state of overlying clays cannot be determined from geophysical logs (Terry, 1998). Therefore, although log signatures in neighboring wells may be nearly identical, correlations of red horizons cannot be made on that basis. Paleosol oxidation states can drastically change within meters, independently of other geophysical properties. Observations of drill cuttings are the only reliable method of determining the presence of the unit in the subsurface.

An isopach map of the Basal Chadron Sandstone in the vicinity of the NTEA is presented on **Figure F.3-5** of Chapter F. The Basal Chadron Sandstone occurs at depths ranging from about 350 to 700 feet bgs and was encountered at all exploration holes. Stratigraphic thickness of the unit within the NTEA ranges from approximately 20 to 75 feet. The unit thickens westward throughout the NTEA with thicknesses of nearly 100 feet immediately west of the permit boundary in Section 28 (e.g., E54) (**Figure F.3-5** of Chapter F). Three distinct sandstone facies are present in the thickest portions of the unit. The unit thins significantly to the east of the basin trough where only two sandstone facies appear to be present on the outermost edges of the NTEA. Regionally, the unit ranges in thickness from 0 to 250 feet (**Figures F.3-5** and **F.3-6** of Chapter F).

The greenish-white channel sandstones of the Basal Chadron Sandstone that overlie the Yellow Mounds Paleosol are the target of ISL mining activities in the NTEA. The channel sandstones typically occur in three distinct intervals within the NTEA, as compared to the occurrence of only two distinct channel sandstone intervals at the CSA to the south and at the Three Crow Site southwest of the City of Crawford. Regionally, deposition of the Basal Chadron Sandstone has been attributed to large, high-energy braided streams. In this regard, the Basal Chadron Sandstone is lenticular with numerous facies changes occurring within short distances. The interbedded thin silt and clay lenses most likely represent flood plain or low-velocity deposits normally associated with fluvial sedimentation.

Thin section examination of Basal Chadron Sandstone samples collected by CBR in the CSA indicates a composition of 50 percent monocrystalline quartz and 30 to 40 percent

undifferentiated feldspar, plagioclase feldspar, and microcline feldspar. The remainder includes polycrystalline quartz, chert, chalcedonic quartz, various heavy minerals, and pyrite. X-ray diffraction analyses indicate that the Basal Chadron Sandstone is 75 percent quartz with the remaining composition made up of potassium feldspar and plagioclase. Mineralogical data from the Basal Chadron Sandstone within the NTEA is currently unavailable for a direct comparison with the mineralogy in the CSA. However, a discussion of the character of the Basal Chadron Sandstone based on geophysical logging within the NTEA and southward across the fold structure is included in Section E.4.2. With respect to geochemical similarities, analytical results from 1996 through 2008 for groundwater samples collected from the Basal Chadron Sandstone within the NTEA indicate similar geochemical conditions to the CSA (see discussion in Section G.2.2.2).

The GR curve distinctly marks the top and bottom of the Basal Chadron Sandstone. The GR shifts distinctly to the right at the lower boundary of the sandstone unit when uranium is present (**Figure F.3-1** of Chapter F). The resistivity curve generally shifts to the left, indicating a transmissive unit. The N-N log generally reads lower counts per second (cps); therefore, the sandstones appear to be more saturated with a higher porosity than the surrounding material. The top of the formation is marked by a gradual return of the GR to the shale/clay baseline.

### E.3.3 Montana Group

#### *E.3.3.1 Montana Group*

##### E.3.3.1.1 Interior Paleosol (Upper Interior Paleosol and Yellow Mounds Paleosol)

The Interior Paleosol of Schultz and Stout (1955) was subsequently divided into the younger Eocene Upper Interior Paleosol and the Cretaceous Yellow Mounds Paleosol (Pierre Shale) (Terry 1991; Evans and Terry 1994; Terry and Evans 1994; Terry 1998) (**Table E.2.-2**). The Upper Interior Paleosol represents pedogenically modified distal overbank deposits of a distinct fluvial system developed on the surface of the Basal Chadron Sandstone which predates deposition of the Chadron Formation. The Yellow Mounds Paleosol developed on the Cretaceous Pierre Shale and altered the normally black marine shale to bright yellow, purple, lavender, and orange.

X-ray diffraction analyses of a single core sample (Sample 14) collected from the Yellow Mounds Paleosol by CBR at borehole T-775 in the NTEA indicate a primary composition of smectite with minor amounts of quartz, plagioclase, and illite mica (**Appendix 3**). Particle grain size distribution analyses indicate that the sample was predominantly composed of approximately 68 percent clay-sized particles.

Review of available data for the NTEA indicates that neither of the two paleosol units could be consistently interpreted based solely on geophysical logs. For simplicity, these units are not represented on the type log, cross-sections, or the 3D geologic model of the area (described in more detail in Section E.4.1). However, a review of existing geophysical logs and driller's notes indicates that the red clay horizon (Upper Interior Paleosol) was often encountered during drilling activities, confirming its presence within the NTEA (**Appendix 4**).

E.3.3.1.2 Pierre Shale

The Cretaceous Interior Seaway resulted in the offshore deposits of the late Cretaceous Pierre Shale (**Table E.2-2**). The Pierre Shale is a thick, homogenous black marine shale with low permeability and represents one of the most laterally extensive formations of northwest Nebraska. Regional geologic data indicate that this formation can be up to 1,500 feet thick in the Dawes County area (Wyoming Fuel Company 1983; PetroTek 2004). The southward retreat of the Cretaceous Interior Seaway resulted in the subaerial exposure and weathering of rock units from Early Cretaceous to Eocene age across the northern Great Plains (Lisenbee 1988). This event resulted in the erosion and pedogenic modification of the surface of the Pierre Shale to form the brightly colored Yellow Mounds Paleosol (Terry and LaGarry 1998) (**Table E.2-2**). Consequently, the pedogenically modified surface of the Pierre Shale marks a major unconformity with the overlying White River Group and exhibits a paleotopography with considerable relief (DeGraw 1969). The Pierre Shale is underlain by organic-rich shale and marl with minor amounts of sandstone, siltstone, limestone, and chalk of the Niobrara Formation (**Table E.2-1**). **Figure F.3-7** of Chapter F depicts a contour map of the top of the Pierre Shale for the NTEA.

X-ray diffraction analyses of a single core sample (Sample 13) of the Pierre Shale collected by CBR at borehole T-775 in the NTEA indicate a primary composition of smectite with minor amounts of quartz, plagioclase, potassium feldspar, and illite mica (**Appendix 3**). Particle grain size distribution analyses indicate that the sample was predominantly composed of approximately 58 percent clay particles. There are no significant sandstone units within the Pierre Shale underlying the NTEA.

Local logging data indicate that the Pierre Shale ranges in thickness from 1,327 to 1,565 feet in the NTEA. Typical log responses for the Pierre Shale have curves that are relatively flat or straight and represent the shale/clay log signature (**Figure F.3-1** of Chapter F). The GR has established the shale/clay baseline. The top of the Pierre Shale is noted where the curves break either sharply to the left or to the right and represent the occurrence of the Basal Chadron Sandstone.

Seven deep oil and gas wells were drilled in the vicinity of the NTEA (Johnson, Ostermeyer, Pinney 1, Leeling 1, True-State, Soester-Wulfoil and Heckman No. 1 (**Appendix 4**, **Figure D.1-1**). The character of the entire Pierre Shale in the vicinity of the NTEA can be observed in geophysical logs from three of the seven nearby abandoned oil and gas wells (Heckman No. 1, Soester-Wulfoil and Leeling 1), as these wells were completed through the entire thickness of the unit (**Figure F.2-2** of Chapter F). The Heckman No.1 well is approximately 3.5 miles southeast of the NTEA in the vicinity of the central CSA (T31N, R52W, Section 24). The log from Heckman No. 1 is believed to be representative of the Pierre Shale within the Crow Butte area, including the NTEA (**Appendix 4**). At Heckman No. 1, the Pierre Shale is 1,565 feet thick. The top of the Pierre Shale occurs at a depth of 525 feet, and the base occurs at 2,090 feet where it rests on the Niobrara Formation. The spontaneous potential and resistivity curves for this borehole qualitatively indicate a lack of permeable, water-bearing zones within the Pierre Shale. The Soester-Wulfoil well is located within the NTEA, in T32N R52W, Section 34 (**Figure F.2-2** of Chapter F). At this location, the Pierre Shale is 1,327 feet thick and also shows no indication of permeable (water bearing) zones. The top of the Pierre occurs at a depth of 627 feet, and the base is encountered 1,954 feet bgs (**Appendix 4**). The Leeling 1 well is located approximately 2

miles northeast of the NTEA (T32N, R52W, Section 13). At Leeling 1, the Pierre Shale is 1,459 feet thick. The top of the Pierre Shale occurs at a depth of 333 feet and the base occurs at 1,792 feet (**Appendix 4**).

### E.3.4 Pre-Pierre Shale Stratigraphy

Underlying the Pierre Shale is a thick sequence of Mississippian through Cretaceous age strata that unconformably overlie pre-Cambrian granite (**Table E.2-1**). Together with the Pierre Shale, the underlying Niobrara Formation, Carlile Shale, Greenhorn Limestone, and Graneros Shale compose a composite lower confining interval approximately 2,500 feet thick which immediately underlies the Basal Chadron Sandstone. There do not appear to be significant sandstone units within this thick sequence of low-permeability strata.

## E.4 Structural Geology

Regional uplift during the Laramide Orogeny forced the southward retreat of the Cretaceous Interior Seaway, resulting in the subaerial exposure and weathering of rock units from Early Cretaceous to Eocene age across the northern Great Plains (including the Pierre Shale). The depositional basin associated with deformation of the Wyoming thrust belt and initial Laramide uplifts to the west of Nebraska represented a structural foredeep. The greatest uplift occurred in the Black Hills, which lies north of Sioux and Dawes Counties in southwestern South Dakota. Lisenbee (1988) provides a comprehensive summary of the tectonic history of the Black Hills uplift. The pre-Oligocene Black Hills uplift (<37 Ma) occurred prior to the deposition of the Eocene-Oligocene strata of the White River Group. Strata of the White River Group cover most of the eroded roots of the Black Hills uplift as well as the syntectonic sedimentary rocks in the Powder River and Williston basins. The Hartville, Laramie, and Black Hills uplifts supplied sediment for rivers that flowed east-southeast across the study area (Clark 1975; Stanley and Benson 1979; Swinehart et al. 1985).

The most prominent structural expression in northwest Nebraska is the Chadron Arch (**Figure F.4-1** of Chapter F). Together with the Chadron Arch, the Black Hills Uplift produced many of the prominent structural features presently observed in the region today. The Chadron Arch represents an anticlinal feature that strikes roughly northwest-southeast along the northeastern boundary of Dawes County. Swinehart et al (1985) suggested multiple phases of probable uplift in northwestern Nebraska near the Chadron Arch between c.a. 28 Ma and <5 Ma. The only known surficial expressions of the Chadron Arch are outcroppings of Cretaceous rocks that predate deposition of the Pierre Shale in the northeastern corner of Dawes County, as well as in small portions of Sheridan County, Nebraska and Shannon County, South Dakota. The general locations of faults in northwest Nebraska are depicted on the State Geologic Map shown on **Figure F.2-1** of Chapter F.

The Crow Butte area, including the CSA and NTEA, lie in what has been named the Crawford Basin (DeGraw 1969). DeGraw (1969) substantiated known structural features and proposed several previously unrecognized structures in western Nebraska based on detailed studies of primarily deep, oil test hole data collected from pre-Tertiary subsurface geology. The Crawford Basin was defined by DeGraw (1969) as a triangular asymmetrical basin about 50 miles long in an east-west direction and 25 to 30 miles wide. The basin is bounded by the Toadstool Park Fault

on the northwest, the Chadron Arch and Bordeaux Fault to the east, and the Cochran Arch and Pine Ridge Fault to the south (**Figure F.4-1** of Chapter F). The Crawford Basin is structurally folded into a westward-plunging syncline that trends roughly east-west. Note that the Bordeaux Fault, Pine Ridge Fault, and Toadstool Park Fault proposed by DeGraw (1969) are not presented on the State Geologic Map (**Figure F.2-1**). The Toadstool Park Fault has been mapped at one location (T33N, R53W) and estimated to have had approximately 60 feet of displacement (Singler and Picard 1980). The City of Crawford is located near the axis of the Crawford Basin. More recent fault interpretations by Hunt (1990) for northwest Nebraska are also shown on **Figure F.4-1**, which include the Whetstone Fault, Eagle Crag Fault, Niobrara Canyon Fault and Ranch 33 Fault in the vicinity of the City of Harrison in Sioux County. The faults identified by Hunt (1990) all trend to the northeast-southwest, sub-parallel to the Pine Ridge Fault (**Figure F.4-1**).As a result of regional deformation (**Figure F.4-1** of Chapter F), stratigraphic units that underlie the NTEA generally dip gently to the south and southeast, with Tertiary deposits dipping slightly less than the older Mesozoic and Paleozoic Formations (Witzel 1974). Cross-sections presented on **Figures F.2-3a through F.2-3d** of Chapter F illustrate local structural trends across the NTEA. Former drilling activities at the Crow Butte project identified a structural feature referred to as the White River Fault located between the current CSA Class III permit area and the proposed NTEA (**Figure F.4-1** of Chapter F). The White River Fault generally follows the drainage of the White River north of Crawford (**Figure H.1-1** of Chapter H). Evidence of a fault was identified during the exploration drilling phase of the Crow Butte project (Collings and Knode 1984). The fault is manifested in the vicinity of the NTEA as a significant northeast-trending, subsurface fold (**Figures F.2-3a** through **F.2-3d** and **F.3-3a** through **F.3-3d** of Chapter F). Contour maps of the top of the Pierre Shale and Basal Chadron Sandstone further support the existence of this fold structure (**Figures F.3-7, F.4-2, and F.4-3** of Chapter F). It has been suggested that Tertiary displacement along the White River Fault is related to reactivation of bounding sutures in Proterozoic basement rocks associated with island arc terranes (Carlson 2002). Deep data are limited, but confirm that the structural relief across the feature ranges from 300 to 500 vertical feet, depending on location, and is upthrown on the south-southeast side.

Prior to preparation of this application, the detailed fault kinematics of the White River Fault had not been thoroughly investigated. In order to decipher whether geological units have been cut (i.e., offset) by the White River Fault at depth, consistent observations of structural thinning by fault offsets (i.e., less stratigraphic section observed than expected), structurally thickening by fault offsets (e.g., repeated stratigraphic sections), missing stratigraphic sections or linear features associated with a fault rupture must be observed regardless of fault kinematics (e.g., reverse slip, oblique strike-slip, normal slip) in the vicinity of the fold structure. Based on an extensive review of geophysical logs in a 3D context, none of the above conditions were observed that could not be associated with other geological processes (e.g., erosional denudation or paleo-topographic highs associated with fold development). Instead, all of the stratigraphic units within the NTEA are well-correlated southward across the fold structure with no apparent offsets or truncated units on the north limb of the fold, with the exception of the Upper/Middle Chadron. Given that 300 to 500 vertical feet of structural relief exists across the structure, depending on location, the observed thinning of individual members of the Chadron Formation are clearly not related to fault offset along a discrete fault surface. Rather, the observed thinning is likely related to either a localized reduction in sediment accommodation along the north limb of the fold structure as part of the developing basin architecture (folding synchronous with

deposition), localized thinning within the fold limb as a result of flexural bending (post-depositional folding) associated with fault-propagation folding above a "blind" reverse fault or highly distributed normal faulting with no apparent fault offsets (**Figure F.4-1a**). A more detailed discussion of possible fault kinematics responsible for the White River fold structure is provided below.

One interpretation for the observed geometry of the White River fold structure is a fault-propagation fold cored by a "blind" reverse fault at depth (i.e., a fault that loses displacement or "tips out" prior to rupturing the surface or the highest stratigraphic unit) (**Figure F.4-1a**) (Suppe, 1983; Allmendinger, 1999). The geometry of the fold is consistent with a southeast-dipping fault surface and with compressive stresses required to generate an anticline-syncline pair structure. However, the White River fold structure is at a high angle to other compressive structures in the area (e.g. Chadron Arch) (**Figure F.4-1a**). Despite the lack of reporting of similarly orientated compressional structures of White River Group age in the region, it should be noted that the White River fold structure was only identified as a result of the dense concentration of exploration boreholes near the NTEA and that similarly oriented, subsurface compressional structures may be present elsewhere in northwest Nebraska.

Another plausible interpretation for the observed geometry of the White River fold structure involves distributed normal faulting within a tri-shear zone (**Figure F.4-1a**). This scenario requires distributed smaller faults above a deeper normal fault with strata flexure or granular flow in coarser, unindurated units above the highest fault penetration. This geometry would be consistent with a minor half-graben-like geometry with a down-side depression and thickening of the Middle Chadron against the fault. The low strength character of the Pierre Shale would be consistent with the shallowing of a normal fault within this unit. Similarly oriented extensional faults have been observed in the Toadstool Park area (**Figure F.4-1**).Therefore, available drilling and logging data in the NTEA suggest that, while a fault may cut the Pierre Shale at depth along with stratigraphically lower units, there is no evidence that a fault offsets the geologic contact between the Pierre Shale and overlying White River Group nor individual members of the White River Group. Additional discussions of the impacts of potential disturbed faulting within the Basal Chadron Sandstone and potential tensile fractures in the overlying Brule Formation are provided in Section G.4.

### E.4.1 3D Geologic Modeling

In an effort to better characterize the spatial distribution and geologic relationships among the alluvium, Eocene-Oligocene strata of the NTEA, and the White River Fault, a 3D geologic model was developed using Mining Visualization Software (MVS) version 9.12 based on an extensive review of existing exploration hole data from the NTEA. **Figures F.3-3a** through **F.3-3d** of Chapter F present 3D visual perspectives focused on specific stratigraphic and structural relationships between the Brule Formation, Upper/Middle Chadron, Basal Chadron Sandstone, and Pierre Shale. Descriptions provided below of the structure of the stratigraphic units beneath the NTEA and interpretations of the timing of fold development are based in part on the 3D geologic model.

For the purposes of 3D visualization, it should be noted that, for locations where the Upper/Middle Chadron was not present, the contact between the Upper Chadron Formation and

the Middle Chadron Formation was inferred. Distinction of the specific contact between Upper and Middle Chadron was not discernable based on available data. Based on the average occurrence of the top and bottom of the Upper/Middle Chadron, a proportional value of 55 percent of the range of thickness between the top of the Upper Chadron and the base of the Middle Chadron was used to infer the contact between the two units. For example, at borehole D-69, the top of the Upper Chadron occurs at 90 feet bgs and the bottom of the Middle Chadron occurs at 388 feet bgs (a difference of 298 feet). The contact between the two units, therefore, was inferred at 254 feet bgs. Observations from drilling within the NTEA indicate the contact between the Upper and Middle Chadron is intertonguing. For simplicity of 3D visualization, the contact is inferred to be a planar contact.

### E.4.2 Timing of Fold Development

The following discussion targets the timing of development of the subsurface fold structure associated with the White River Fault and its relationship to stratigraphic units within the NTEA. Descriptions are provided in order of first geological occurrence based on review and interpretation of available data.

Based on structural interpretation and the presence of lithologic marker beds, the timing of fold development clearly post-dates deposition of the Cretaceous Pierre Shale and formation of the overlying Yellow Mounds Paleosol. Structural relief of the Pierre Shale appears to be greater toward the southwest of the NTEA compared to the relief to the northeast of the NTEA (**Figures F.3-7 and F.3-3d** of Chapter F). This may, in part, be due to the westward-plunging synclinal axis of the Crawford Basin.

Based on observations from drilling and logging data in the White River Group, the Basal Chadron Sandstone is present at all exploration holes within the NTEA and CSA and can be correlated across the fold structure (**Figures F.2-3a** through **F.2-3d**, **F.3-3a**, **F.3-6** and **F.4-2** of Chapter F). There appears to be a spatial correlation between topographic lows on the eroded surface of the Pierre Shale and the thickest sections of the Basal Chadron Sandstone (e.g., Sections 27 and 33), suggesting that the paleo-topography of the eroded Pierre Shale was partly responsible for the basin fill architecture (**Figures F.3-5** and **F.3-3d** of Chapter F). As depicted in the lower left panel on **Figure F.3-3a** and **Figure F.3-5** of Chapter F, the observed eastward thinning (i.e., localized westward thickening) of this unit in the vicinity of the NTEA may be attributed to the following:

- reduced eastward sediment accommodation related to regional basin subsidence as indicated by regional westward thickening shown on **Figure F.3-6** of Chapter F,
- differential uplift associated with initial activity of the White River Fault,
- elevated paleo-topography east of the NTEA, or
- any combination of the above

Though some degree of flexural thinning appears to have occurred on the limb of the fold, the Basal Chadron Sandstone maintains a relatively consistent range in stratigraphic thickness between the southernmost portion of the NTEA and the top of the fold structure indicating: (1) little, if any, elevated topography existed along the fold structure during deposition of the unit

and (2) the absence of any significant erosional denudation on the northwest limb and axis of the fold structure (**Figures F.3-3a** and **F.3-5** of Chapter F). The nature of the large, high-energy braided streams that deposited this unit also suggests that little topography existed near the fold structure. A review of geophysical logs indicates that the character of the sandstone is different on the fold limb and uplifted side to the south compared to the sandstone in the central NTEA, which is likely related to the depositional environment.

Within the central NTEA, the Basal Chadron Sandstone consists of three distinct sandstone intervals, each typically 10 feet thick. Along the fold limb, the unit is restricted to only 1 or 2 sandstone intervals, each typically 15 to 20 feet thick. South of the fold structure, the unit consists of approximately 5 thin sandstone intervals, each typically 4 to 8 feet thick. The sandstone intervals are more widely spaced in the vertical direction within the central NTEA than within the fold limb and south of the fold structure, possibly indicating more sediment accommodation space at the time of deposition to the north of the fold structure. In addition, the interbedded clay units that separate the sandstone intervals similarly increase in thickness northward. This may be, in part, due to the existing basin fill architecture related to paleotopography of the eroded Pierre Shale discussed above.

Following deposition, this Basal Chadron Sandstone was dramatically folded by deformation related to displacement on the White River Fault at depth. Up to 500 vertical feet of structural relief exists between the NTEA and the uplifted fold axis along the top surface of the Basal Chadron Sandstone. Based on these observations, it is possible that initial displacement on the White River Fault predated deposition of the Basal Chadron Sandstone. However, at the time of the deposition of this unit, any surficial uplift associated with fold development in the vicinity of the NTEA was minimal. Therefore, deposition of the Basal Chadron Sandstone is inferred to predate most, if not all, of the fold development.

The 3D geometry of the Middle Chadron (Peanut Peak Member) strongly suggests that growth of the fold in the subsurface was synchronous with deposition. The Middle Chadron can be correlated throughout the NTEA and across the fold structure (**Figures F.2-3a** through **F.2-3d** of Chapter F). The most pronounced thickening occurs within the NTEA boundary (**Figures F.2-3a** through **F.2-3d** of Chapter F). Noticeable thinning of the unit towards the southeast is spatially coincident with the entire length of the fold axis, indicating reduced sediment accommodation in the vicinity of the fold structure. Given the coeval relationship between fold development and deposition, the interbedded sandstones in the Middle Chadron may indicate episodic uplift along the fold structure. The unit is also structurally folded with up to 650 vertical feet of structural relief between the NTEA and the uplifted fold axis along the bottom surface of the Middle Chadron, clearly indicating that folding also post-dates deposition of this unit.

The Upper/ Middle Chadron dips slightly to the southeast within the NTEA and appears to have been either erosionally denudated or not deposited along the entire length of the fold structure south of the NTEA (**Figures F.2-3a** through **F.2-3d, F.3-4**, and **F.3-3b** of Chapter F). Due to the limited spatial distribution, it is difficult to discern whether this unit was folded within the NTEA. Multiple scenarios could explain the absence of this unit to the south. One scenario involves isolated deposition of the Upper/Middle Chadron to the north of the fold structure. In this scenario, sufficient topographic relief was present to the south by the time the Upper/Middle Chadron was deposited as a result of uplift associated with the fold structure, effectively creating

a localized, topographic barrier to fluvial sedimentation to the south. A second scenario would involve deposition of the Upper/Middle Chadron across the fold structure with a limited southward extent (as indicated by the absence of the Upper/Middle Chadron in the CSA), followed by uplift and erosional removal of the Upper/Middle Chadron along the fold axis prior to deposition of the overlying Upper Chadron. Both scenarios indicate the presence of an erosional unconformity to varying degrees between the Middle Chadron and Upper Chadron in the vicinity of the fold. Available data preclude a distinction between the suggested depositional environments. Based on indications that folding was coincident with the deposition of units stratigraphically above (discussed below) and below the Upper/Middle Chadron, it is inferred that folding was coincident with deposition of this unit.

Available data strongly suggest that growth of the fold was coincident with deposition of the Upper Chadron. The Upper Chadron dips gently to the northeast and can be correlated throughout the NTEA and across the fold structure. Similar to the Middle Chadron, the Upper Chadron is noticeably thin along the entire length of the fold axis to the east and southeast of the NTEA, indicating a similar reduction in sediment accommodation in the vicinity of the fold (**Figures F.2-3a** through **F.2-3d** and **F.3-2** of Chapter F). The unit exhibits less pronounced folding compared to stratigraphically lower and geologically older units (i.e., Middle Chadron, Basal Chadron Sandstone and Pierre Shale), nevertheless indicating that folding also post-dates deposition of this unit. This geometry can be explained by the cumulative effect of continued folding synchronous with deposition where underlying units are progressively more deformed with depth (**Figure F.2-3a** of Chapter F). The most pronounced thickening occurs north of the fold structure and west of the NTEA (**Figure F.2-3a** through **F.2-3d** of Chapter F). Based on available data, localized northward thickening is likely the result of reduced sediment accommodated near the fold structure related to fold development. Based on regional studies, westward thickening of the Upper Chadron was likely the result of increased sediment accommodation from regional basin subsidence and/or synclinal folding of the Crawford Basin (DeGraw 1969; Clark 1975; Stanley and Benson 1979; Swinehart et al. 1985).

In contrast to members of the underlying Chadron Formation and Basal Chadron Sandstone, the Brule Formation does not appear to be significantly folded. An isolated section of the Brule Formation in the vicinity of borings A-698, A-299, and A-686 does appear to be mildly uplifted and broadly folded, though the unit generally maintains a consistent dip of approximately $10^{\circ}$ to the northeast across the area (**Figures F.2-3a, F.2-3d** and **F.3-3c** of Chapter F). Though the stratigraphic thickness varies across the NTEA and to the south, no obvious thinning related to the original depositional environment was observed. Basin fill architecture was likely the predominate control on distribution of the Brule Formation. Thickness variations are mostly attributable to exposure and subsequent erosion of the unit prior to deposition of the overlying colluvial and alluvial cover materials. In summary, deposition of the Middle Chadron, Upper/Middle Chadron, and Upper Chadron appear to be coincident with continued or episodic fold development in the vicinity of the City of Crawford. It is possible that fold development was coincident with the deposition of the Basal Chadron Sandstone; however, any topographic uplift associated with fold development pre-dating deposition of the Basal Chadron Sandstone was minimal. Available data suggest that the White River Fault was active during the late Eocene and possibly early Oligocene, and not entirely during the Oligocene as previously reported. The decreased sediment accommodation across the fold structure (i.e., southward thinning stratigraphic units) observed in some stratigraphic units (Middle Chadron, Upper/Middle

Chadron, and Upper Chadron) is likely related to topographic uplift south of the NTEA along the fold structure and possible regional basin subsidence to the west. Viewed in this context, it is apparent that the depositional environments of selected members of the White River Group (exclusive of the Basal Chadron Sandstone and Brule Formation) were impacted by the growing fold structure southeast of the NTEA. Given the relationship between the protracted history of displacement on the White River Fault and proximal deposition of the White River Group, the Middle Chadron, Upper/Middle Chadron, and Upper Chadron should be considered synorogenic in nature in the vicinity of the CSA and NTEA. There does not appear to be clear temporal or structural relationships between folding associated with the White River Fault and faults that clearly offset the Middle Chadron, Upper/Middle Chadron, and Upper Chadron in the Toadstool Park area (LaGarry 1998; Terry and LaGarry 1998).

## E.5 Relationship Of ISL Mining To Site Geology And Hydrology

The description of the proposed mining operation and relationship to geology and hydrology is presented in Section G.5 of Chapter G.

## E.6 Seismology

The Crow Butte Project Area, including the NTEA, is in northwest Nebraska within the Stable Interior of the United States. The majority of Nebraska is located within seismic risk Zone 1 on the Seismic Risk Map for the United States, and is therefore in an area of low Seismic Hazard (**Figure F.6-1** of Chapter F) as presented by the United States Geologic Survey (USGS) (USGS 2008a, USGS 2008d). The NTEA, including Dawes and Sioux Counties, northwest corner of Box Butte County, and north end of Sheridan County, are located within seismic risk Zone 2 (USGS 2008d). Most of the central United States is within seismic risk Zone 1, and only minor damage is expected from earthquakes that occur within this area. The closest Zone 3 area is approximately 60 miles to the west in eastern Wyoming (USGS 2008d).

Although the project area is within an area of relatively low seismic risk (USGS 2008d), occasional earthquakes have been reported. More than 1,100 earthquakes have been catalogued within the Stable Interior of the U.S. since 1699 by Docekal (1970). This study noted several earthquake epicenters within northwest Nebraska. All but two of these earthquakes were classified within the lowest category, Intensity I-IV, on the Modified Mercalli Intensity Scale of 1931.

**Figure F.6-2** of Chapter F is a seismicity map of Nebraska prepared by the USGS for the 1990 to 2006 time period (USGS 2008b). The locations of the principal structural features of Nebraska, including the Chadron and Cambridge Arches, are shown in **Figure F.4-1** of Chapter F. The earthquakes that have been recorded along these two structural features are tabulated in **Table E.6-1.**

The strongest earthquake in northwest Nebraska (No. 21) occurred July 30, 1934 with an intensity of VI and was centered near Chadron. This earthquake resulted in damaged chimneys, plaster, and china. Earthquake No. 26 occurred on March 24, 1938 near Fort Robinson. This earthquake had an intensity of IV; no additional information is available. An Intensity IV earthquake should be felt indoors by many and disturb dishes, windows, and doors. Earthquake

No. 30 occurred on March 9, 1963 near Chadron. This earthquake was reported to last about a second, was not accompanied by any damage or noise, and was not even noticed by many of the residents of Chadron. Earthquake No. 32 occurred on March 28, 1964 near Merriman. The vibrations from this earthquake lasted about a minute and caused much alarm, but no major damage occurred. Books were knocked off shelves and closet and cupboard doors swung open. On May 7, 1978 an earthquake (No. 40) with Intensity V occurred in southwestern Cherry County, also near the Chadron Arch. No major damage was reported from this earthquake.

Although the risk of major earthquakes in Nebraska is slight (Burchett 1990), some low to moderate tectonic activity has occurred (Rothe et al. 1981). This tectonic movement is also suggested by geomorphic and sedimentation patterns during the Pleistocene (Rothe et al. 1981), which reflect such movement. Recent seismicity on the Cambridge Arch appears to be related to secondary recovery in the Sleepy Hollow oil field (Rothe et al. 1981). Deeper events, however, suggest current low-level tectonic activity on the Chadron and Cambridge Arches. This activity is not expected to affect the mining operations in the North Trend Area.

The most recent earthquakes recorded in Nebraska occurred as follows:

- February 1, 2006 (CERI 2008). The epicenter was about 20 miles east-northeast of Ainsworth, Nebraska, and was therefore more than 200 miles east of Crawford. This earthquake had a recorded magnitude of 2.9, but was not felt at Crawford or the Crow Butte/North Trend area.
- April 16, 2007 (USGS 2008e). The epicenter was approximately 25 miles NNW of McCook, Nebraska, and was therefore more than 210 miles southeast of Crawford or the NTEA. This earthquake had a recorded magnitude of 3.0, but was not felt at Crawford. According to the USGS, no earthquakes have been felt in Nebraska since the April 16, 2007 event (USGS 2008c).

The intensity and magnitude designations measure different characteristics of earthquakes (USGS 2008e). Intensity measures the strength of shaking produced by an earthquake at a specific location, and magnitude is determined from measurements on seismographs. A comparison and explanation of the measurements has been developed by the USGS (USGS 2008f).

## E.7 Soils

The Crow Butte NTEA is located in the semiarid west-central portion of Dawes County, Nebraska, just north of the City of Crawford. The local soils were investigated for the proposed project. Soils data for the North Trend Project Area were obtained from the United States Department of Agriculture (USDA), Natural Resource Conservation Service (NRCS) (USDA/NRCS 2006).

The project area is bounded on the south by the White River and is located in the White River watershed. The terrain is generally flat with gentle rolling hills. Natural vegetation is dominated by drought-tolerant short-grass prairie and large areas of mixed-grass prairie, but they have been largely replaced by agricultural crops within the project area.

Dawes County soils were formed by weathering of materials of the underlying geologic formations or of materials deposited by wind and water. The Brule Formation is widely exposed on lower slopes, is soft, and weathered rapidly producing the Epping, Kadoka, Deota, Schamber, and Mitchell soils. As this material weathered, it produced the Epping, Kadoka variant, Keota, and Mitchell soils. Overlying Tertiary-age bedrock at higher elevations is the Arikaree Group. This massive sandstone contains layers of compacted silt and clay. Soils formed from this fine-grained material are Alliance, Busher, Canyon, Oglala, Tassel, and Rosebud. Sandstone mixed with loess formed soils such as Bayard, Bridget, and Vetal formed in colluvial and alluvial materials.

Soil association is a landscape that has a distinctive proportional pattern of soils, consisting of one or more major soils and at least one minor soil. Three soil associations exist within the project area: Kadoka-Keith-Mitchell, Busher-Tassel-Vetal, and Tripp-Haverson-Glenberg.

The Kadoka-Keith-Mitchell soils are deep, nearly level to steep, well drained silty soils that formed in loess and in material weathered from siltstones on uplands and foot slopes. Typically, this association consists of undulating to rolling uplands that are dissected by many spring-fed creeks. Areas of this association are mostly west of the project area. Approximate percentages of soils in this association are Kadoka at 28 percent, Keith at 23 percent, and Mitchell at 18 percent. Minor soils and land types make up the remaining 31 percent. Minor soils in this series are Bridget, Duroc, Epping, Ulysses, Keota, and Schamber series, and areas of loamy alluvial land and badland.

The Busher-Tassel-Vetal soils are deep and shallow, very gently sloping to steep, well drained to somewhat excessively drained sandy soils that formed in colluvium and in material weathered from sandstone. These sandy soils are found on undulating to hilly uplands that are crossed by numerous creeks and intermittent drainageways. Approximate percentages of soils in this association are Busher 35 at percent, Tassel at 32 percent, and Vetal at 15 percent. Minor soils and land types make up the remaining 18 percent. These include the Bayard, Jayem, and Sarben soil types and sandy alluvial land.

The Tripp-Haverson-Glenberg soils are deep and shallow, very gently sloping to steep, well-drained to somewhat excessively drained sandy soils that formed in colluvium and in material weathered from sandstone on uplands and foot slopes. These soils are found in undulating and hilly uplands that are crossed by numerous creeks and intermittent drainageways. Approximate percentages of soils in this association are: Busher soils at 35 percent, Tassel soils at 32 percent, and Vetal soils at 15 percent. Minor soils and land types make up the remaining 18 percent. Minor soils in this association are soils in the Bayard, Jayem, and Sarben series and areas of sandy alluvial land and rock outcrop.

In certain areas, the soil material is so rocky, shallow, severely eroded, or variable that it has not been classified by soil series. These areas are called land types and are given descriptive names. An example of this is "sandy alluvial land" found within the Busher-Tassel-Vetal association.

Certain mapping units are composed of soil complexes or undifferentiated soil groups. A soil complex consists of areas of two or more soils so intricately mixed or so small that they cannot be shown separately on the soil map. Undifferentiated soil groups are made up of two or more

soils that could be delineated individually but are shown as one unit because, for the purpose of the soil survey, there is little value in separating them. The name given uses the two dominant soil series represented in the group. Four of the mapping units within the restricted area belong to this category, where the names of dominant soils are joined by "and".

### E.7.1 Soils Mapping Unit Descriptions

**Table E.7-1** summarizes those soils found within the North Trend Project Area. The first capital letter is the initial one of the soil name. The lower case letter that follows separates mapping units having names that begin with the same letter except that it does not separate sloping or eroded phases. The second capital letter indicates the class of the slope. Symbols without a slope letter are for soils that have a slope range of 0 to 2 percent or miscellaneous land types that have a wide range of slopes. A final number 2 in the symbol indicates that the soil is eroded. Those soils are also shown on **Figure F.7-1** of Chapter F.

Each soil description contains a designated ecological code. An ecological code is used for the designation of an ecological site, which refers to a distinctive kind of land with specific characteristics that differs from other kinds of land in its ability to produce a distinctive kind and amount of vegetation (NRCS 2003). For example, ecological codes may refer to rangelands or forestlands. For the discussions in this application, the ecological codes consist of 5 parts (e.g., R 064X Y 036 NE).

1. **R**: identifies the type of ecological site as rangeland. This designation precedes the 10-character site number. For forestland, it would be F.
2. **Three-digit Number and a one-digit letter:** This sequence designates the Major Land Resource Area (MLRA). The letters A, B, C, etc. following the MLRA 3 digit number represents the MLRA subdivision. When no MLRA subdivision exists (as with the codes in this report), an X is placed in the fourth space. If the MLRA is only two numbers and no letters, a zero is inserted in the first space followed by the two numbers.

   Note: MLRA refers to the USDA national database of broad geographic areas that are characterized by a particular pattern of soils, climate, water resources, vegetation and land use. Each MLRA in which rangeland and forest land occur is further broken into Land Resource Units (LRUs). MLRAs and the associated LRUs are the basic units for delineating statewide patterns of soils, climate, water resources, and land use.

3. **Single letter identifying a Land Resource Unit (LRU):** This designation is used where applicable. A Y is inserted when the LRUs are not used. LRUs are geographic areas that are characterized by common patterns of soil, climate, water resources and the use of the land. LRUs are the basic elements from which the USDA Soil Conservation Service (SCS) determined MLRAs. MLRAs are geographically related LRUs.
4. **Three-digit Site number:** This is a number representing the individual ecological site number assigned by the state. The number 0 is placed in front of all state-assigned numbers less than 100.
5. **Two-letter State Postal Code**: Postal code of the state developing the site description.

**Bg - Bridget silt loam, 0 to 1 percent slopes**

The Bridget component makes up 100 percent of the map unit. Slopes are 0 to 1 percent. This component is on hillslopes on uplands. The parent material consists of loamy colluvium. Depth to a root restrictive layer is greater than 60 inches. The natural drainage class is well drained. Water movement in the most restrictive layer is moderately high. Availability of water to a depth of 60 inches is very high. Shrink-swell potential is low. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter content in the surface horizon is about 2 percent. This component is in the R064XY036NE Loamy 17 to 20 inches P.z. ecological site. Nonirrigated land capability classification is 2c. Irrigated land capability classification is 1. This soil does not meet hydric criteria. The calcium carbonate equivalent within 40 inches typically does not exceed 6 percent.

Soil blowing can be a hazard in cultivated areas. A large acreage of this soil is cultivated and is dryfarmed, with wheat and alfalfa being the principal crops.

**DuB - Duroc very fine sandy loam, 1 to 3 percent slopes**

The Duroc component makes up 99 percent of the map unit. Slopes are 1 to 3 percent. This component is on swales on uplands. The parent material consists of alluvium. Depth to a root-restrictive layer is greater than 60 inches. The natural drainage class is well drained. Water movement in the most restrictive layer is moderately high. Availability of water to a depth of 60 inches is high. Shrink-swell potential is moderate. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter content in the surface horizon is about 2 percent. This component is in the R064XY036NE Loamy 17 to 20 inches P.z. ecological site. Nonirrigated land capability classification is 2e. Irrigated land capability classification is 2e. This soil does not meet hydric criteria. The calcium carbonate equivalent within 40 inches typically does not exceed 5 percent.

Much of the soil is suited for irrigation and cultivated; however, the area is mostly dryfarmed to wheat, oats, or alfalfa. The rest of the acreage is in native and tame grasses used for grazing or hay production.

**HbB - Haverson silt loam, occasionally flooded, 0 to 3 percent slopes**

The Haverson component makes up 100 percent of the map unit. Slopes are 0 to 3 percent. This component is on flood plains on valleys. The parent material consists of stratified calcareous alluvium. Depth to a root-restrictive layer is greater than 60 inches. The natural drainage class is well drained. Water movement in the most restrictive layer is moderately high. Availability of water to a depth of 60 inches is high. Shrink-swell potential is low. This soil is occasionally flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter content in the surface horizon is about 1 percent. This component is in the R064XY026NE Loamy Overflow ecological site. Nonirrigated land capability classification is 2w. Irrigated land capability classification is 2w. This soil does not meet hydric criteria. The calcium carbonate equivalent within 40 inches typically does not exceed 6 percent.

Approximately half the acreage of this soil is in crops with the other half in range. Alfalfa is the main crop. Trees and shrubs cover some areas.

**JmC - Jayem loamy very fine sand, 1 to 5 percent slopes**

The Jayem component makes up 99 percent of the map unit. Slopes are 1 to 5 percent. This component is on hillslopes on uplands. The parent material consists of sandy and silty eolian deposits. Depth to a root-restrictive layer is greater than 60 inches. The natural drainage class is well drained. Water movement in the most restrictive layer is high. Availability of water to a depth of 60 inches is moderate. Shrink-swell potential is low. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter content in the surface horizon is about 2 percent. This component is in the R064XY032NE Sandy 17 to 20 inches P.z. ecological site. Nonirrigated land capability classification is 3e. Irrigated land capability classification is 3e. This soil does not meet hydric criteria. The calcium carbonate equivalent within 40 inches typically does not exceed 1 percent.

Soil blowing is a hazard if the soil surface is left unprotected. Most of the acreage of this soil is in native grass, which is used for grazing or hay. The rest of the acreage is cultivated with wheat or alfalfa being the main crops.

**KaD2 - Kadoka silt loam, deep variant, 3 to 9 percent slopes, eroded**

The Thirtynine component of the KaD2 map unit makes up 99 percent of the map unit. Slopes are 3 to 9 percent. This component is on hillslopes on uplands. The parent material consists of alluvium derived from siltstone. Depth to a root-restrictive layer is greater than 60 inches. The natural drainage class is well drained. Water movement in the most restrictive layer is moderately high. Availability of water to a depth of 60 inches is very high. Shrink-swell potential is moderate. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter content in the surface horizon is about 3 percent. This component is in the R064XY036NE Loamy 17 to 20 inches P.z. ecological site. Nonirrigated land capability classification is 3e. Irrigated land capability classification is 3e. This soil does not meet hydric criteria. The calcium carbonate equivalent within 40 inches typically does not exceed 8 percent.

Water erosion is the main hazard. Nearly all the acreage of this soil is cultivated to wheat, alfalfa, or oats. A few areas are seeded to grass, which is used for grazing or hay production.

**KeB - Keith silt loam, 1 to 3 percent slopes**

The Keith component makes up 99 percent of the map unit. Slopes are 1 to 3 percent. This component is on plains on uplands. The parent material consists of loess. Depth to a root-restrictive layer is greater than 60 inches. The natural drainage class is well drained. Water movement in the most restrictive layer is moderately high. Availability of water to a depth of 60 inches is very high. Shrink-swell potential is low. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter content in the surface horizon is about 2 percent. This component is in the R064XY036NE Loamy 17 to 20 inches P.z. ecological site. Nonirrigated land capability classification is 2e. Irrigated land capability classification is 2e. This soil does not meet hydric criteria. The calcium carbonate equivalent within 40 inches typically does not exceed 6 percent.

Soil erosion is the main hazard with modest water erosion potential in some areas. This soil is used for both crops and range. Winter wheat, alfalfa, and oats are the principal dryfarmed crops. Some areas are in grass and are used for grazing or hay production.

**KeD - Keith silt loam, 3 to 9 percent slopes**

The Keith component makes up 99 percent of the map unit. Slopes are 3 to 9 percent. This component is on hillslopes on uplands. The parent material consists of loess. Depth to a root-restrictive layer is greater than 60 inches. The natural drainage class is well drained. Water movement in the most restrictive layer is moderately high. Availability of water to a depth of 60 inches is very high. Shrink-swell potential is low. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter content in the surface horizon is about 2 percent. This component is in the R064XY036NE Loamy 17 to 20 inches P.z. ecological site. Nonirrigated land capability classification is 3e. Irrigated land capability classification is 3e. This soil does not meet hydric criteria. The calcium carbonate equivalent within 40 inches typically does not exceed 6 percent.

Water erosion is the main hazard, with soil erosion a concern of management. A small acreage of this soil is used for crops, but most areas are in native grass used for grazing or hay production.

**KfD - Keith and Ulysses silt loams, 3 to 9 percent slopes**

The Keith component makes up 50 percent of the map unit. Slopes are 3 to 9 percent. This component is on hillslopes on uplands. The parent material consists of loess. Depth to a root-restrictive layer is greater than 60 inches. The natural drainage class is well drained. Water movement in the most restrictive layer is moderately high. Availability of water to a depth of 60 inches is very high. Shrink-swell potential is low. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter content in the surface horizon is about 2 percent. This component is in the R064XY036NE Loamy 17 to 20 inches P.z. ecological site. Nonirrigated land capability classification is 3e. Irrigated land capability classification is 3e. This soil does not meet hydric criteria. The calcium carbonate equivalent within 40 inches typically does not exceed 6 percent.

The Ulysses component makes up 49 percent of the map unit. Slopes are 3 to 6 percent. This component is on hillslopes on uplands. The parent material consists of calcareous loess. Depth to a root-restrictive layer is greater than 60 inches. The natural drainage class is well drained. Water movement in the most restrictive layer is moderately high. Availability of water to a depth of 60 inches is high. Shrink-swell potential is low. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter content in the surface horizon is about 2 percent. This component is in the R064XY036NE Loamy 17 to 20 inches P.z. ecological site. Nonirrigated land capability classification is 3e. Irrigated land capability classification is 3e. This soil does not meet hydric criteria. The calcium carbonate equivalent within 40 inches typically does not exceed 8 percent.

Water erosion is a hazard, along with the controlling of soil blowing. Nearly all of the acreage of this soil is used for crops such as wheat, alfalfa, and oats. Only a few areas are irrigated, and a small acreage is seeded to tame grasses used for grazing or hay production.

**KpD - Keota-Epping silt loams, 3 to 9 percent slopes**

The Keota component makes up 70 percent of the map unit. Slopes are 3 to 6 percent. This component is on hillslopes on uplands. The parent material consists of calcareous loamy residuum weathered from siltstone. Depth to a root-restrictive layer, bedrock, paralithic, is 20 to 40 inches. The natural drainage class is well drained. Water movement in the most restrictive layer is moderately high. Available water to a depth of 60 inches is low. Shrink-swell potential is low. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter content in the surface horizon is about 1 percent. This component is in the R064XY037NE Thin Upland ecological site. Nonirrigated land capability classification is 4e. Irrigated land capability classification is 4e. This soil does not meet hydric criteria. The calcium carbonate equivalent within 40 inches typically does not exceed 5 percent.

The Epping component makes up 29 percent of the map unit. Slopes are 3 to 9 percent. This component is on ridges on uplands. The parent material consists of loamy residuum weathered from siltstone. Depth to a root-restrictive layer, bedrock, paralithic, is 10 to 20 inches. The natural drainage class is well drained. Water movement in the most restrictive layer is moderately high. Available water to a depth of 60 inches is very low. Shrink-swell potential is low. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter content in the surface horizon is about 1 percent. This component is in the R064XY040NE Shallow ecological site. Nonirrigated land capability classification is 6s. This soil does not meet hydric criteria. The calcium carbonate equivalent within 40 inches typically does not exceed 6 percent.

Water erosion and soil blowing are hazards. Most of the acreage of this mapping unit is used for dryfarmed crops such as wheat, oats, or alfalfa. The rest of the acreage is in native tame grasses, which are used for grazing or hay production.

**Lo - Loamy alluvial land**

The Haverson component makes up 98 percent of the map unit. Slopes are 0 to 3 percent. This component is on flood plains on valleys. The parent material consists of stratified calcareous alluvium. Depth to a root-restrictive layer is greater than 60 inches. The natural drainage class is well drained. Water movement in the most restrictive layer is moderately high. Available water to a depth of 60 inches is high. Shrink-swell potential is low. This soil is frequently flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter content in the surface horizon is about 1 percent. This component is in the R064XY026NE Loamy Overflow ecological site. Nonirrigated land capability classification is 6w. This soil does not meet hydric criteria. The calcium carbonate equivalent within 40 inches typically does not exceed 6 percent.

Most areas of this land type are used for grazing but grass in a few areas is cut for hay. The hazard of flooding and deposition of sediment generally makes this land type unsuited to cultivation. The native vegetation is mostly grasses, and some areas support trees or shrubs. Most areas provide good food and cover for wildlife.

**OgF - Oglala loam, 9 to 30 percent slopes**

The Oglala component makes up 100 percent of the map unit. Slopes are 9 to 30 percent. This component is on hillslopes on uplands. The parent material consists of loamy residuum weathered from soft, fine-grained sandstone. Depth to a root-restrictive layer, bedrock, paralithic, is 40 to 60 inches. The natural drainage class is well drained. Water movement in the most restrictive layer is moderately high. Availability of water to a depth of 60 inches is low. Shrink-swell potential is low. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter content in the surface horizon is about 2 percent. This component is in the R064XY036NE Loamy 17 to 20 inches P.z. ecological site. Nonirrigated land capability classification is 6e. This soil does not meet hydric criteria. The calcium carbonate equivalent within 40 inches typically does not exceed 3 percent.

Soil blowing and water erosion are hazards if the soil surface is not protected. Nearly all the acreage of this soil is in native grass. A few areas are seeded to tame grasses. This soil is unsuited to cultivation because of the steepness of the slopes.

**OhF - Oglala-Canyon loams, 9 to 20 percent slopes**

The Oglala component makes up 70 percent of the map unit. Slopes are 9 to 20 percent. This component is on hillslopes on uplands. The parent material consists of loamy residuum weathered from soft fine-grained sandstone. Depth to a root-restrictive layer, bedrock, paralithic, is 40 to 60 inches. The natural drainage class is well drained. Water movement in the most restrictive layer is moderately high. Available water to a depth of 60 inches is low. Shrink-swell potential is low. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter content in the surface horizon is about 2 percent. This component is in the R064XY036NE Loamy 17 to 20 inches P.z. ecological site. Nonirrigated land capability classification is 6e. This soil does not meet hydric criteria. The calcium carbonate equivalent within 40 inches typically does not exceed 3 percent.

The Canyon component makes up 30 percent of the map unit. Slopes are 9 to 20 percent. This component is on ridges on uplands. The parent material consists of calcareous loamy residuum weathered from limestone and sandstone. Depth to a root-restrictive layer, bedrock, paralithic, is 6 to 20 inches. The natural drainage class is well drained. Water movement in the most restrictive layer is moderately high. Available water to a depth of 60 inches is very low. Shrink-swell potential is low. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter content in the surface horizon is about 2 percent. This component is in the R064XY040NE Shallow ecological site. Nonirrigated land capability classification is 6s. This soil does not meet hydric criteria. The calcium carbonate equivalent within 40 inches typically does not exceed 6 percent.

Water erosion is a hazard if the cover of native grass is removed from these soils. Nearly all the acreage of this unit is in native grass and is used mostly for grazing. Nearly all of the areas that were cultivated have been seeded to grass. These soils are not suited to cultivation.

**SrC - Sarben fine sandy loam, 1 to 5 percent slopes**

The Sarben component makes up 100 percent of the map unit. Slopes are 1 to 5 percent. This component is on hillslopes on uplands. The parent material consists of sandy and loamy eolian deposits. Depth to a root-restrictive layer is greater than 60 inches. The natural drainage class is well drained. Water movement in the most restrictive layer is high. Availability of water to a depth of 60 inches is moderate. Shrink-swell potential is low. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter content in the surface horizon is about 1 percent. This component is in the R064XY032NE Sandy 17 to 20 inches P.z. ecological site. Nonirrigated land capability classification is 3e. Irrigated land capability classification is 2e. This soil does not meet hydric criteria. The calcium carbonate equivalent within 40 inches typically does not exceed 6 percent.

Water erosion is a hazard in some areas but wind erosion is the main hazard. Nearly all the acreage of this soil is in cultivated crops such as wheat, alfalfa, and oats. Some areas are seeded to tame grass used for grazing or hay production.

**SrD - Sarben fine sandy loam, 5 to 9 percent slopes**

The Sarben component makes up 99 percent of the map unit. Slopes are 5 to 9 percent. This component is on hillslopes on uplands. The parent material consists of sandy and loamy eolian deposits. Depth to a root-restrictive layer is greater than 60 inches. The natural drainage class is well drained. Water movement in the most restrictive layer is high. Availability of water to a depth of 60 inches is moderate. Shrink-swell potential is low. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter content in the surface horizon is about 1 percent. This component is in the R064XY032NE Sandy 17 to 20 inches P.z. ecological site. Nonirrigated land capability classification is 4e. Irrigated land capability classification is 4e. This soil does not meet hydric criteria. The calcium carbonate equivalent within 40 inches typically does not exceed 6 percent.

Water and wind erosion is a hazard in areas with disturbed surface. Nearly all the acreage of this soil is in cultivated crops: wheat, alfalfa, or oats. Some areas are seeded to tame grass used for grazing or hay production.

**SvF - Sarben and Vetal loamy very fine sands, 9 to 30 percent slopes**

The Sarben component makes up 70 percent of the map unit. Slopes are 9 to 30 percent. This component is on hillslopes on uplands. The parent material consists of sandy and loamy eolian deposits. Depth to a root-restrictive layer is greater than 60 inches. The natural drainage class is well drained. Water movement in the most restrictive layer is high. Availability of water to a depth of 60 inches is moderate. Shrink-swell potential is low. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter content in the surface horizon is about 1 percent. This component is in the R064XY032NE Sandy 17 to 20 inches P.z. ecological site. Nonirrigated land capability classification is 6e. This soil does not meet hydric criteria. The calcium carbonate equivalent within 40 inches typically does not exceed 6 percent.

The Vetal component makes up 30 percent of the map unit. Slopes are 9 to 10 percent. This component is on hillslopes on uplands. The parent material consists of loamy alluvium over eolian deposits. Depth to a root-restrictive layer is greater than 60 inches. The natural drainage class is well drained. Water movement in the most restrictive layer is high. Available water to a depth of 60 inches is moderate. Shrink-swell potential is low. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter content in the surface horizon is about 2 percent. This component is in the R064XY032NE Sandy 17 to 20 inches P.z. ecological site. Nonirrigated land capability classification is 4e. This soil does not meet hydric criteria. The calcium carbonate equivalent within 40 inches typically does not exceed 3 percent.

Water erosion and soil blowing are hazards if the soil surface is not protected. All the acreage of this mapping unit is in native grass used for grazing or hay production. This unit is too steep for the commonly grown crops.

**VeC - Vetal and Bayard soils, 1 to 5 percent slopes**

The Vetal component makes up 50 percent of the map unit. Slopes are 1 to 5 percent. This component is on stream terraces on valleys. The parent material consists of loamy alluvium over eolian deposits. Depth to a root-restrictive layer is greater than 60 inches. The natural drainage class is well drained. Water movement in the most restrictive layer is high. Availability of water to a depth of 60 inches is moderate. Shrink-swell potential is low. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter content in the surface horizon is about 2 percent. This component is in the R064XY032NE Sandy 17 to 20 inches P.z. ecological site. Nonirrigated land capability classification is 3e. Irrigated land capability classification is 3e. This soil does not meet hydric criteria. The calcium carbonate equivalent within 40 inches typically does not exceed 3 percent.

The Bayard component makes up 49 percent of the map unit. Slopes are 1 to 5 percent. This component is on stream terraces on valleys. The parent material consists of colluvial-alluvial sediments from calcareous sandstone. Depth to a root-restrictive layer is greater than 60 inches. The natural drainage class is well drained. Water movement in the most restrictive layer is high. Availability of water to a depth of 60 inches is high. Shrink-swell potential is low. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter content in the surface horizon is about 2 percent. This component is in the R064XY032NE Sandy 17 to 20 inches P.z. ecological site. Nonirrigated land capability classification is 3e. Irrigated land capability classification is 3e. This soil does not meet hydric criteria. The calcium carbonate equivalent within 40 inches typically does not exceed 6 percent.

Soil blowing is a hazard if the soil surface is not protected. About half the acreage of these soils is in crops and half is in range. Wheat, alfalfa, and oats are the principal crops. Some areas are seeded to tame grasses used for hay production. Areas of native grass are used for grazing or the grass is cut for hay production.

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**Table E.2-1 General Stratigraphic Chart for Northwest Nebraska**

| System | Series | Formation or Group | Rock Types | Thickness (ft) |
|---|---|---|---|---|
| Miocene | | Ogallala | SS, Slt | 1560* |
| | | Arikaree | SS, Slt | 1070* |
| Oligocene/Eocene | | White River | SS, Slt, Cly | 1450* |
| Cretaceous | Upper | Pierre | Sh | 1500 |
| | | Niobrara | Chalk, Ls, Sh | 300 |
| | | Carlile | Sh | 200-250 |
| | | Greenhorn | Ls | 30 |
| | | Graneros | Sh | 250-280 |
| | | D Sand | SS | 5-30 |
| | | D Shale | Sh | 60 |
| | | G Sand | SS | 10-45 |
| | | Huntsman | Sh | 60-80 |
| | Lower | J Sand | SS | 10-30 |
| | | Skull Creek | Sh | 220 |
| | | Dakota | SS, Sh | 180 |
| Jurassic | Upper | Morrison | Sh, SS | 300 |
| | | Sundance | SS, Sh, Ls | 300 |
| Permian | Guadalupe | Satanka | Ls, Sh, Anhy | 450 |
| | Leonard | Upper | Ls, Anhy | 150 |
| | | Lower | Sh | 150 |
| | Wolfcamp | Chase | Anhy | 80 |
| | | Council Grove | Anhy, Sh | 300 |
| | | Admire | Dolo, Ls | 70 |
| Pennsylvanian | Virgil | Shawnee | Ls | 80 |
| | Missouri | Kansas City | Ls, Sh | 80 |
| | Des Moines | Marmaton/ | Ls, Sh | 130 |
| | | Cherokee | | |
| | Atoka | Upper/Lower | Ls, Sh | 200 |
| Mississippian | Lower | Lower | Ls, Sh | 30 |
| Pre-Cambrian | | | Granite | |

* Maximum thickness based on Swinehart, et. al, 1985.

**Table E.2-2 North Trend Representative Stratigraphic Section**

| DEPTH (FT-BGS) | GROUP | FORMATION & MEMBER (SCHULTZ AND STOUT, 1955) | | | FORMATION & MEMBER (REVISED) | | REFERENCES (REVISED) |
|---|---|---|---|---|---|---|---|
| 25-110 | White River Group | Brule Formation | Whitney Member | | Brule Formation | "Brown Siltstones" | LaGarry (1998) |
| | | | | | | Whitney Member | |
| | | | Orella Member | Orella D | | Orella Member | |
| | | | | Orella C | | | |
| | | | | Orella B | | | |
| | | | | Orella A | | Big Cottonwood Creek Member | Terry (1998)<br>Terry & LaGarry (1998) |
| 110-290 | | Chadron Formation | Upper Chadron | Chadron C | Chadron Formation | | |
| ~290-390 | | | Upper/Middle Chadron | Chadron B | | | |
| 390-615 | | | Middle Chadron | | | Peanut Peak Member | Terry (1998)<br>Terry & LaGarry (1998) |
| 400-700 | | | Red Clay Horizon | Chadron A | Chamberlain Pass Formation | Upper Interior Paleosol | Terry (1998) |
| | | | Basal Chadron Sandstone | | | Channel Sandstone | Terry (1998) |
| Varying | Montana Group | Pierre Shale | Interior Paleosol | | Pierre Shale | Yellow Mounds Paleosol | Retallack (1983)<br>Terry (1998) |
| 659+ | | | Pierre Shale | | | Pierre Shale | Terry (1998) |

NOTES:
1) Topsoil, colluvial and alluvial deposits are not shown, but are Quaternary in age and range in thickness from 0 to 25 ft-bgs.
2) ft-bgs = feet below ground surface

**Table E.6-1 Earthquakes in Nebraska**

| Date | Central Standard Time | Locality | Latitude Degrees North | Longitude Degrees West | Modified Mercalli (MM) Intensity | Source |
|---|---|---|---|---|---|---|
| March 17, 1884 | 14:00 | North Platte | 41.133 | 100.75 | IV | A |
| Dec. 16, 1916 | ----- | Stapleton | 41.55 | 100.467 | II-III | A |
| Sept. 24, 1924 | 5:00 | Gothenburg | 40.95 | 100.133 | IV | A |
| Aug. 8, 1933 | ----- | Scottsbluff | 41.867 | 103.667 | IV-V | A |
| 30-Jul-34 | 1:20 | Chadron | 42.85 | 103 | VI | A |
| 24-Mar-38 | 7:11 | Fort Robinson | 42.683 | 103.417 | IV | A |
| 9-Mar-63 | 9:25 | Chadron | 42.85 | 103 | II-III | A |
| 28-Mar-64 | 4:21 | Merriman | 42.8 | 101.667 | VII | A |
| 7-May-78 | 10:06 | SW Cherry County | 42.26 | 101.95 | V | B |
| 6-May-83 | 0:15 | NE Sheridan County | 42.96 | 102.2 | III | B |
| 1-Jan-87 | 2:02 | Crawford | 42.79 | 103.48 | III | B |
| 8-Feb-89 | 23:16 | Merriman | 42.8 | 101.6 | IV | B |

Sources: A = Docekal 1970
B = National Earthquake Information Service (USGS 2008f)

**Table E.7-1 Summary of Soil Resources within the Project Area**

| Map Unit | Map Unit Name | Acres | % of Project Area |
|---|---|---|---|
| Bg | Bridget silt loam, 0 to 1 percent slopes | 2.067 | 0.18% |
| DuB | Duroc very fine sandy loam, 1 to 3 percent slopes | 80.367 | 6.90% |
| HbB | Haverson silt loam, occasionally flooded, 0 to 3 percent slopes | 2.805 | 0.24% |
| JmC | Jayem loamy very fine sand, 1 to 5 percent slopes | 31.887 | 2.74% |
| KaD2 | Kadoka silt loam, deep variant, 3 to 9 percent slopes, eroded | 15.837 | 1.36% |
| KeB | Keith silt loam, 1 to 3 percent slopes | 515.732 | 44.27% |
| KeD | Keith silt loam, 3 to 9 percent slopes | 6.408 | 0.55% |
| KfD | Keith and Ulysses silt loams, 3 to 9 percent slopes | 111.304 | 9.55% |
| KpD | Keota-Epping silt loams, 3 to 9 percent slopes | 27.180 | 2.33% |
| Lo | Loamy alluvial land | 5.730 | 0.49% |
| OgF | Oglala loam, 9 to 30 percent slopes | 8.878 | 0.76% |
| OhF | Oglala-Canyon loams, 9 to 20 percent slopes | 1.195 | 0.10% |
| Sn | Sandy alluvial land | 7.521 | 0.65% |
| SrC | Sarben fine sandy loam, 1 to 5 percent slopes | 159.725 | 13.71% |
| SrD | Sarben fine sandy loam, 5 to 9 percent slopes | 7.184 | 0.62% |
| SvF | Sarben and Vetal loamy very fine sands, 9 to 30 percent slopes | 35.704 | 3.06% |
| VeC | Vetal and Bayard soils, 1 to 5 percent slopes | 145.501 | 12.49% |
| TOTAL | All Soil Units | **1165.025** | **100.00%** |

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# CHAPTER F. GEOLOGICAL MAPS AND DRAWINGS

*Generalized maps and cross sections detailing the regional geologic setting and geologic structure of the local area including faults if known or expected. Seismicity and seismic hazard maps for Nebraska, including the North Trend region.*

The maps and drawings in this section are referenced in Chapter E – Geology and Seismology. The numbers of the figures correspond to the number of the different sections in Chapter E.

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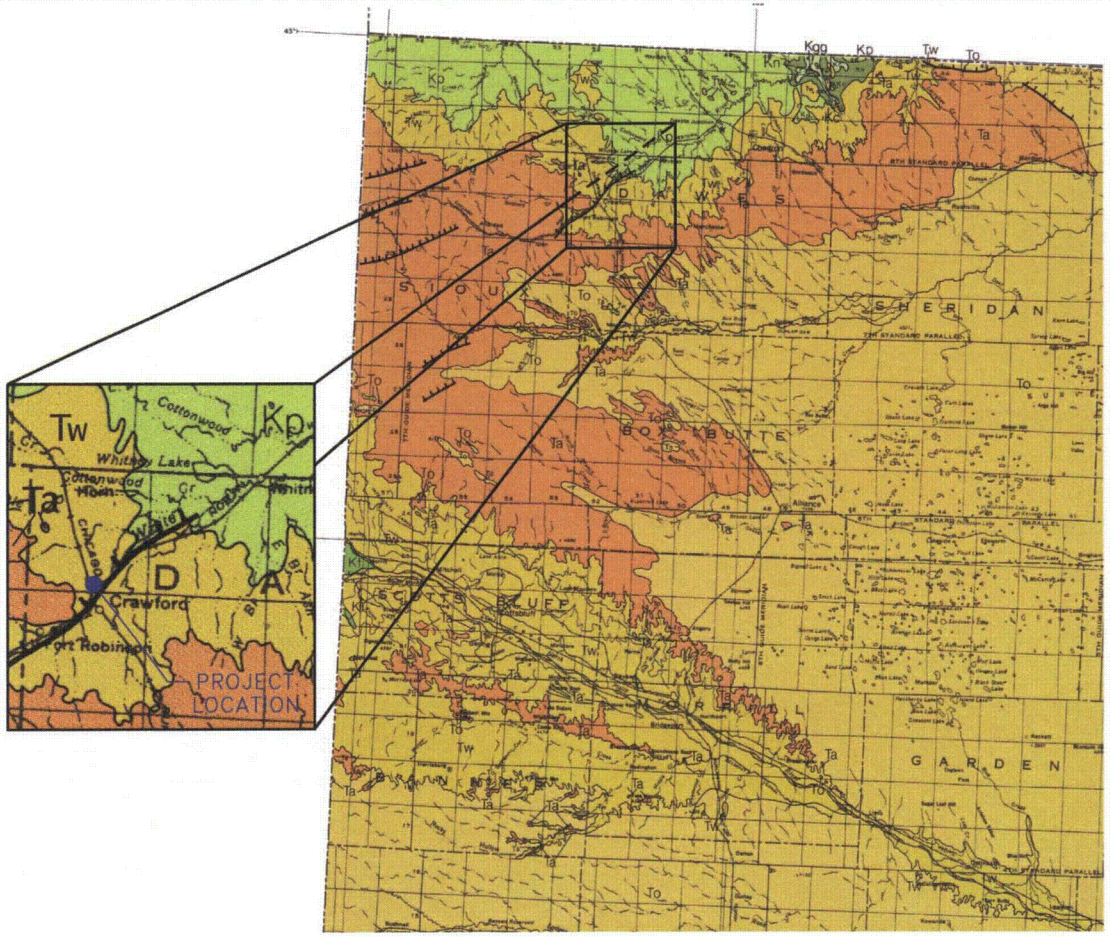


## LEGEND

| SYSTEM | SERIES | | GROUP OR FORMATION | |
|---|---|---|---|---|
| T TERTIARY | MIOCENE | | OGALLALA | To |
| | | | ARIKAREE | Ta |
| | OLIGOCENE | | WHITE RIVER | Tw |
| K CRETACEOUS | UPPER CRETACEOUS | MONTANA | Fox Hills | Kf |
| | | | Pierre | Kp |
| | | COLORADO | Niobrara | Kn |
| | | | Carlile | Kc |
| | | | Greenhorn-Graneros | Kgg |
| | LOWER CRETACEOUS | | DAKOTA | Kd |
| J JURASSIC | | | | |
| P PERMIAN | BIG BLUE | | CHASE | Pc |
| | | | COUNCIL GROVE | Pcg |
| | | | ADMIRE | Pa |
| IP PENNSYLVANIAN | VIRGIL | | WABAUNSEE | IPw |
| | | | SHAWNEE | IPs |
| | | | DOUGLAS | IPd |
| | MISSOURI | | LANSING | IPl |
| | | | KANSAS CITY | IPkc |
| | DES MOINES | | MARMATON | IPm |

M MISSISSIPPIAN
D DEVONIAN
S SILURIAN
O ORDOVICIAN (Middle & Upper)
CO CAMBRIAN & ORDOVICIAN (Lower)
PC PRECAMBRIAN

(PLIOCENE AND QUATERNARY deposits not shown)

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FIGURE F. 2-1
BEDROCK GEOLOGY OF THE NORTH TREND EXPANSION AREA

PROJECT: CO001322 MAPPED: JC CHECKED: MS

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Source: Nebraska Geological Survey

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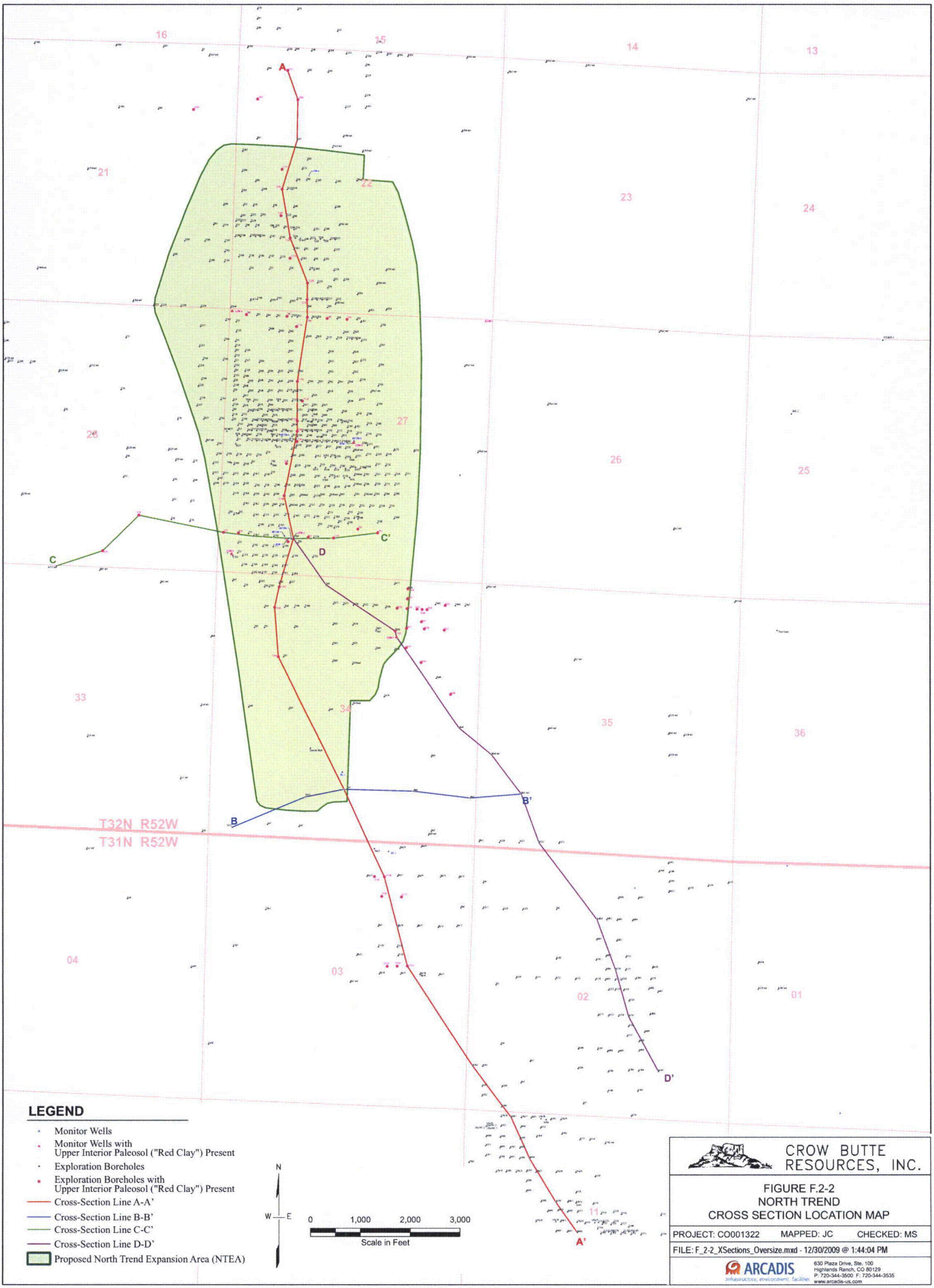
16
15
14
13
21
22
23
24
27
28
26
25
33
34
35
36
04
03
02
01
11
A
A'
B
B'
C
C'
D
D'
T32N R52W
T31N R52W
LEGEND
Monitor Wells
Monitor Wells with Upper Interior Paleosol ("Red Clay") Present
Exploration Boreholes
Exploration Boreholes with Upper Interior Paleosol ("Red Clay") Present
Cross-Section Line A-A'
Cross-Section Line B-B'
Cross-Section Line C-C'
Cross-Section Line D-D'
Proposed North Trend Expansion Area (NTEA)
N
W
E
0
1,000
2,000
3,000
Scale in Feet
CROW BUTTE RESOURCES, INC.
FIGURE F.2-2
NORTH TREND
CROSS SECTION LOCATION MAP
PROJECT: CO001322
MAPPED: JC
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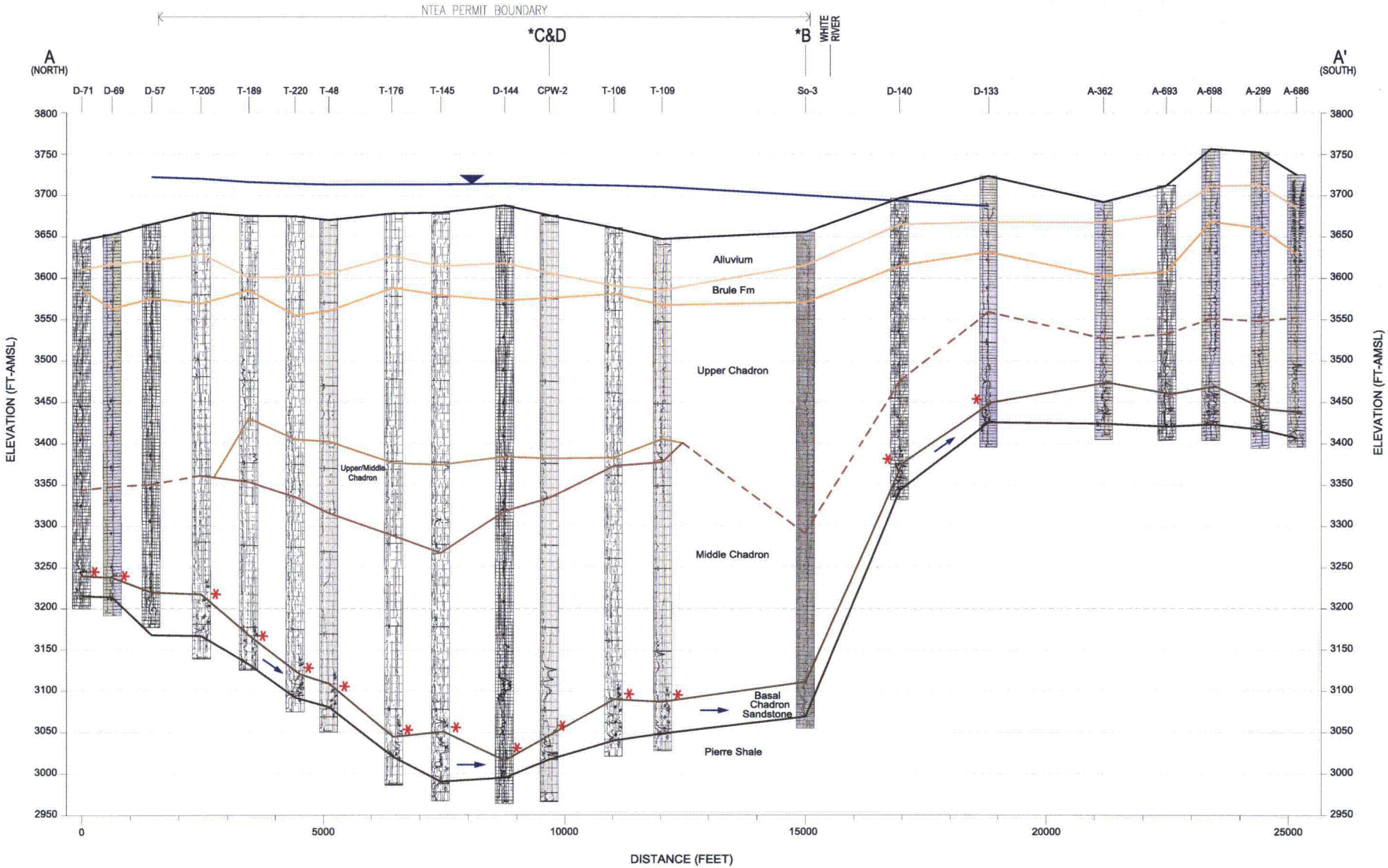


Notes:

1) Geologic units that underlie the Pierre Shale are not shown.

2) For locations where the Upper/Middle Chadron Fm was not observed in elogs, the contact between the Upper Chadron Fm and the Middle Chadron Fm was extrapolated based on known occurrence, and is shown as dashed lines.

3) Groundwater elevations were measured on 4/16/2008 (FT-AMSL).

* Letter indicates location of intersecting cross-section lines shown on Figure 4.

Legend:

- Topographic Surface
- Top of Brule Fm
- Top of Upper Chadron
- Top of Upper/Middle Chadron
- Top of Middle Chadron
- Top of Basal Chadron Sandstone
- Top of Pierre Shale
- Potentiometric Surface (Basal Chadron Sandstone) - 4/16/08
- Groundwater Flow Direction
- Approximate Location of Upper Interior Paleosol ("Red Clay")

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FIGURE F. 2-3a
NORTH TREND STRUCTURAL CROSS-SECTION: A-A'

PROJECT: CO001322 MAPPED: JC CHECKED: MS

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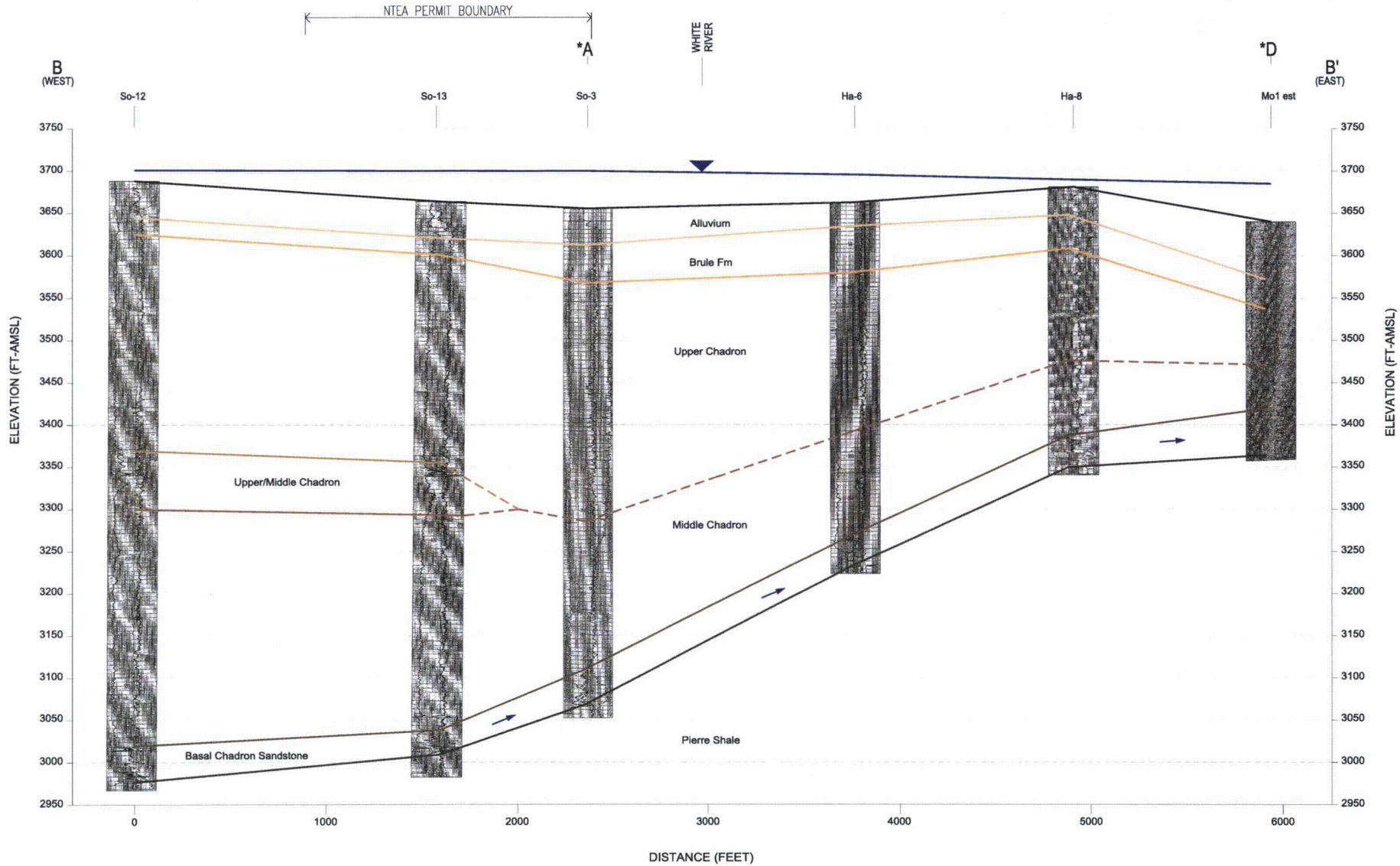


Notes:

1) Geologic units that underlie the Pierre Shale are not shown.

2) For locations where the Upper/Middle Chadron Fm was not observed in elogs, the contact between the Upper Chadron Fm and the Middle Chadron Fm was extrapolated based on known occurrence, and is shown as dashed lines.

3) Groundwater elevations were measured on 4/16/2008 (FT-AMSL).

* Letter indicates location of intersecting cross-section lines shown on Figure 4.

Legend:

- Topographic Surface
- Top of Brule Fm
- Top of Upper Chadron
- Top of Upper/Middle Chadron
- Top of Middle Chadron
- Top of Basal Chadron Sandstone
- Top of Pierre Shale
- Potentiometric Surface (Basal Chadron Sandstone) - 4/16/08
- Groundwater Flow Direction

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FIGURE F. 2-3b
NORTH TREND STRUCTURAL
CROSS-SECTION: B-B'

PROJECT: CO001322 MAPPED: JC CHECKED: MS

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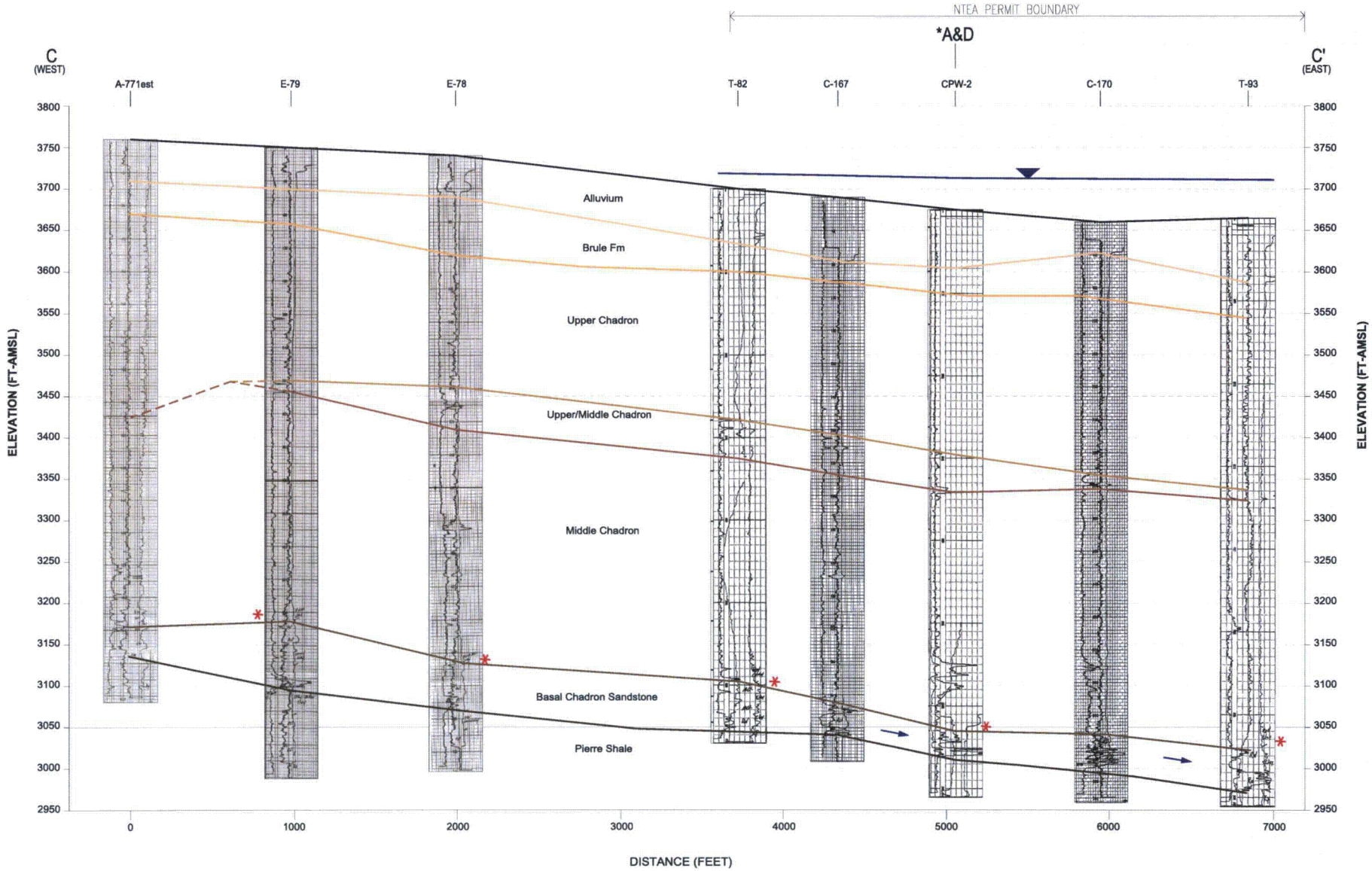


Notes:

1) Geologic units that underlie the Pierre Shale are not shown.

2) For locations where the Upper/Middle Chadron Fm was not observed in elogs, the contact between the Upper Chadron Fm and the Middle Chadron Fm was extrapolated based on known occurrence, and is shown as dashed lines.

3) Groundwater elevations were measured on 4/16/2008 (FT-AMSL).

* Letter indicates location of intersecting cross-section lines shown on Figure 4.

Legend:

- Topographic Surface
- Top of Brule Fm
- Top of Upper Chadron
- Top of Upper/Middle Chadron
- Top of Middle Chadron
- Top of Basal Chadron Sandstone
- Top of Pierre Shale
- Potentiometric Surface (Basal Chadron Sandstone) - 4/16/08
- Groundwater Flow Direction
- Approximate Location of Upper Interior Paleosol ("Red Clay")

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FIGURE F. 2-3c
NORTH TREND STRUCTURAL
CROSS-SECTION: C-C'

PROJECT: CO001322 MAPPED: JC CHECKED: MS

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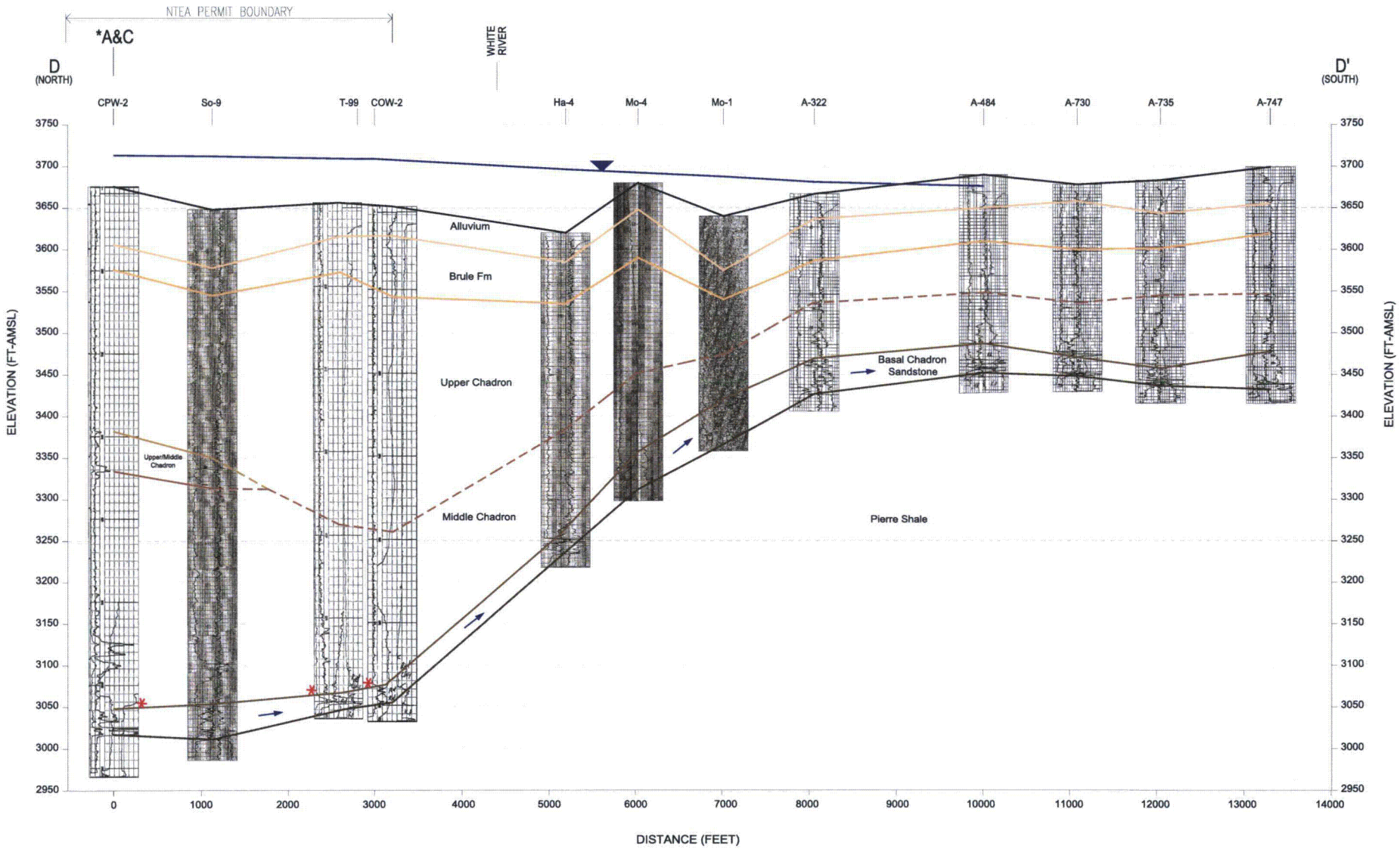


Notes:

1) Geologic units that underlie the Pierre Shale are not shown.

2) For locations where the Upper/Middle Chadron Fm was not observed in elogs, the contact between the Upper Chadron Fm and the Middle Chadron Fm was extrapolated based on known occurrence, and is shown as dashed lines.

3) Groundwater elevations were measured on 4/16/2008 (FT-AMSL).

* Letter indicates location of intersecting cross-section lines shown on Figure 4.

Legend:

- Topographic Surface
- Top of Brule Fm
- Top of Upper Chadron
- Top of Upper/Middle Chadron
- Top of Middle Chadron
- Top of Basal Chadron Sandstone
- Top of Pierre Shale
- Potentiometric Surface (Basal Chadron Sandstone) - 4/16/08
- Groundwater Flow Direction
- * Approximate Location of Upper Interior Paleosol ("Red Clay")

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FIGURE F.2-3d
NORTH TREND STRUCTURAL
CROSS-SECTION: D-D'

PROJECT: CO001322 MAPPED: JC CHECKED: MS

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**Figure F.3-1 North Trend Expansion Area Type Log (SO-9)**

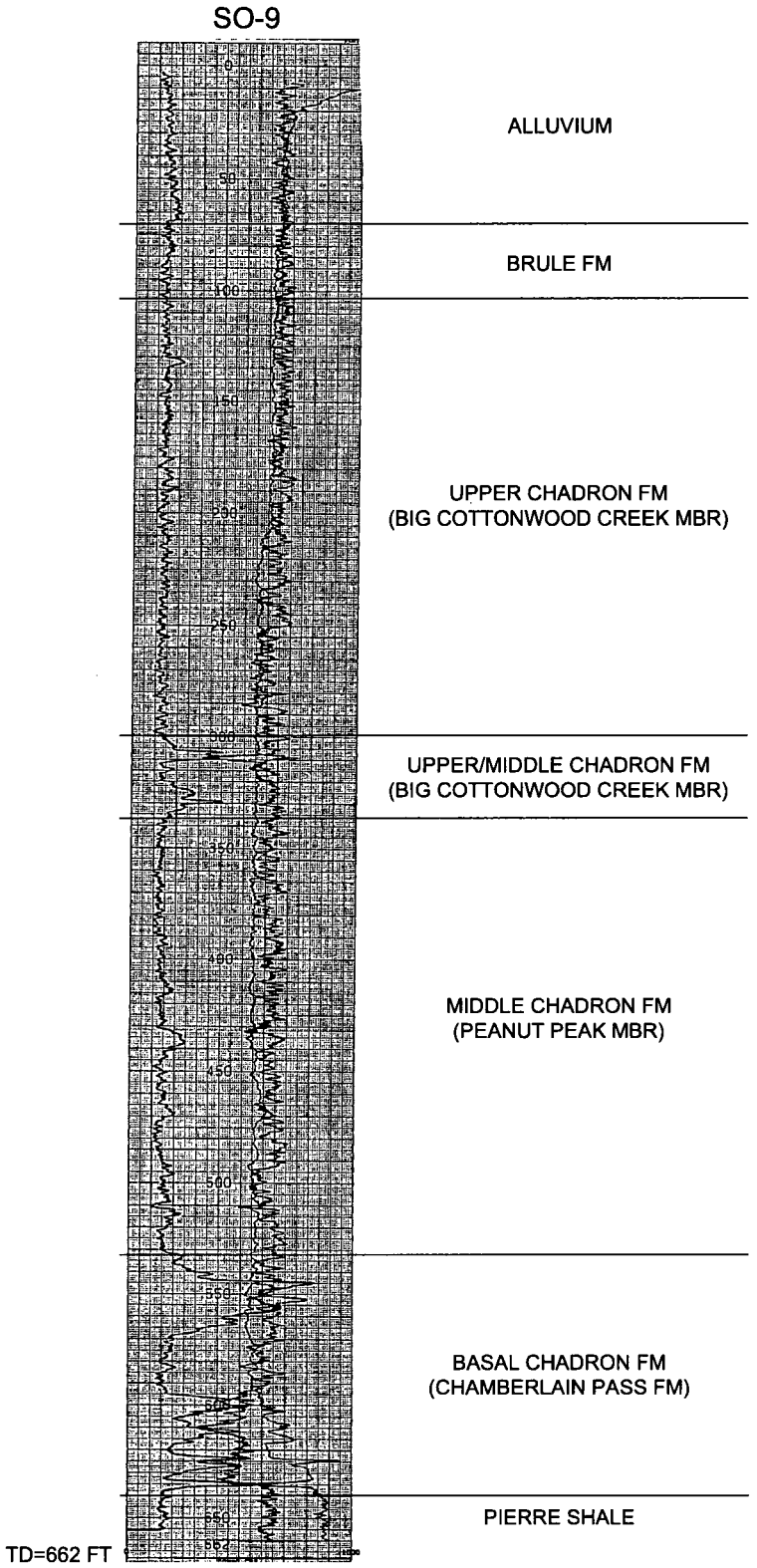


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FIGURE F.3-1
NORTH TREND EXPANSION AREA
TYPE LOG (SO-9)

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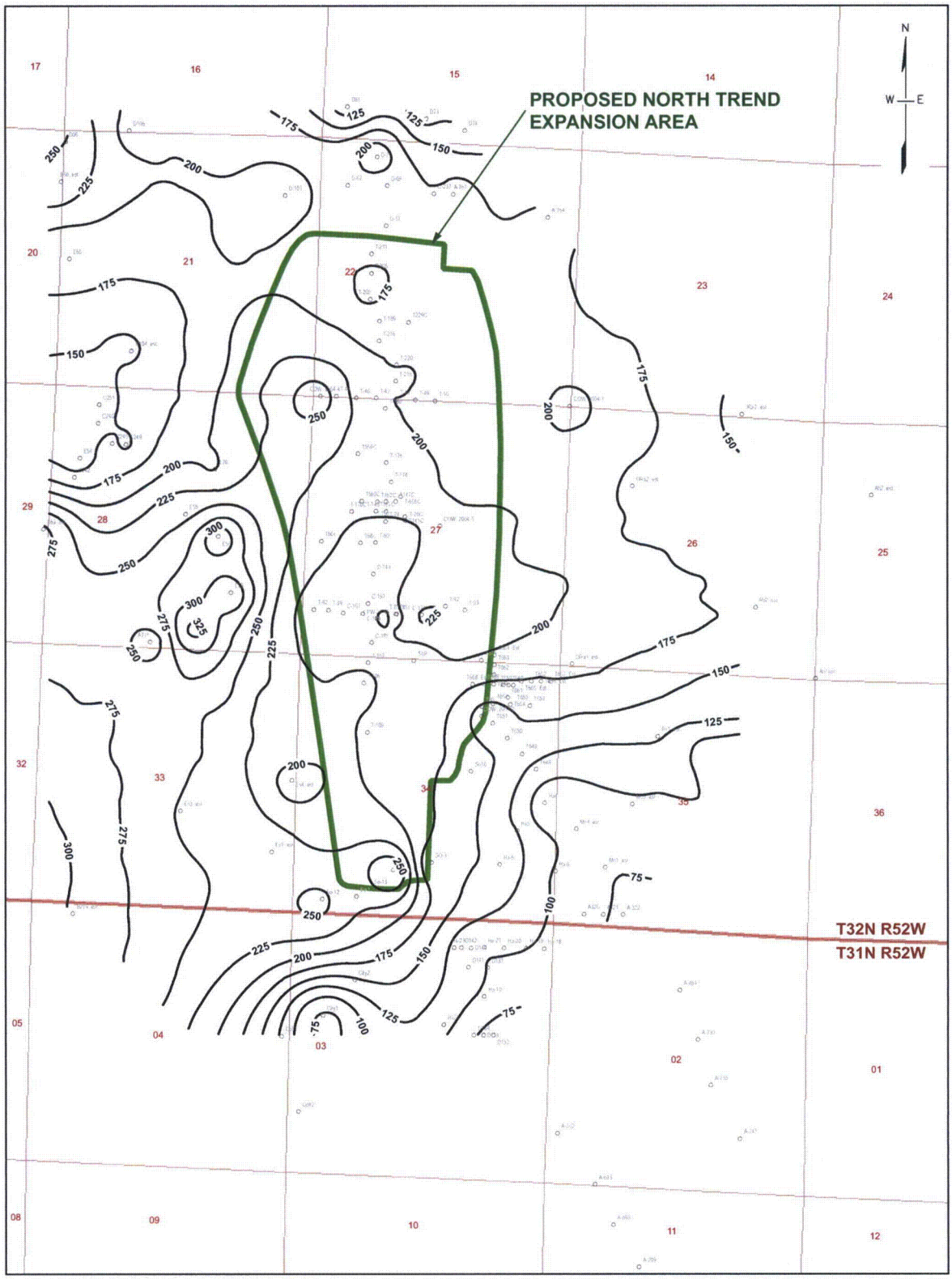


LEGEND

- Exploration Borehole
- Isopach Contour (Feet)
- Proposed North Trend Expansion Area (NTEA)

0 1,000 2,000
Scale in Feet

Contour Interval in feet

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FIGURE F.3-2
NORTH TREND ISOPACH MAP - UPPER CHADRON

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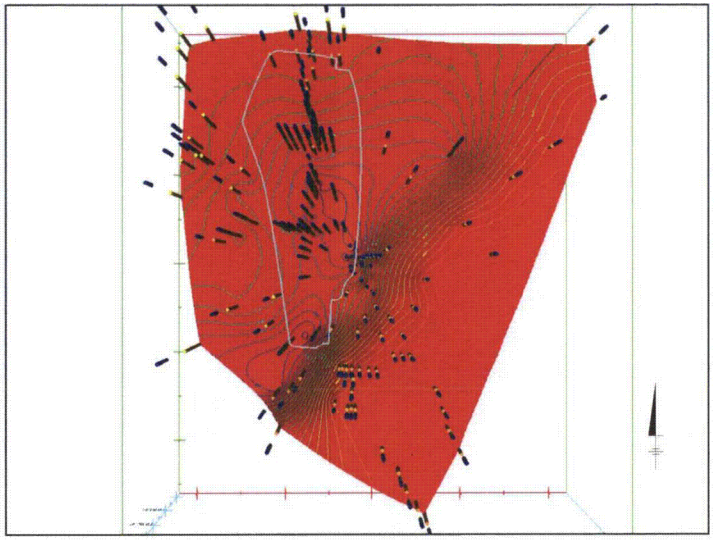
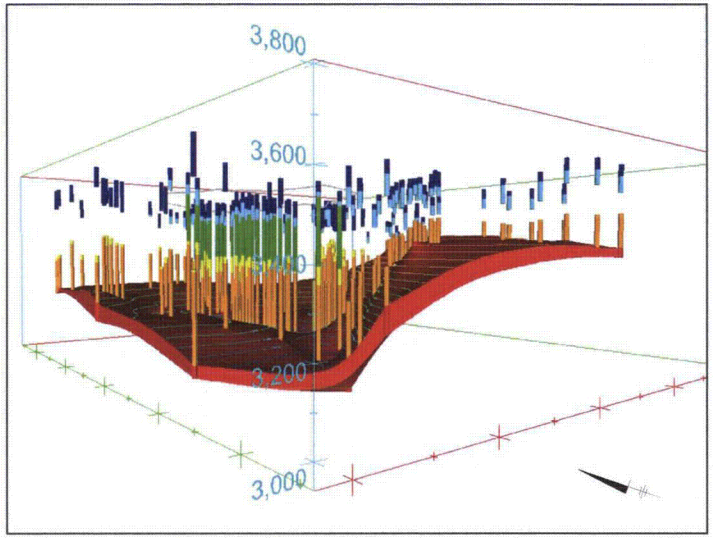
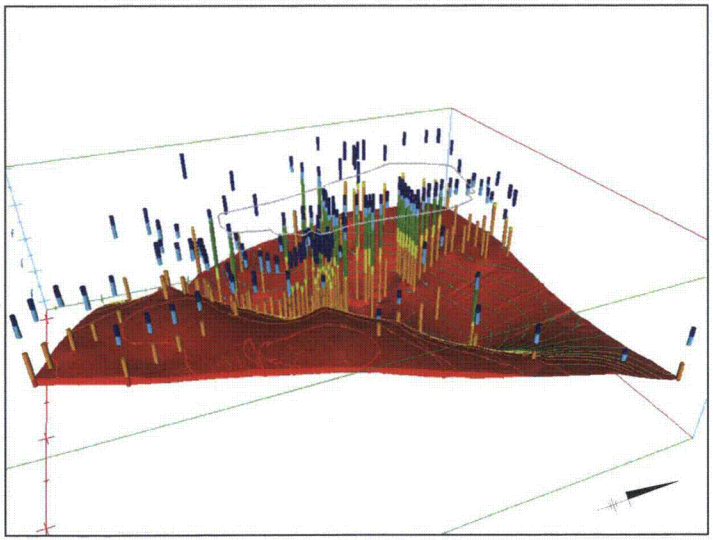


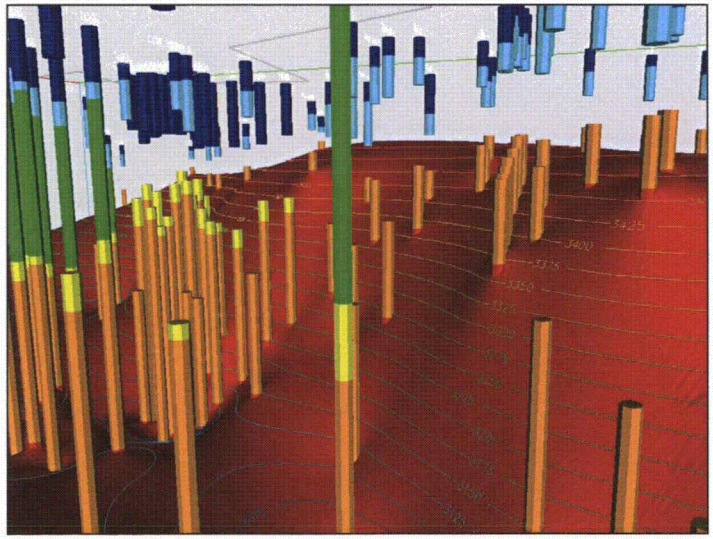
PLAN VIEW (PERMIT BOUNDARY SHOWN)




OBLIQUE VIEW - FACING NORTHEAST (PARALLEL TO FOLD AXIS)



OBLIQUE VIEW - FACING NORTHWEST (PERPENDICULAR TO FOLD AXIS)



OBLIQUE VIEW - FACING EAST-NORTHEAST INTO NORTH LIMB OF FOLD

**LEGEND:**

STRATIGRAPHY

- Alluvium
- Brule Fm
- Upper Chadron Fm (Big Cottonwood Creek Mbr)
- Upper/Middle Chadron Fm (Big Cottonwood Creek Mbr)
- Middle Chadron Fm (Peanut Peak Mbr)
- Basal Chadron Fm (Chamberlain Pass Fm)

**NOTES:**

- All of the 3D model output has a 10x vertical exaggeration.
- Elevations are in ft-amsl (axes and contours).

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**FIGURE F.3-3a**
**BASAL CHADRON SANDSTONE (CHAMBERLAIN PASS FM)**

PROJECT: CO001322 MAPPED: CHECKED: MS

FILE: FIGURE F.3-3a

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CO001332/0003/00002/CDR/CO001G01.CDR

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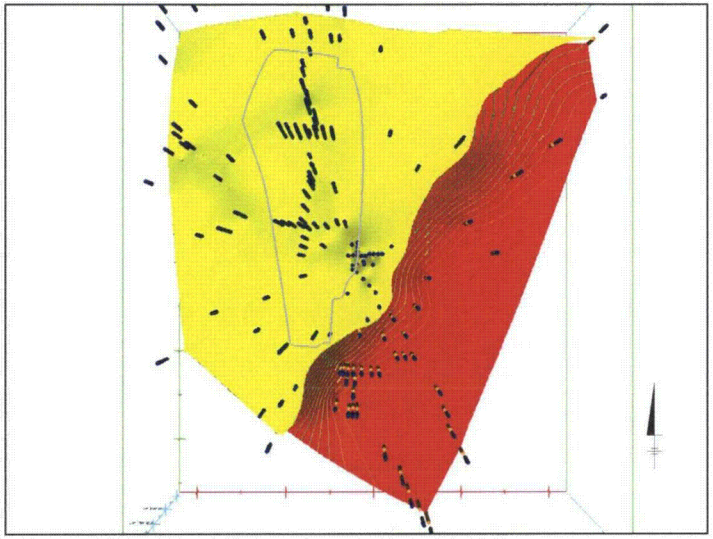
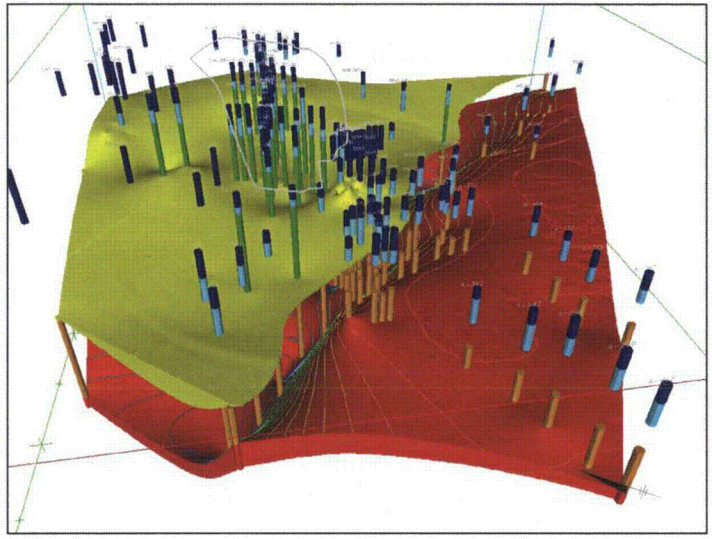
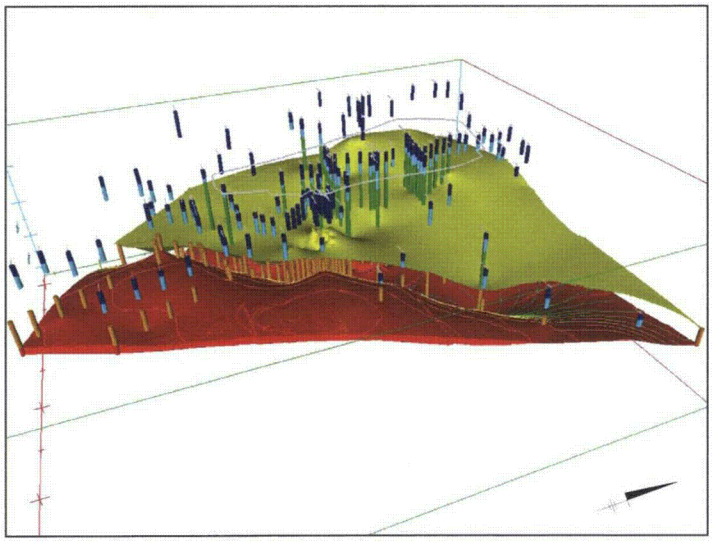


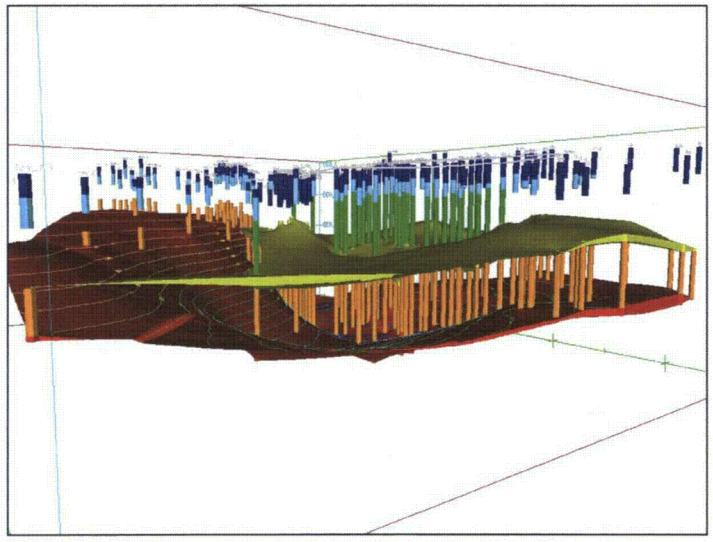
PLAN VIEW (PERMIT BOUNDARY SHOWN)



OBLIQUE VIEW - FACING NORTHEAST ( PARALLEL TO FOLD AXIS)



OBLIQUE VIEW - FACING NORTHWEST (PERPENDICULAR TO FOLD AXIS)



OBLIQUE VIEW - FACING EAST-NORTHEAST INTO NORTH LIMB OF FOLD

LEGEND:

STRATIGRAPHY

- Alluvium
- Brule Fm
- Upper Chadron Fm (Big Cottonwood Creek Mbr)
- Upper/Middle Chadron Fm (Big Cottonwood Creek Mbr)
- Middle Chadron Fm (Peanut Peak Mbr)
- Basal Chadron Fm (Chamberlain Pass Fm)

NOTES:

- All of the 3D model output has a 10x vertical exaggeration.
- Elevations are in ft-amsl (axes and contours).

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**FIGURE F.3-3b**
**BASAL CHADRON SANDSTONE (CHAMBERLAIN PASS FM) AND UPPER/MIDDLE CHADRON (BIG COTTONWOOD CREEK MBR)**

PROJECT: CO001322 MAPPED: CHECKED: MS

FILE: FIGURE F.3-3b

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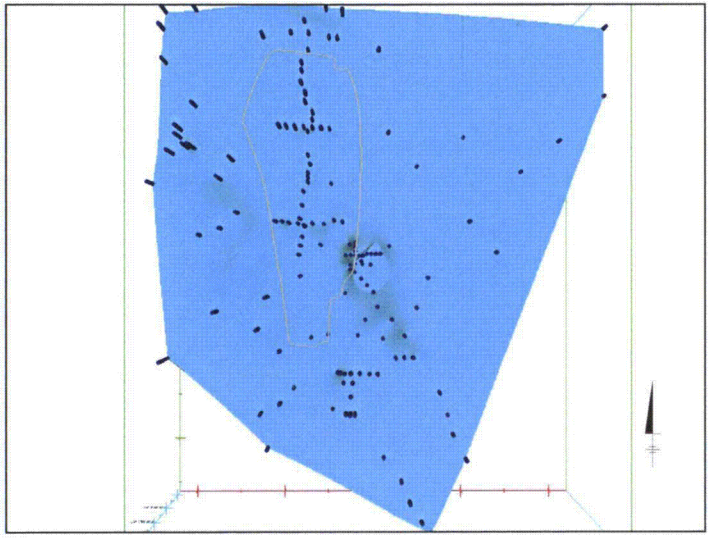
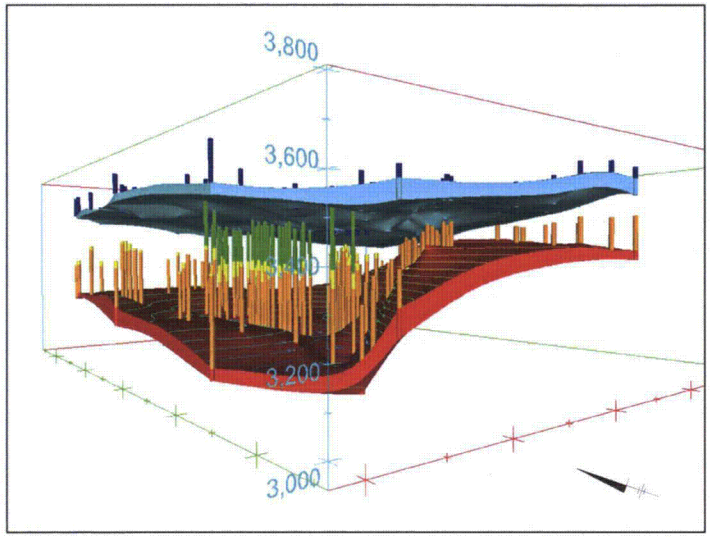
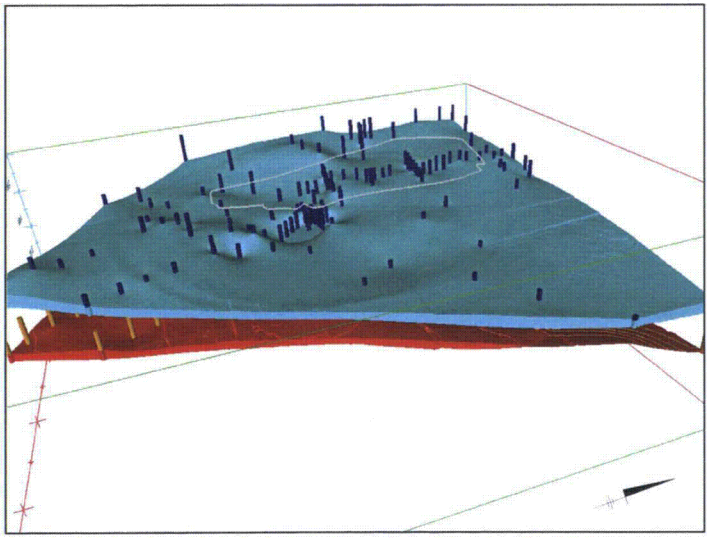


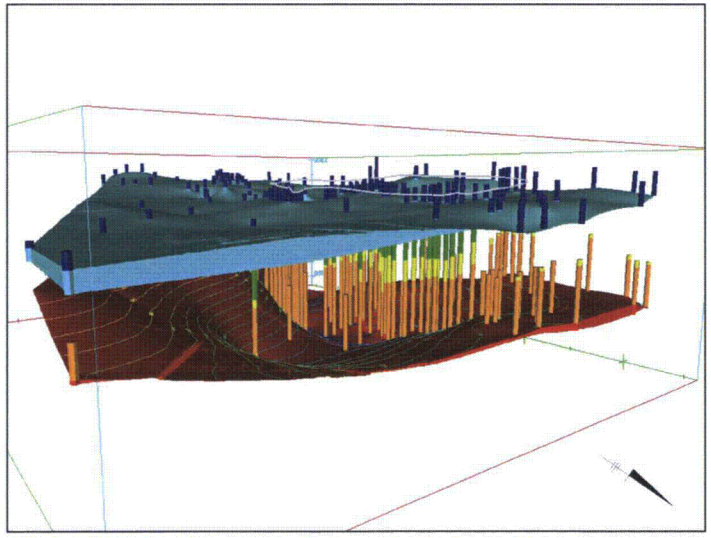
PLAN VIEW (PERMIT BOUNDARY SHOWN)




OBLIQUE VIEW - FACING NORTHEAST (PARALLEL TO FOLD AXIS)



OBLIQUE VIEW - FACING NORTHWEST (PERPENDICULAR TO FOLD AXIS)



OBLIQUE VIEW FACING SOUTHWEST (PARALLEL TO FOLD AXIS)

**LEGEND:**

STRATIGRAPHY

- Alluvium
- Brule Fm
- Upper Chadron Fm (Big Cottonwood Creek Mbr)
- Upper/Middle Chadron Fm (Big Cottonwood Creek Mbr)
- Middle Chadron Fm (Peanut Peak Mbr)
- Basal Chadron Fm (Chamberlain Pass Fm)

**NOTES:**

- All of the 3D model output has a 10x vertical exaggeration.
- Elevations are in ft-amsl (axes and contours).

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**FIGURE F.3-3c**
**BASAL CHADRON SANDSTONE (CHAMBERLAIN PASS FM) AND BRULE FM**

PROJECT: CO001322 MAPPED: CHECKED: MS

FILE: FIGURE F.3-3c

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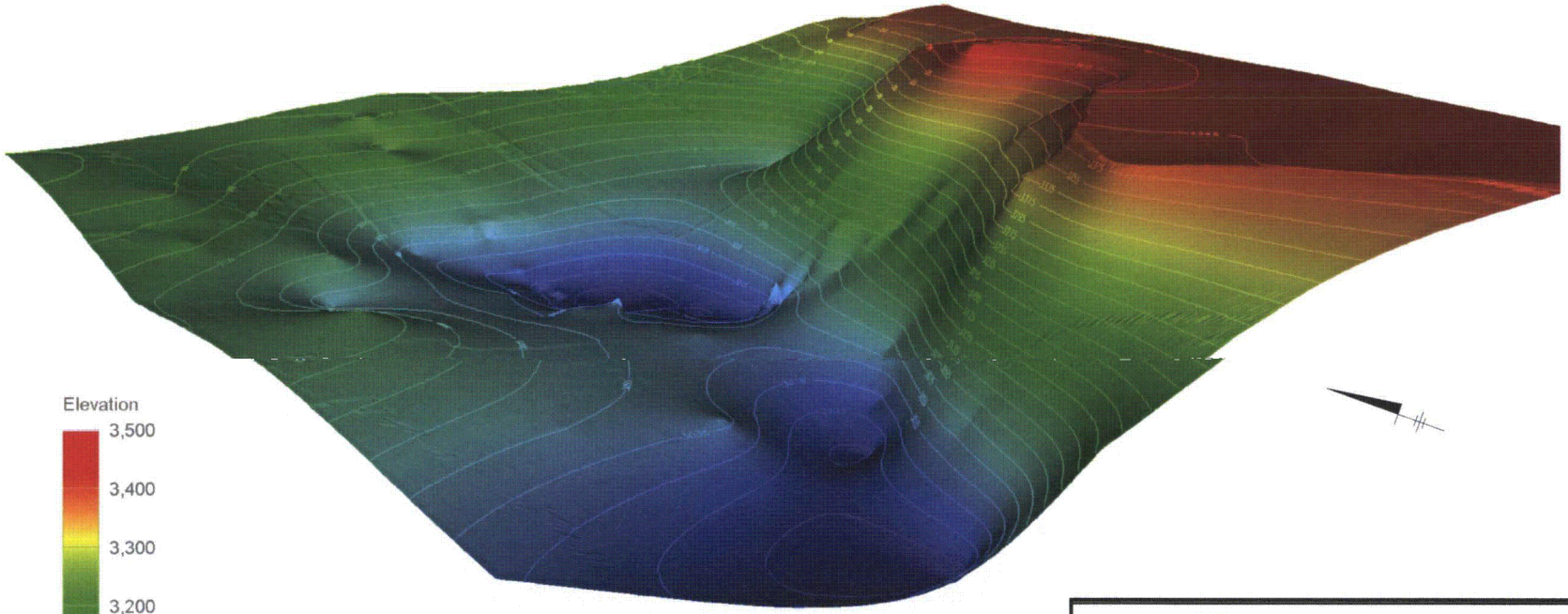
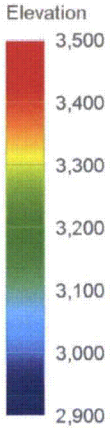
CO001332/0003/00002/CDR/CO001G04.CDR






**NOTES:**

- All of the 3D model output has a 10x vertical exaggeration.
- Elevations are in ft-amsl (color legend and contours).

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**FIGURE F.3-3d**
**TOP OF PIERRE SHALE**

PROJECT: CO001322 MAPPED: CHECKED: MS

FILE: **FIGURE F.3-3d**

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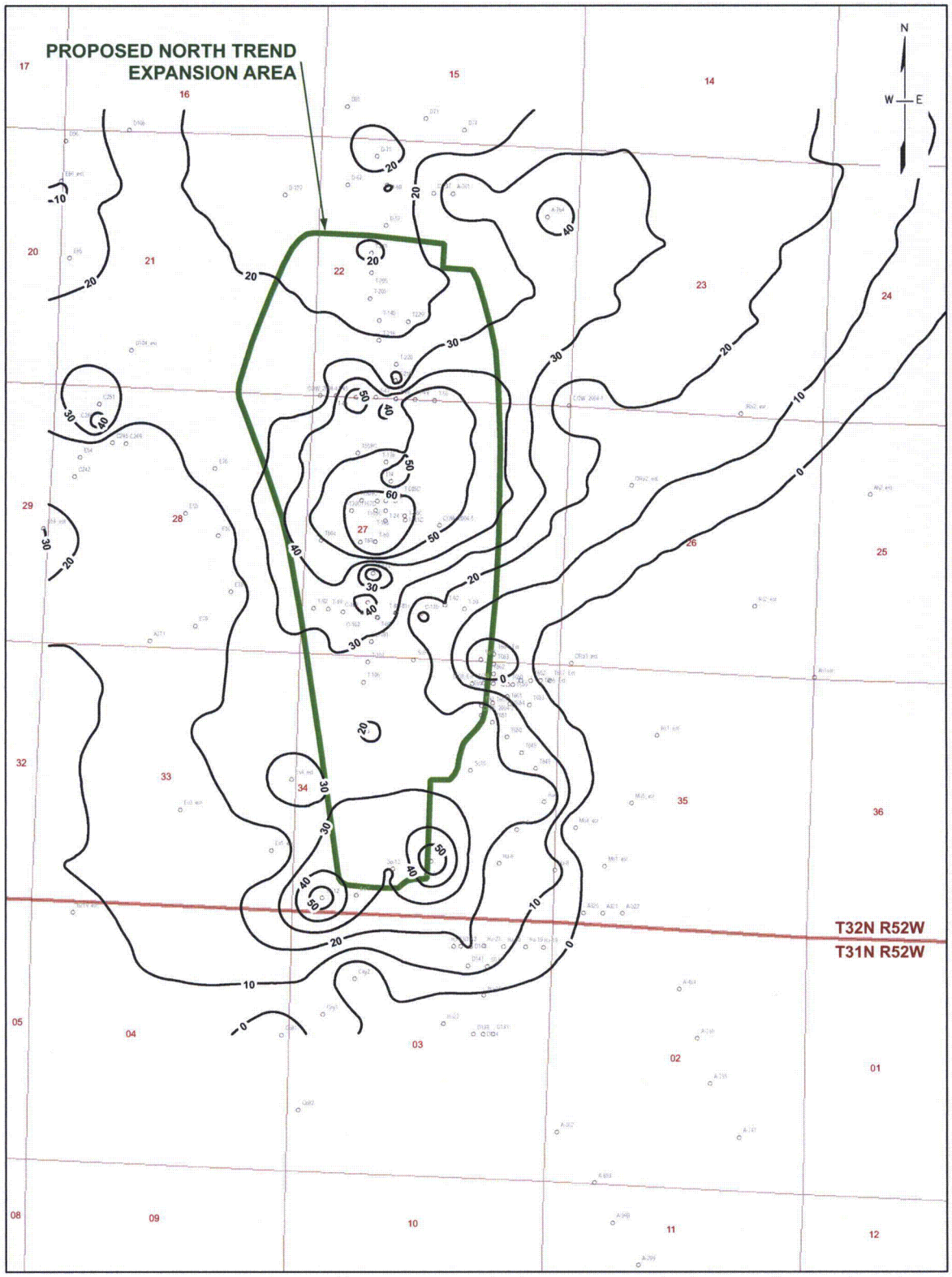


LEGEND

- Exploration Borehole
- Isopach Contour (Feet)
- Proposed North Trend Expansion Area (NTEA)

0 1,000 2,000
Scale in Feet

Contour Interval in feet

CROW BUTTE RESOURCES, INC.

FIGURE F.3-4
NORTH TREND ISOPACH MAP - UPPER/MIDDLE CHADRON

FILE: F_3-4_NTIsopach_UpperMiddleChadron.mxd - 1/4/2010 @ 2:48:24 PM

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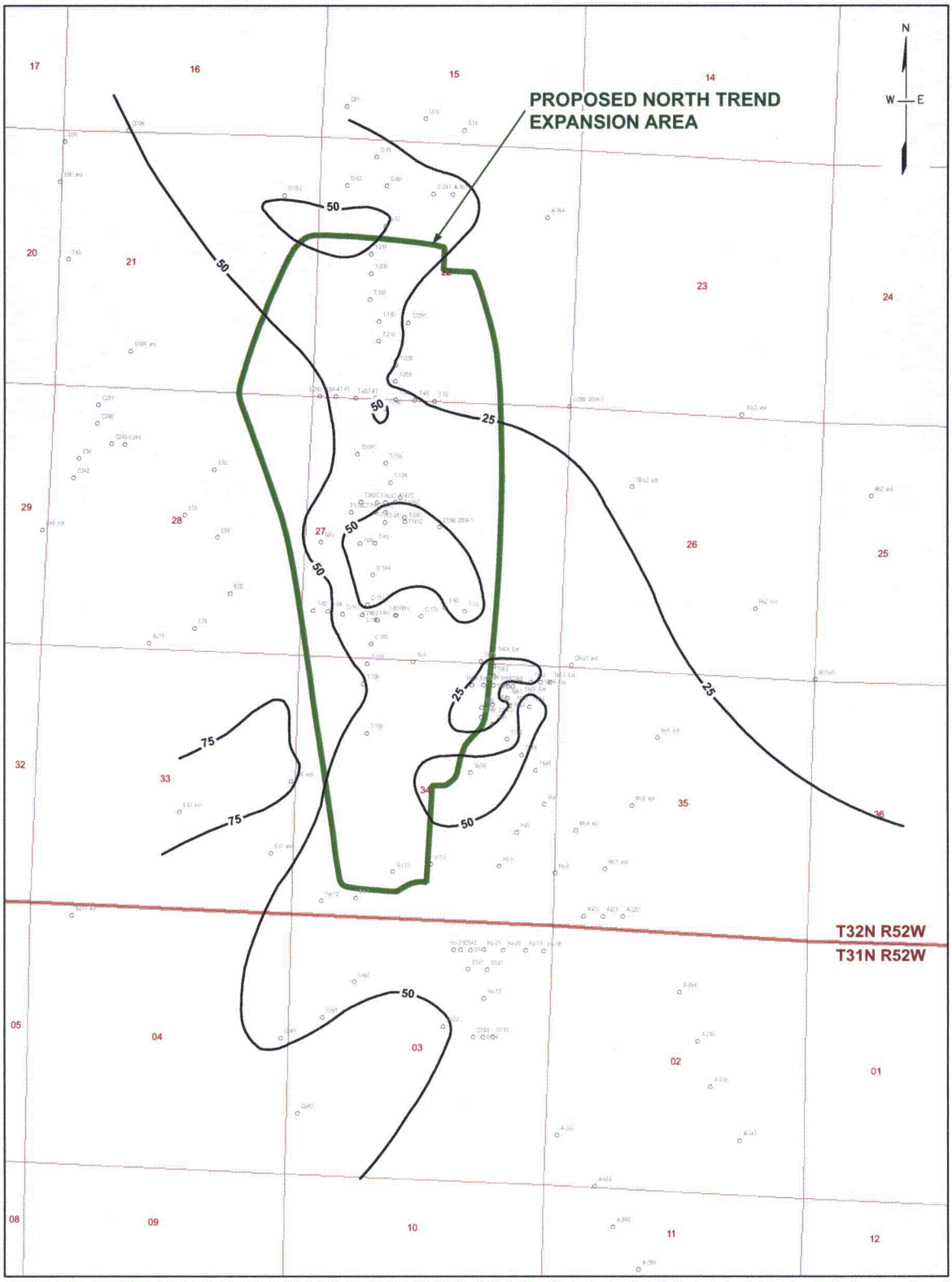


LEGEND

- Exploration Borehole
- Isopach Contour (Feet)
- Proposed North Trend Expansion Area (NTEA)

0 1,000 2,000
Scale in Feet

Contour Interval in feet

CROW BUTTE RESOURCES, INC.

FIGURE F.3-5
NORTH TREND ISOPACH MAP -
BASAL CHADRON SANDSTONE (REV 05/09)

FILE: F_3-5_NTIsopach_BasalChadron.mxd - 12/30/2009 @ 1:44:53 PM

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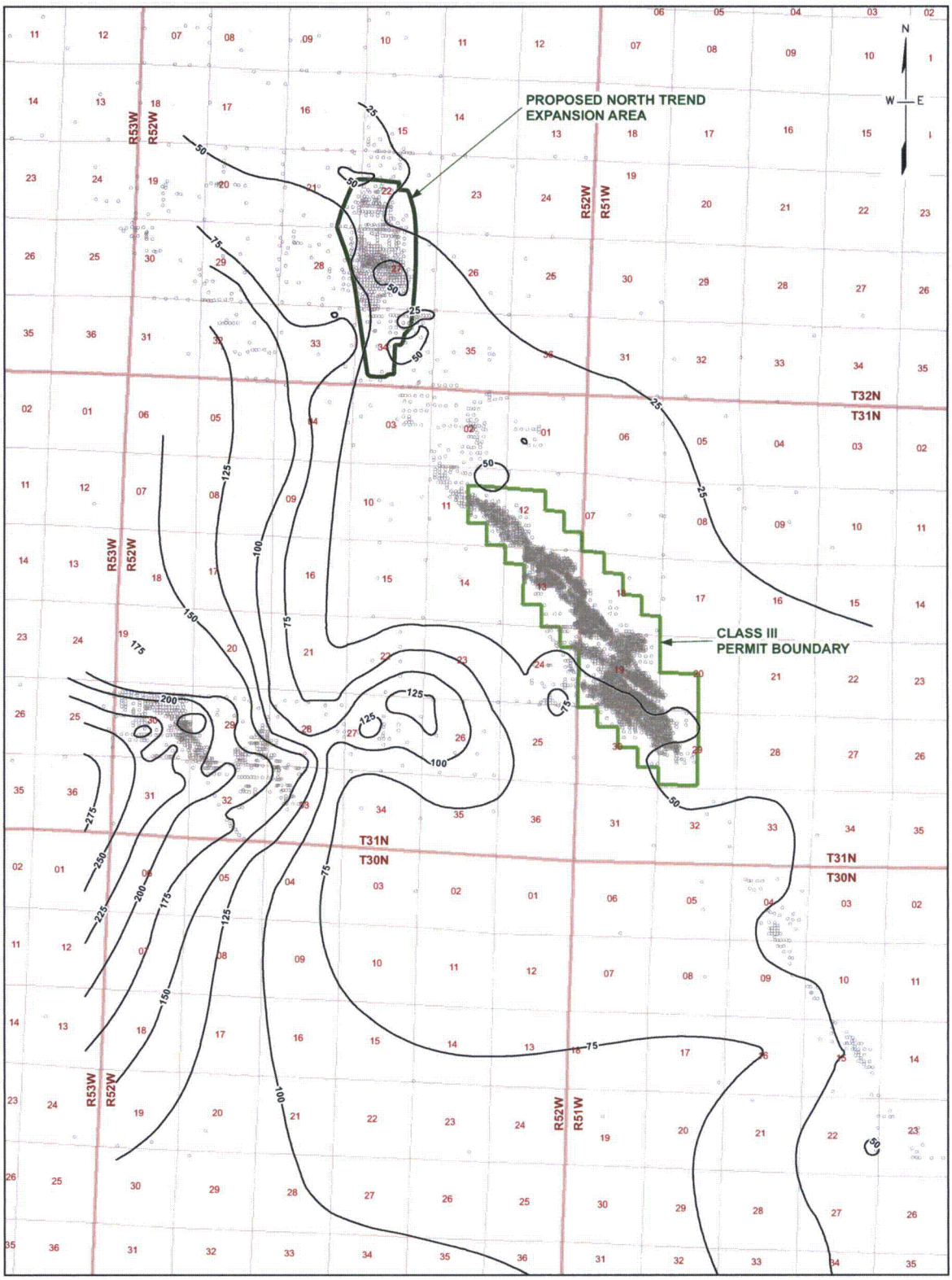


LEGEND

Unit Thickness (Feet)

Exploration Borehole

0 4,000 8,000

Scale in Feet

Contour Interval in feet [amsl]

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FIGURE F.3-6
REGIONAL ISOPACH MAP -
BASAL CHADRON SANDSTONE (REV 05/09)

FILE: F_3-6_Regional_Isopach_Map_BasalChadron.mxd - 12/30/2009 @ 1:42:35 PM

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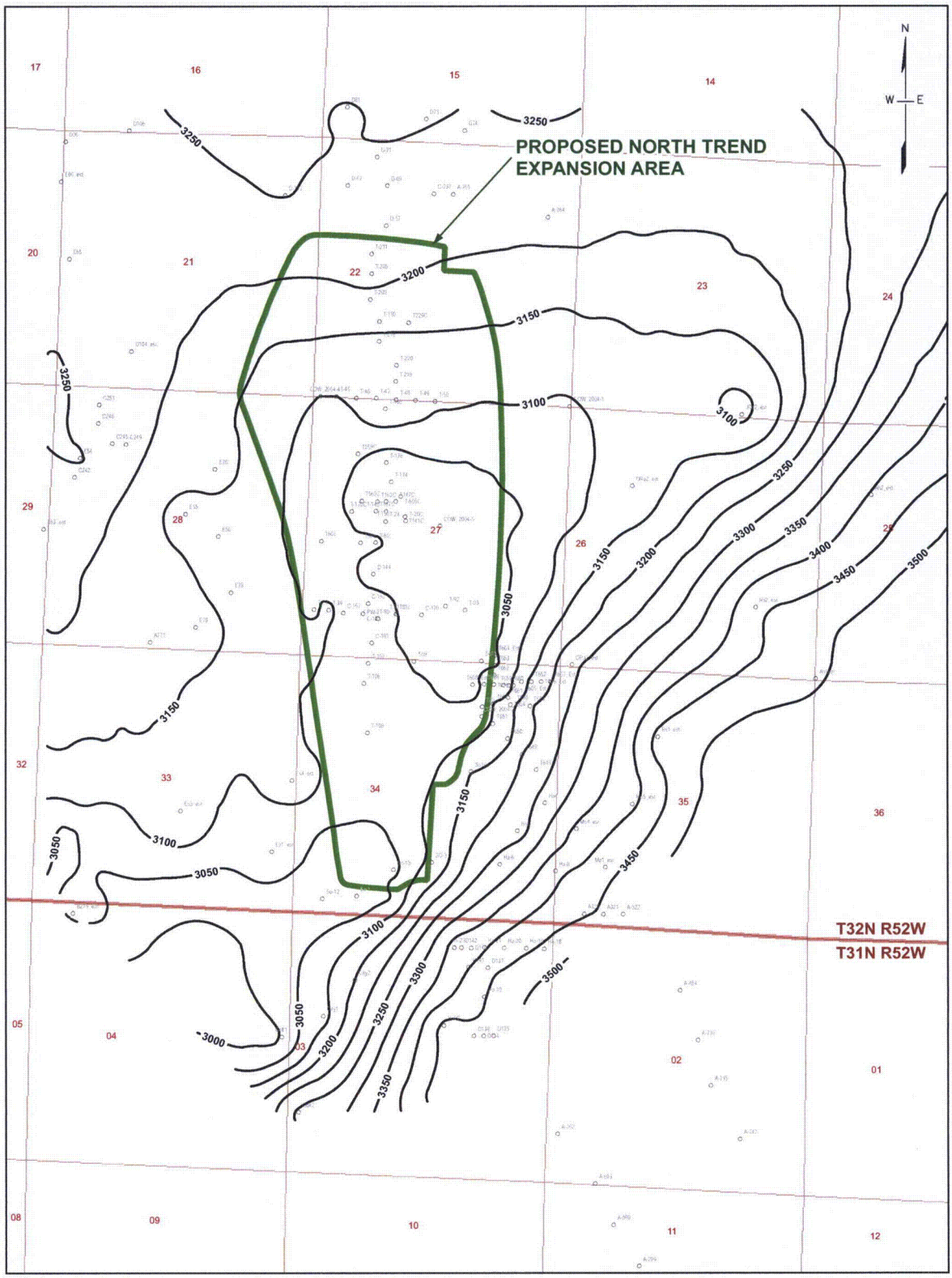


LEGEND

- Exploration Borehole
- Elevation Contour (Feet-AMSL)
- Proposed North Trend Expansion Area (NTEA)

0 1,000 2,000
Scale in Feet

Contour Interval in feet [amsl]

CROW BUTTE RESOURCES, INC.

FIGURE F.3-7
NORTH TREND CONTOUR MAP - THE TOP OF PIERRE (REV 05/09)

FILE: F_3-7_NTIsopach_TopOfPierre.mxd - 12/30/2009 @ 1:45:54 PM

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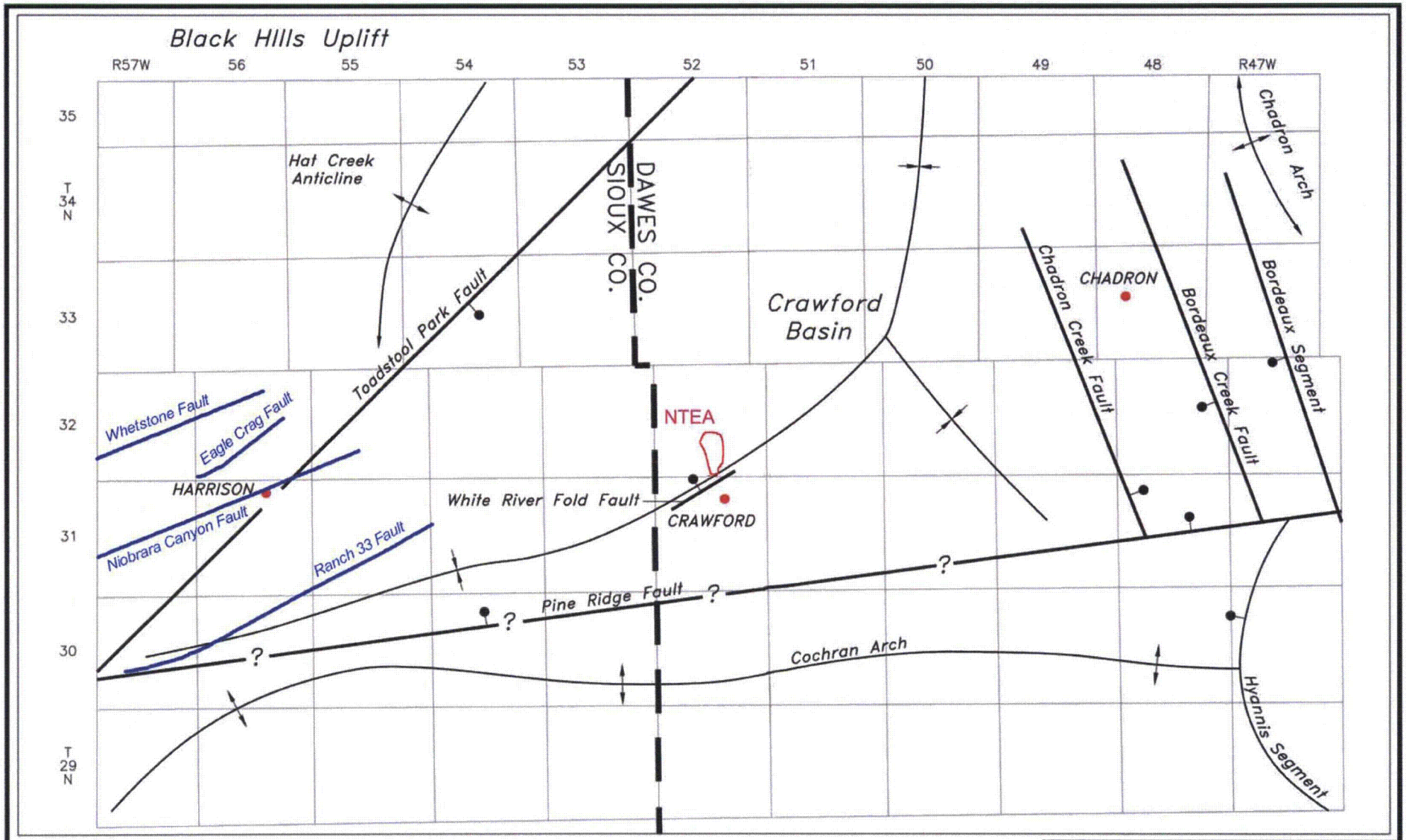


LEGEND

Fault (Ball on downthrown side)

Anticline

Syncline

Fault Interpretations by Hunt (1990)

0 5 10 20 MILES

N

W E

Modified from DeGraw, 1969; WFC-White River Fault only

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FIGURE F.4-1
REGIONAL STRUCTURAL FEATURE MAP
NORTHERN NEBRASKA

PROJECT: CO001322 MAPPED: JC CHECKED: MS

FILE: K:\CO001322_UIC\PDF\..\CBR NT UIC F_4-1.PSD

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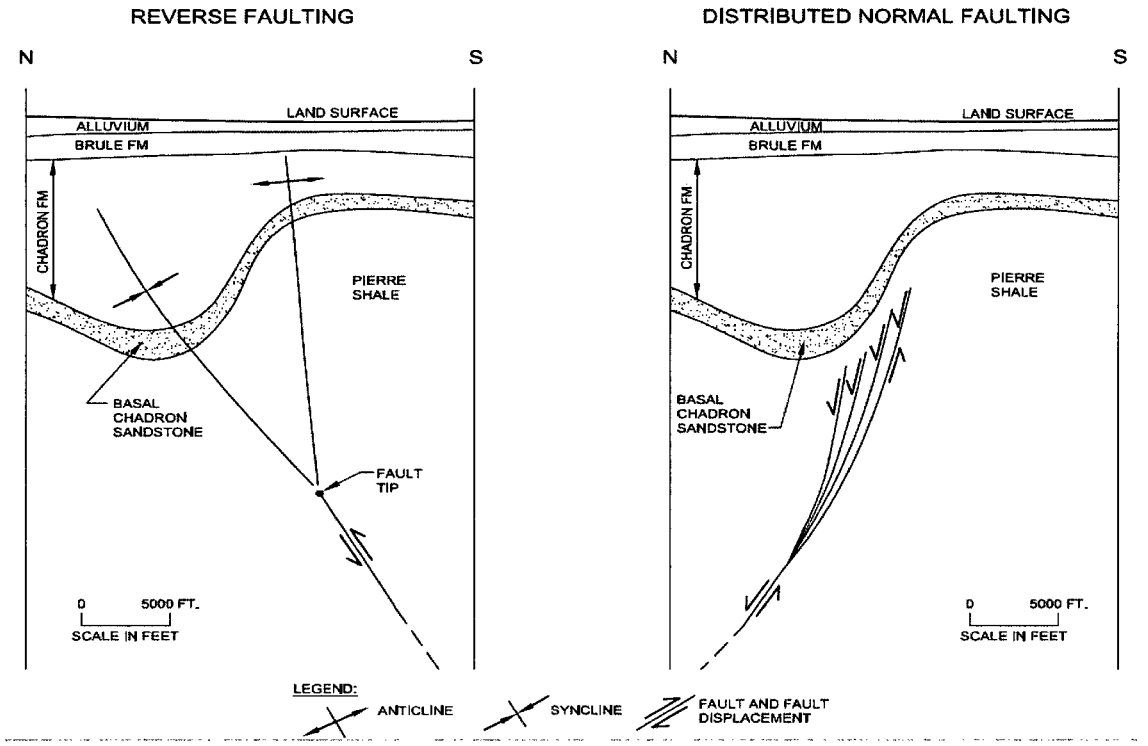
**Figure F.4-1a. Generalized Schematic Diagram of Potential Fault Kinematics Responsible for the White River Fault-Cored Structure**



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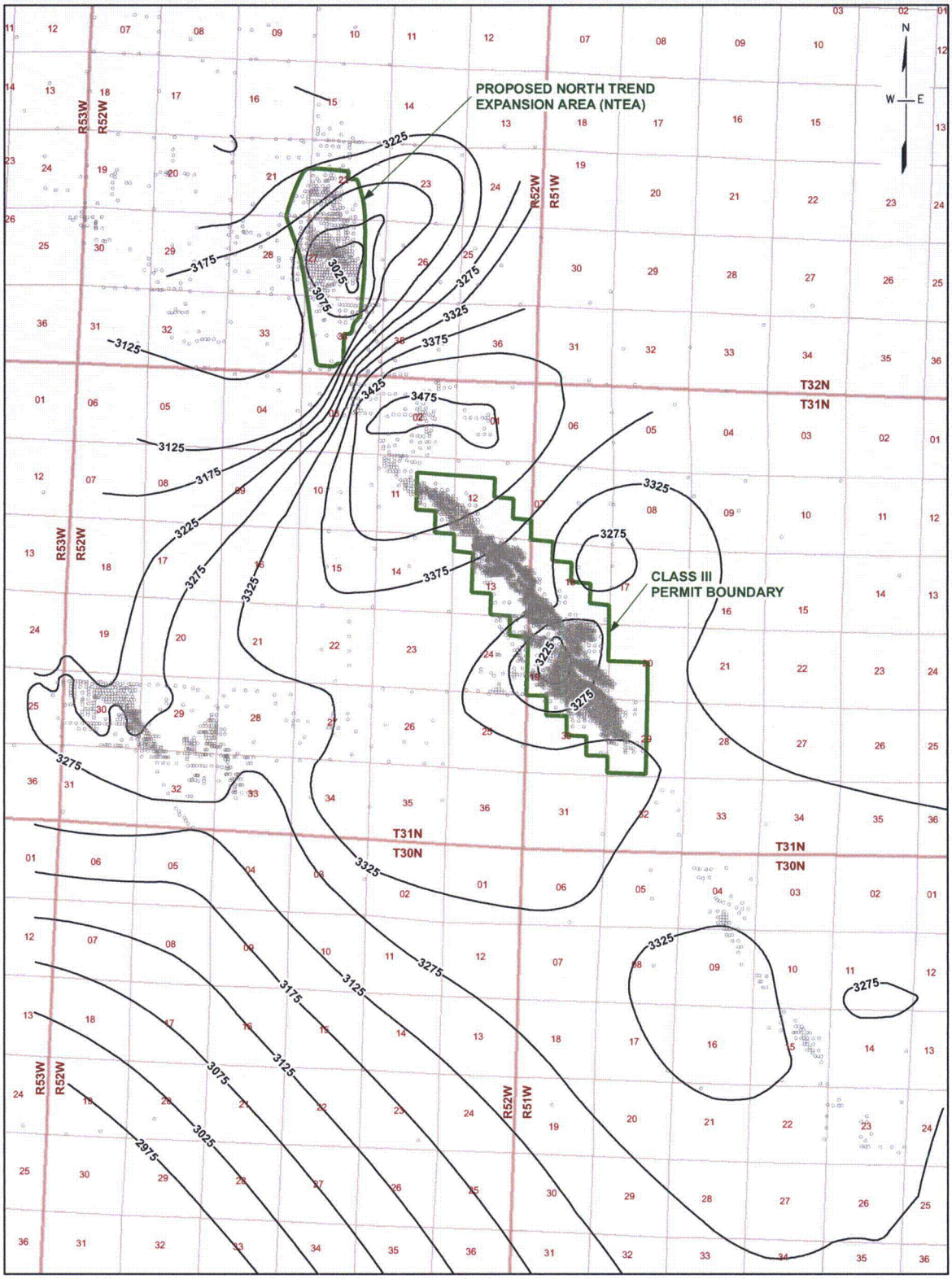


LEGEND

Exploration Borehole

Groundwater Potentiometric Surface (FT-AMSL)

0 4,000 8,000

Scale in Feet

Contour Interval in feet [amsl]

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FIGURE F.4-2
REGIONAL CONTOUR MAP OF THE
TOP OF BASAL CHADRON SANDSTONE

FILE: F_4-2_Regional_Structure_Contour_Map_Top_of_BasalChadron.mxd - 12/30/2009 @ 1:40:59 PM

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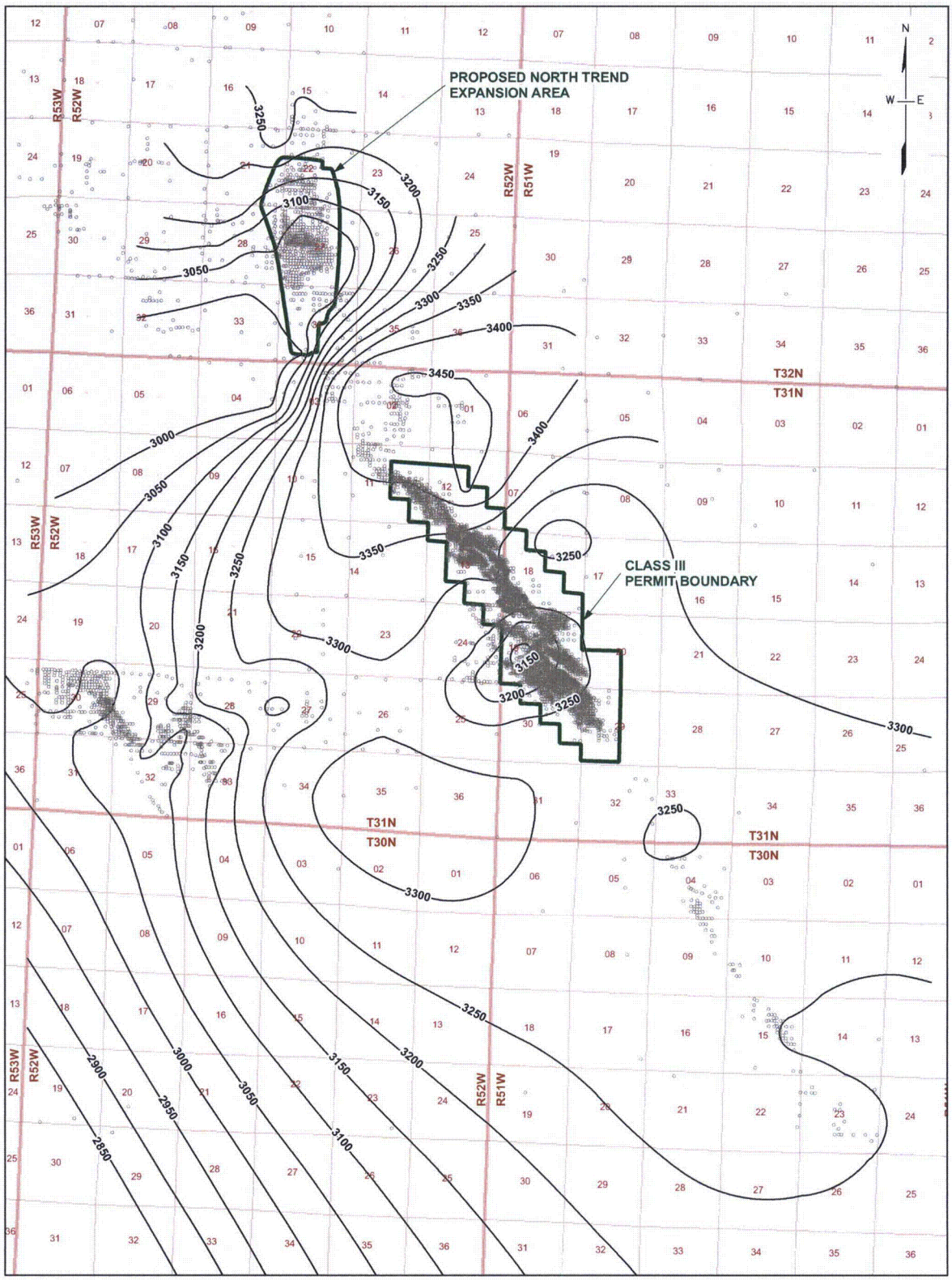


LEGEND

Elevation Contour (FT-AMSL)

section_poly

0 4,000 8,000

Scale in Feet

Contour Interval in feet [amsl]

CROW BUTTE RESOURCES, INC.

FIGURE F.4-3
REGIONAL CONTOUR MAP OF
THE TOP OF PIERRE SHALE (REV 05/09)

FILE: F_4-3_Regional_Contour_Map_Top_of_PierreShale.mxd - 11/12/2009 @ 1:57:15 PM

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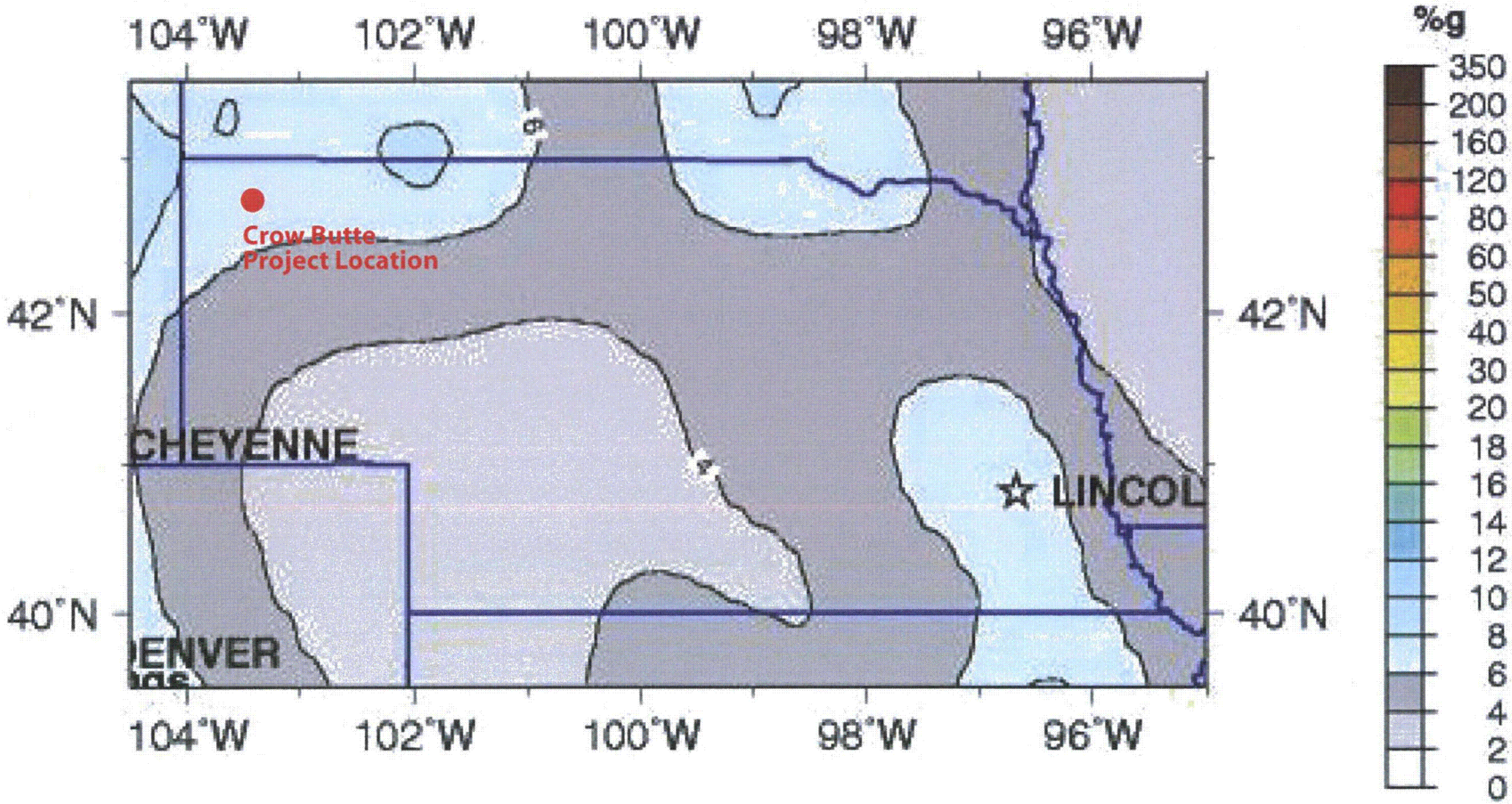


Peak Acceleration (%g) with 2% Probability of Exceedance in 50 Years
Site: NEHRP B-C boundary
National Seismic Hazard Mapping Project (2008)

N
W — E

CROW BUTTE RESOURCES, INC.

FIGURE F. 6-1
SEISMIC HAZARD MAP
FOR NEBRASKA

PROJECT: CO001322 MAPPED: JC CHECKED: J.CEARLEY

FILE: CBR NT F_6-1.PDF @ 06/11/2008

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*SOURCE: USGS EARTHQUAKE HAZARDS PROGRAM (http://earthquake.usgs.gov/regional/states/nebraska/seismicity.php)*

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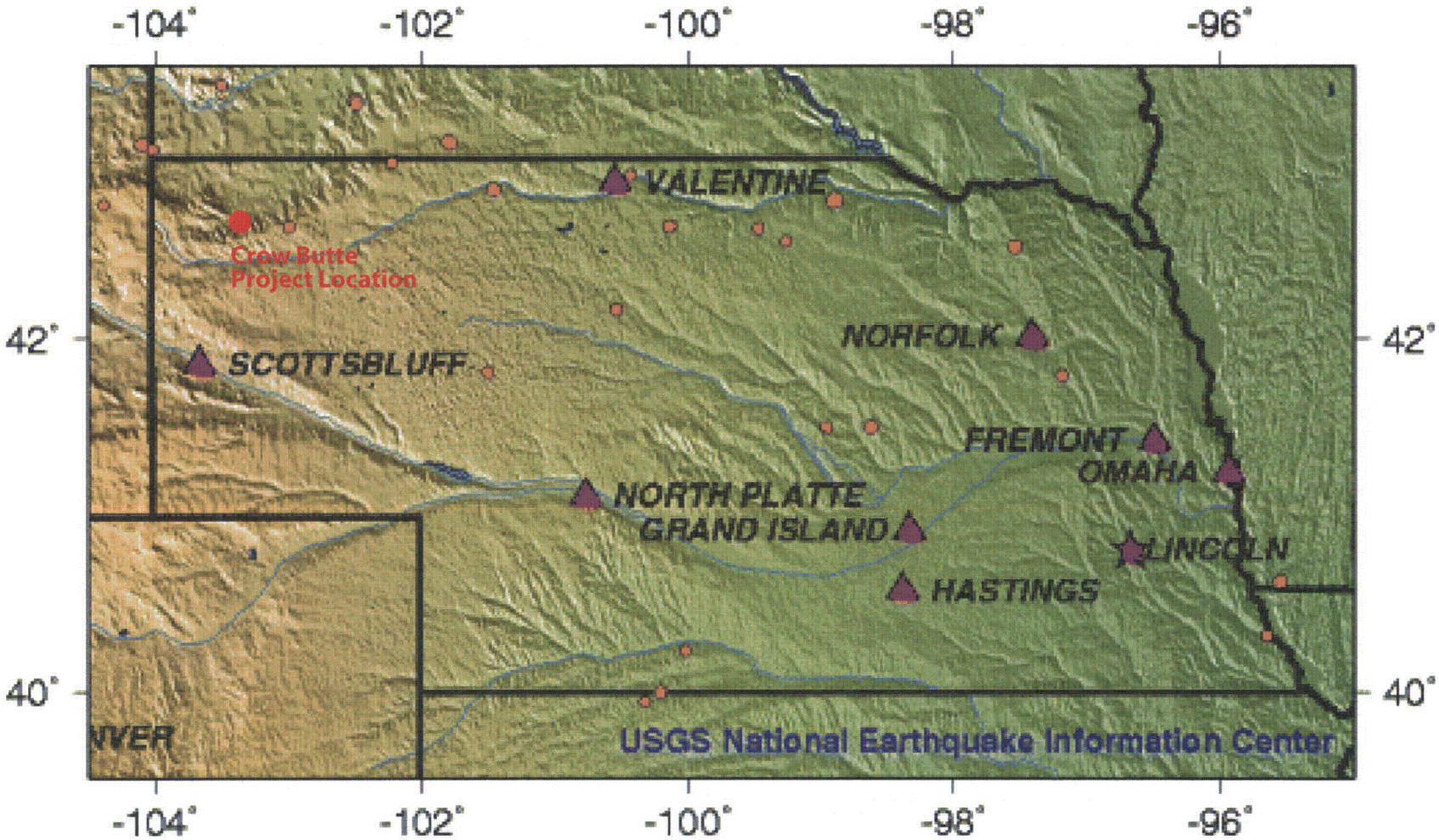


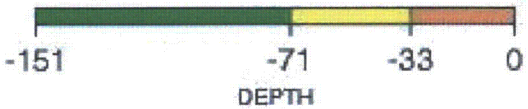


Depth is in kilometers.
Purple Triangles: Cities
Purple Star: Capital City
Circles: Earthquakes (color represents depth range)
Earthquake locations are from the USGS/NEIC PDE catalog

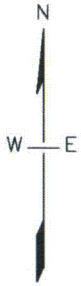


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FIGURE F. 6-2
SEISMICITY OF NEBRASKA
1990-2006

PROJECT: CO001322 MAPPED: JC CHECKED: J.CEARLEY

FILE: CBR NT F_6-2.PDF @ 06/11/2008

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SOURCE: USGS EARTHQUAKE HAZARDS PROGRAM (http://earthquake.usgs.gov/regional/states/nebraska/seismicity.php)

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**LEGEND: Soils**

- Bg, Bridget silt loam, 0 to 1 percent slopes
- DuB, Duroc very fine sandy loam, 1 to 3 percent slopes
- HbB, Haverson silt loam, occasionally flooded
- JmC, Jayem loamy very fine sand, 1 to 6 percent slopes
- KaD2, Thirtynine silt loam, 2 to 11 percent slopes, eroded
- KeB, Keith silt loam, 1 to 3 percent slopes
- KeD, Keith silt loam, 3 to 9 percent slopes
- KfD, Keith and Ulysses silt loams, 3 to 9 percent slopes
- KpD, Keota-Epping silt loams, 3 to 9 percent slopes
- Lo, Haverson loam, frequently flooded
- OgF, Oglala loam, 9 to 30 percent slopes
- OhF, Oglala-Canyon loams, 9 to 20 percent slopes
- Sn, Bankard loamy fine sand, frequently flooded
- SrC, Sarben fine sandy loam, 1 to 6 percent slopes
- SrD, Sarben fine sandy loam, 6 to 9 percent slopes
- SvF, Sarben and Vetal loamy very fine sands, 9 to 30 percent slopes
- VeC, Vetal and Bayard soils, 1 to 6 percent slopes

0 1,500 3,000
Scale in Feet

*Source: Aerial - NAIP NE045, 2006; Soil - NRCS Soil Mart*

CROW BUTTE RESOURCES, INC.

FIGURE F. 7-1
NORTH TREND SOILS

PROJECT: CO001322 MAPPED: JC CHECKED: MS

FILE: F_7-1_NT_Soils_11x17.mxd - 12/30/2009 @ 1:41:57 PM

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# CHAPTER G. HYDROLOGY

*Discussion of the regional and local area hydrological conditions (surface and groundwater), including aquifer testing and monitoring results.*

**Note: All figures referenced in this section are located in the following Chapter H. The Chapter figures are numbered to correspond with the section numbers of Chapter G**

## G.1 Surface Water

The North Trend Expansion Area (NTEA) lies within the watershed of Spring Creek and an unnamed creek which are small tributaries to the major regional water course, the White River. The White River is the only major surface water feature in close proximity to the NTEA. The river runs approximately 800 feet along the boundery of the southeast corner of the NTEA (Figure H.1-1). The river does not flow through the NTEA. The White River supports agricultural production, wildlife habitat, and both warm and cold-water fish. Upstream from the NTEA, the White River supplies drinking water for the City of Crawford.

### G.1.1 Location

The NTEA occupies Sections 21, 22, 27, 28, and 34 of Township 32 North, Range 52 West within the drainage basin of the White River. The White River originates in Sioux County and flows northeasterly across Dawes County into South Dakota. Tributaries of the White River northeast of the Crawford area cross upland portions of the Pierre Shale, an impermeable formation. These streams are dry except for runoff flow and include the ephemeral Spring Creek and an unnamed creek. .A historic diversion canal (the Hall Canal) was constructed to direct flow from Spring Creek to the White River, originating at Spring Creek north of the NTEA and terminating at White River near the southeast corner of the NTEA. The use of the canal for such conveyance has been abandoned, with vestiges of this diversion canal still being found in some locations. Remaining vestiages are dry except for runoff flow. The southern tributaries, across the White River and to the south – southeast of the NTEA, originate in the Pine Ridge escarpment and flow primarily over forest, range, and agricultural land. These streams are generally ephemeral except for source water from occasional springs.

Spring Creek and the lower portion of the abandoned Hall Canal within the NTEA are northern tributaries of the White River, although the remaining Hall Canal flow contribution is limited. The unnamed creek, which is located near the southwest corner of the NTEA, originates in Red Cloud Buttes southwest of the NTEA. Spring Creek originates in the hills of the Fort Robinson Wildlife Area west of the NTEA. From the headwaters, Spring Creek and the unnamed creek (ephemeral streams) flow eastward over range and agricultural land to the White River. The remaining vestiges of the Hall Canal flow along the eastern NTEA boundary primarily through agricultural land. Contributions to flow in Spring Creek, the unnamed creek, and vestiges of Hall Canal appear to be snowmelt and runoff, as well as some springs. **Figure H.1-1** of Chapter H shows the location of all surface water features in the NTEA.

Spring Creek flows west to east through the northwest corner of the NTEA license boundary in Sections 21 and 22. The creek flow direction then changes to nearly due north, and eventually

flows into the White River well to the east of the NTEA. The lower portion of the Hall Canal flows through the southern end of the NTEA, entering the White River. The unnamed creek is located near the southwest corner of the NTEA and joins the White River directly south of the NTEA.Little Cottonwood and Sand Creeks flow west-to-east along the northern portion of the 2.25-mile review area, where they join the White River. Squaw, English, and White Clay Creeks flow to the White River in the southeastern portion of the 2.25-mile review area. On the south side of the review area, Dead Man's, Cherry, and Bozle Creeks flow northward to the White River. Dead Man's Creek is not shown on **Figure H.1-1**, being located to the west of Cherry Creek outside of the North Trend Area of Review. Dea Man's Creek runs parallel to Cherry Creek in Dawes County and enters the White River in Sioux County. The confluence of Dead Man's Creek and the White River is approximately 6 miles southwest of the City of Crawford. The creek extends from the White River approximately 7 miles to the southeast toward the Pine Ridge Escarpment.

Based on available maps and site investigations conducted by Crow Butte Resources, Inc. (CBR), no surface water impoundments, lakes, or ponds have been identified within the NTEA. Several small impoundments are located on private ranches within or adjacent to the 2.25-mile radius review area for the NTEA, primarily along Squaw and White Clay Creeks (eastern portion of the review area) and Little Cottonwood Creek (northern portion of the review area). Based on field inspections by CBR personnel, there is no irrigated farmland within the NTEA boundary.

### G.1.2 Stream Flow

**Table G.1-1** shows the mean monthly discharge of the White River compared to the mean monthly precipitation over several years (NOAA 2002). These extended data show that a general correlation can be made between the direct precipitation and discharge. Higher flows are recorded in spring and early summer with lowest flow rates in late summer to early fall, reflecting seasonal changes related to precipitation. For the period of 1931 to 2004 the average normal annual mean discharge at the White River Station at Crawford was 20.3 cubic feet per second (cfs) with a standard deviation of 2.8 $ft^3$/sec (**Table G.1-1) (USGS 2004)**. The maximum was 27 $ft^3$/sec, and the minimum was 13 $ft^3$/sec. Based on Nebraska DNR data, **Table G.1-2** provides mean monthly discharge information for the White River for 1999 through 2006 (NDNR 2008a), with monthly averages ranging from 16.7 $ft^3$/sec in 2000 to 21.9 $ft^3$.sec in 2005. The more recent data for the White River are comparable to the stream flow data shown in **Table G.1-1.**

Peak rainfall at Harrison and Scottsbluff, Nebraska occurs in May and June (NOAA 2002), and this precipitation pattern appears to be representative of the Crawford area.

No flow measurements have been attempted on Spring Creek or the unnamed creek due to the seasonal nature of flow in these features.

### G.1.3 Surface Water Impoundments

No private surface water impoundments have been identified at or within the NTEA. Similarly, no naturally occurring lakes, ponds or springs have been identified within the NTEA boundary.

There are five private impoundments (I-2, I-3, I-4, I-5 and I-6), and one reservoir (Crawford Lake) located adjacent to or within the 2.25-mile radius boundary. These water bodies are shown in **Figure H.1-1** of Chapter H. Approximately one fifth of Lake Crawford is included within the southern part of the 2.25-mile radius boundary, and is located approximately 0.75 mile south of Crawford. There are also two small impoundments (I-7 and I-8, **Figure H.1-1** of Chapter H) located on private ranches within the southeastern part of the 2.25-mile review area. Impoundment I-7 is formed by a small earthen dam across English Creek that is used for livestock watering. Impoundment I-8 is located in the alluvial valley of White Clay Creek and is also used for livestock watering. Impoundment I-2 is formed by a small earthen dam on White Clay Creek. Impoundment 5 is formed by a small earthen dam across English Creek, and Impoundment 6 is formed by an earthen dam across Squaw Creek. These two latter impoundments are used for livestock watering and are located just outside of the southeast corner of the 2.2.5-mile radius boundary. Impoundments 5 and 6 are located within the existing Crow Butte commercial permit area and are sampled for analysis when water is present. It should be noted that the water bodies referenced above have historically experienced prolonged dry periods.

Only one naturally occurring spring (# 8001) is documented within the 2.25-mile AOR (**Figure H.1-1**).

### G.1.4 Assessment of Surface Water Flooding

As shown in **Tables G.1-1** and **G.1-2** the average monthly stream flow of the White River at the Crawford gauge station is about 20 cfs. The highest discharge and gauge height on record between 1920 and 2004 occurred on May 10, 1991. On that date, severe thunderstorms resulted in significant rainfall, the gauge height was 16.32 feet, and the stream flow exceeded 13,300 cfs (NDNR 2004). Several city facilities were damaged by floodwaters and hail, including the local golf course and fish hatchery, and the event was considered a "100-year" flood. However, it is noted that, while there are certainly historical extremes, the average gauge height on the White River at Crawford is less than 5 feet, with an average annual stream flow of 20.3 cfs.

An assessment of the potential for flooding or erosion that could impact the in-situ mining processing facilities and surface impoundments has been performed based on data from the Federal Emergency Management Agency (FEMA 2008). FEMA has not mapped unincorporated Dawes County north of Crawford, Nebraska; however, FEMA maps are available for the City of Crawford, and an analogy can be drawn between the flooding potential in Crawford and that immediately north of Crawford adjacent to the proposed NTEA. As shown in **Figure H.1-2** of Chapter H, FEMA has classified the portion of Crawford between the D M & E Railroad (immediately west of First Street) as Zone A (i.e., an area that could be impacted by a 100-year flood) (FEMA 2008). The elevation of the White River in the Zone A classification ranges from 3,669 to 3,659 feet above mean sea level (amsl). The surface elevation of the railroad tracks ranges from 3,678 to 3,671 feet amsl. These data suggest that significant flooding potential exists with a rise in the White River elevation of 9 to 12 feet above base flow conditions. This is consistent with the data from the 1991 100-year flood event, where the river elevation was approximately 11.3 feet above base gauge height (approximately 5 feet).

The proposed NTEA surface facilities are to be located in the north-central portion of Section 27, approximately 1 mile northwest of White River, and approximately 70 feet topographically above the common river elevation. Proposed wellfields are planned for portions of Sections 21, 22, 27, 28, and 34, T32N, R52W (**Figure 2.7-1**). With the exception of Section 34, the wellfields are projected to be at least 50 feet above the White River elevation.

The portion of the proposed NTEA where the greatest flooding potential related to the White River exists is the southeast part of Section 34 (**Figure H.1-1** of Chapter H). The White River elevation in that area varies from 3,645 feet AMSL on the western portion of the southern permit boundary to 3,622 feet amsl to the northeast. Because of lower elevation and proximity to the White River, final wellfield layout in Section 34 may necessitate consideration of potential flood impacts (e.g., below a surface elevation of 3,657 feet on the west and 3,634 feet to the northeast).

Based on these data, the NTEA surface facilities occur outside of the 100-year floodplain, and are not considered to be in a "flood prone" area. Therefore, consistent with NUREG-1623, erosion modeling was not considered necessary nor was it performed.

The NTEA does not include any major surface water features other than the White River.

## G.1.5 Surface Water Quality

### *G.1.5.1 Non-Radiological Water Quality*

Water samples were collected from, the White River, which is the single perennial surface water feature identified within the NTEA. White River water quality data were assembled by the U.S. Environmental Protection Agency (USEPA) for various years from 1969 to 1994 (**Table G.1-3**). Water quality data collected by the Nebraska Department of Environmental Quality (NDEQ) for the year 2003 is presented in **Table G.1-4**. Preoperational water quality data for the current CBR license area were collected from the White River from February 1982 to October 1985 for sample points W-1, W-2 and W-3 (FEN 1987). Locations for W-1 and W-2 are shown in **Figure H.1-1**, while the location of W-3 is not shown. W-3 is located downstream of W-2, approximately 5.5 miles northeast of Crawford, outside the Area of Review. No additional non-radiological samples were collected from W-3 following the establishment of the 1982-1985 database. These preoperational data are presented in **Table G.1-5**.

Data from the USEPA STORET database for the White River at Crawford (60 sampling events from 1968 to 1980) indicate an average specific conductance of 380 microSiemens per centimeter (µS/cm) (USEPA 2006). USEPA STORET data from the White River tributaries in the vicinity of the NTEA (Soldier Creek [west of Crawford]; Squaw Creek, White Clay Creek and English Creek [all east of Crawford]; and Dead Man's Creek [southwest of Crawford]) indicated that the specific conductance for these tributaries ranged from 36 to 507 µS/cm (8 sampling events from 1981 to 1995). With the exception of Dead Man's Creek, the locations of the tributaries are shown in Figure H.1-1. Dead Man's Creek is located beyond the extent shown on Figure H.1-1, therefore its location is not shown on the figure. The confluence of Dead Man's Creek and the White River is approximately 6 miles southwest of the City of Crawford. Dead Man's Creek extends from the White River approximately 7 miles to the southeast toward the Pine Ridge Escarpment.

Based on NDNR data collected at the White River at Crawford sampling station in 2003, specific conductance ranged from 349 to 386, with an average of 374 µS/cm (NDNR 2008a).

#### *G.1.5.2 Radiological Water Quality*

Preoperational radiological monitoring data for the Crow Butte site have been collected on the White River at locations W-1, W-2 and W-3 in connection with the current CBR license area (**Figure H.1-1** of Chapter H). As stated above, locations for W-1 and W-2 are shown in Figure H.1-1, while W-3 is not due to the distance from the NTEA. The location of W-2 northeast of the NTEA was deemed to be more suitable than W-3 for use as a downstream sample location for the NTEA. Preoperational data (nonradiological and radiological parameters) collected for W-1, W-2 and W-3 from 1982 to 1985 are included in **Table G.1-5** referenced above.

Five sets of surface water samples were collected from W-1 and W-2 on a quarterly basis from the third quarter of 2004 through the third quarter of 2005. The results for the preoperational radiological surface water monitoring are summarized in **Table G.1-6**. All samples were analyzed for the concentration of natural uranium, thorium-230, radium-226, lead-210, and polonium-210 with the exception of the first and third quarters of 2005, when an error in the chain of custody resulted in no analysis for thorium-230, polonium-210, and lead-210. The samples were filtered, and the results of the analysis represent the dissolved concentrations. The primary analytical laboratory was Energy Laboratories in Casper, Wyoming.

## G.2 Groundwater

### G.2.1 Groundwater Occurrence and Flow Direction

Within the Crawford Basin, the alluvium, Brule Formation, and Basal Chadron Sandstone are considered water-bearing intervals. The alluvial deposits are not typically considered to be a reliable water source. Sandy siltstones, overbank sheet sandstones, and occasional thick channelized sandstones that occur throughout the Orella Member of the Brule Formation may be locally water-bearing units. These sandstone and siltstone units are difficult to correlate over any long distance and are discontinuous lenses rather than laterally continuous strata. Although the Brule Formation is a locally water-bearing unit, it does not always produce usable amounts of water. Despite this characteristic, the Brule Formation has historically been considered the shallowest aquifer above the Basal Chadron Sandstone aquifer and water supply wells have been completed in this unit. The Basal Chadron Sandstone contains the uranium mineralization in the NTEA as well as the current CSA.

Locations of all groundwater monitor wells in the vicinity of the NTEA are shown on **Figure H.2-1** of Chapter H. There is one active well screened in the alluvium (RA-1), two active monitor wells screened in the Brule Formation (BOW-1 and BOW-2), four active monitor wells screened in the Upper/Middle Chadron (MCOW-1, MCOW-2, MCOW-3, and MCOW-4), and nine active monitor wells screened in the Basal Chadron Sandstone (COW-1, COW-2, COW-3, COW-4, COW-5, COW-6, CPW-2, RC-1, and RC-2) (**Figure H.2-1** of Chapter H). Well completion reports for these monitor wells are included in the North Trend Hydraulic Pumping Test #6 (**Appendix 5**). Monitor well COW-6 was installed from February 11 to 13, 2008 in Section 22 of the NTEA to establish a more spatially comprehensive network of monitor wells screened in the Basal Chadron Sandstone (**Appendix 1**). Several water supply wells are also

screened in the Brule Formation and Basal Chadron Sandstone, though none of these wells are used for drinking water within the NTEA (**Figure H.2-2** of Chapter H, **Figure C.1-2** of Chapter C, **Table G.2-1**).

The static water level for wells screened in the Brule Formation in the vicinity of the NTEA typically range from 10 to 60 feet below ground surface (bgs) (Beins, W. 2008). However, monitor wells screened in the Brule Formation are often dry. Water level measurement events were conducted at two monitor wells screened in the Brule Formation (BOW-1 and BOW-2) during four water level measurement events in March and April 2008. Consistent water levels of approximately 3,620 feet amsl were obtained at well BOW-1 during all four events (**Table G.2-2**). In contrast, well BOW-2 was dry during each measurement event (**Table G.2-2).** Following consistent precipitation in May and early June 2008, water levels were measured again from the Brule Formation in June 2008 (**Table G.2-2**). During this event, BOW-2 exhibited a measurable static water level. The resulting groundwater elevations are shown on **Figure H.2-3** of Chapter H. Water levels ranged from approximately 3,588 to 3,676 feet amsl. Groundwater elevations for the June 9, 2008 event indicate groundwater flow is convergent with the White River. Groundwater flow is directed to the southeast in the northern portion of the NTEA and to the northeast (parallel with flow in the White River) in the southern portion of the NTEA (**Figure H.2-3** of Chapter H). The average hydraulic gradient within the NTEA is 0.0081 ft/ft. South of the White River, historical water levels measured in the Brule Formation in the 1982-1983 timeframe indicate a regional hydraulic gradient to the north (**Figure H.2-4** of Chapter H).

Despite the installation of monitor wells screened in the Upper/Middle Chadron, the wells have not historically produced sufficient water such that they could be adequately developed. It is possible that the unit could contain recoverable water; however, the production capacity is limited on the order of <0.01 gallons per minute (gpm) based on a 2004 recovery test in wells located in the southern part of Section 27 (see Section G.3). No domestic or livestock wells in the NTEA are completed in this interval. For these reasons, no attempts were made to collect water levels from wells screened in the Upper/Middle Chadron.

Monitor wells screened in the Basal Chadron Sandstone are known to be artesian with flow at the surface at many locations within the NTEA. Water levels were determined based on pressure readings collected from the nine available monitor wells and two water supply wells (wells 97 and 123) screened in the Basal Chadron Sandstone during five water level measurement events in March and April 2008 (**Table G.2-2**). Fluctuating water levels were observed at two monitor wells (COW-2 and CPW-2) and the two water supply wells (wells 97 and 123) during events between March 4 and April 4, 2008. It was subsequently discovered that wells 97 and 123 had been turned on periodically by local landowners to allow artesian flow to fill livestock tanks. The two water supply wells were subsequently closed and allowed to equilibrate for a 12-hour period prior to collecting additional pressure readings on April 16, 2008. The resulting potentiometric surface on April 16, 2008 is shown on **Figures F.2-3a** through **F.2-3d** of Chapter F and **Figure H.2-5** of Chapter H. The potentiometric surface ranged from 3,672 to 3,729 feet AMSL and was above the ground surface at all locations within the NTEA. Data for the April 16, 2008 event indicate that groundwater flow is predominantly to the southeast with an average hydraulic gradient of 0.0018 ft/ft within the NTEA and steepened gradient of 0.0058 ft/ft southeast of the NTEA within the north-dipping fold limb. **Figure H.2-6** of Chapter H shows historical regional water levels for the Basal Chadron Sandstone from 1982 to 1983 for two wells in the vicinity of

the NTEA and additional wells from the CSA. Because a limited number of data points exist, an inferred potentiometric surface has not been presented for the 1982 to 1983 data. However, the limited historical water levels suggest similar southward flow from the NTEA converging with north and northeast flow from the CSA in that time period.

Prior to starting the 2006 pumping test (described in Section G.3), static water levels were collected in June 2006 from the Brule Formation, Upper/Middle Chadron, and Basal Chadron Sandstone. Water levels ranged from 3,608 to 3,621 feet amsl in the Brule Formation, 3,605 to 3,609 feet amsl in the Upper/Middle Chadron, and 3,693 to 3,711 feet amsl in the Basal Chadron Sandstone (see North Trend Hydrologic Testing Report - Test #6 [**Appendix 5**]). Historically, potentiometric levels in the overlying Upper/Middle Chadron Sand and Brule Formation average approximately 90 feet and 80 feet below the potentiometric surface for the Basal Chadron Sandstone, respectively, indicating that an upward hydraulic gradient exists between the Basal Chadron Sandstone and the Brule Formation.

Available groundwater data for both the Brule Formation and Basal Chadron Sandstone at the NTEA do not indicate that there are any documented flow rate variations or recharge issues that would impact groundwater quality as a result of ISL mining operations in the Basal Chadron Sandstone. There are no surface water ponds within the area and only limited stream flow. The Brule Formation, while considered an overlying aquifer, is not an extensive or exceptionally productive system. The available monitoring data do not indicate any seasonality or pumping effects by domestic wells within this zone. There are no domestic wells completed in the Basal Chadron Sandstone within the NTEA, and there is no information to indicate that there are recharge or flow rate issues associated with the Basal Chadron Sandstone that would affect groundwater quality.

### G.2.2 Groundwater Quality

#### *G.2.2.1 Baseline Monitoring for Current Commercial Site Area*

Groundwater quality within the White River drainage is generally poor (Engberg and Spalding 1978). Groundwater obtained from the Basal Chadron Sandstone aquifer emits a strong sulfur odor as a result of localized reducing conditions associated with the ore body (**Figure H.2-7** of Chapter H). Groundwater quality data were collected from 1982 to 1987 within and near the CSA to establish background conditions in the vicinity of the Crow Butte Project. Water quality information for the Alluvium, Brule Formation, and Basal Chadron Sandstone is summarized in **Table G.2-3**. Wells sampled from the Brule Formation include RA-1, RA-2, RB-1, and RB-3 (Ferret Exploration of Nebraska 1987). Wells sampled from the Chadron Formation include RC-1, RC-2, RC-3, RC-4, RC-5, RC-6, and RC-7 (Ferret Exploration of Nebraska 1987).

#### *G.2.2.2 Baseline Monitoring for NTEA and 2.25-Mile Area of Review*

CBR conducted an initial water well user survey in 1996 to identify and locate all water supply wells within the 2.25-mile AOR of the NTEA. The water user survey determined the location, depth, casing size, depth to water, and flow rate of all wells within the area that were (or could) be used for domestic, agricultural, or livestock uses. CBR updated the water user survey for the 2.25-mile AOR of the NTEA again in 2004, 2007 and 2008. Active, inactive, and abandoned water wells within the 2.25-mile AOR of the NTEA are summarized in **Table G.2-1** and

**Appendix 6**. More detailed discussions as to the water well user survey and resulting well inventory are discussed in Section I.1.3.2.

Based on the data collected during the water well user survey, CBR selected a Basal Chadron Sandstone well (W-007, also identified as Well 81A) and a Brule Formation well (W-008, also identified as Well 78) for water quality analyses (**Figure H.2-1** of Chapter H). It should be noted that well W-007 (Well 81A) was subsequently abandoned. CBR collected groundwater samples from the two water supply wells during four monitoring periods, obtained from September 1996 through July 1997, to assess seasonable variability in water quality. **Tables G.2-4** and **G.2-5** summarize the water quality results for these two well locations for a full suite of analyses including major ions, nonmetals, trace metals, and select radionuclides. When uranium undergoes radioactive decay, highly radioactive elements are produced. Radionuclides of the uranium-238 decay series include uranium, thorium-230, radium-226, lead-210, and polonium-210. Water quality results indicate that the total dissolved solids (TDS) for the Basal Chadron Sandstone ranged from 1,790 to 1,820 milligrams per liter (mg/L), while the TDS for the Brule Formation ranged from 423 to 479 mg/L. Major ion content in groundwater was slightly higher in the Basal Chadron Sandstone than the Brule Formation, as would be expected by the concentrations of TDS. Alkalinity and conductivity are higher in the Basal Chadron Sandstone than in the Brule Formation. Neither formation had significant measurable concentrations of most trace metals. Measurable uranium ranging in concentration from nondetect to 0.006 mg/L was detected in groundwater from Basal Chadron Sandstone. Concentrations of radium-226 ranged from 10.3 to 14.7 picocuries per liter (pCi/L) in groundwater from the Basal Chadron Sandstone, which is above the USEPA maximum contaminant level (MCL) and NDEQ standard of 5 pCi/L. Measurable uranium was also present in all four groundwater samples from the Brule Formation and ranged in concentration from nondetect to 0.016 mg/L. Radium-226 was only detected in two groundwater samples from the Brule Formation and ranged in concentration from nondetect to 0.5 pCi/L.

Additional quarterly groundwater sampling was conducted in the NTEA from September 1996 to June 1997 and July 2004 to September 2005. Groundwater samples were collected from one Basal Chadron Sandstone well (Well 81A) and four Brule Formation wells (Well 77, Well 78, Well 83, and Well 107) (**Figure H.2-2**). The sample locations were chosen based on proximity to the proposed mining operation, use, and distribution throughout the NTEA. Groundwater samples were only analyzed for select radionuclides (natural uranium, thorium-230, radium-226, lead-210, and polonium-210), with the exception of First Quarter 2005 results ,when only natural uranium and radium-226 were analyzed as a result of an error on the chain of custody (**Table G.1-6**). Analytical results for the Brule Formation indicate that natural uranium concentrations ranged from 6.1 to 31.1 pCi/L, radium-226 concentrations ranged from nondetect to 1.3 pCi/Lm, thorium-230 concentrations ranged from nondetect to 1.2 pCi/L, lead-210 concentrations ranged from nondetect to 13.5 pCi/L, and polonium-210 concentrations ranged from nondetect to 8.6 pCi/L. Analytical results from the Basal Chadron Sandstone indicate that natural uranium concentrations ranged from nondetect to 8.8 pCi/L, radium-226 concentrations ranged from 9.2 to 13.5 pCi/L, thorium-230 concentrations ranged from nondetect to 10.8 pCi/L, lead-210 concentrations ranged from nondetect to 12.9 pCi/L, and polonium-210 concentrations ranged from non-detect to 12.4 pCi/L. The 1996 and 1997 water quality data establish the initial water quality conditions associated with the Brule Formation and the mineralized Basal Chadron Sandstone (**Tables G.2-4, G.2-5 and G.1-7**).

Additional water-quality samples were collected during three biweekly sampling events from wells in the NTEA in March 2008 to meet the current NRC permit requirements (SUA-1534, Section 10.3). Groundwater sample locations included one Brule Formation well (BOW-1), nine Basal Chadron monitor wells (COW-1, COW-2, COW-3, COW-4, COW-5, COW-6, CPW-2, RC-1, and RC-2), and two Basal Chadron water supply wells (Wells 97 and 123) (**Figure H.2-1** of Chapter H). Attempts were made to collect groundwater samples from a second Brule Formation well (BOW-2); however, this well was dry during each sampling event. All groundwater samples were analyzed for major ions, metals, physical properties, and radionuclides (**Table G.2-6** and **Appendix 7**). Groundwater samples collected in March 2008 from wells in the NTEA were analyzed for each of these daughter products.

Extensive water quality results for the March 2008 sampling event indicate that the Brule Formation and Basal Chadron Sandstone have different geochemical signatures. For the Brule Formation, TDS ranged from 429 to 474 mg/L, uranium concentrations ranged from 0.025 to 0.026 mg/L; polonium-210 concentrations ranged from nondetect to 0.9 pCi/L; and radium-226, thorium-230, and lead-210 concentrations were nondetect for all three sampling events (**Table G.2-6**). For the Basal Chadron Sandstone, TDS ranged from 1,200 to 2,550 mg/L, uranium concentrations ranged from nondetect to 0.0361 mg/L, radium-226 concentrations ranged from nondetect to 44.6 pCi/L, thorium-230 concentrations ranged from nondetect to 0.2 pCi/L, lead-210 concentrations ranged from nondetect to 39.2 pCi/L, and polonium-210 concentrations ranged from nondetect to 7.6 mg/L (**Table G.2-6**). Note that uranium concentrations were nondetect at all sampling locations outside of the NTEA (RC-1, Well 97, and Well 123) (**Figure H.2-1** of Chapter H). Based on the March 2008 results, concentrations of TDS, major ions, uranium, and all daughter products of uranium decay are elevated in the Basal Chadron Sandstone.

Water quality samples collected from the Basal Chadron Sandstone in the CSA and the NTEA indicate that both areas have similar geochemical conditions. Water quality results for the Basal Chadron Sandstone in the CSA are presented in **Table G.2-3** and for the NTEA in **Table G.1-7** and **Table G.2-4** through **Table G.2-6**. Total dissolved solids range from 1,500 to 2,500 umhos in the CSA and from 423 to 2,510 micromhos (umhos) in the NTEA. Calcium ranged from 11 to 41 mg/L in the CSA and from 8 to 77 mg/L in the NTEA. Magnesium ranged from 0.8 to 7.2 mg/L in the CSA and from non-detect to 12 mg/L in the NTEA. Sodium ranged from 340 to 540 mg/L in the CSA and from 41 to 848 mg/L in the NTEA. Potassium ranged from 7 to 19.8 mg/L in the CSA and from 9 to 31 mg/L in the NTEA. Bicarbonate ranged from 308 to 411 mg/L in the CSA and from 244 to 531 mg/L in the NTEA. Sulfate ranged from 254 to 620 mg/L in the CSA and from 51 to 1200 mg/L in the NTEA. Chloride ranged from 134 to 250 mg/L in the CSA and from 27 to 328 mg/L in the NTEA. Uranium concentrations ranged from non-detect to 2.4 mg/L in the CSA and from non-detect to 0.0361 mg/L in the NTEA. Radium-226 concentrations ranged from 0.1 to 619 pCi/L in the CSA and from non-detect to 44.6 pCi/L in the NTEA.

## G.3 Aquifer Testing and Hydraulic Parameter Identification Information

During the initial permitting and development activities within the CSA, two pumping tests were conducted in the central portion of the CSA to: (1) assess the hydraulic characteristics of the Chadron Sandstone and (2) demonstrate the confinement provided by the overlying and underlying aquicludes. Those tests, referred to as Test #1 and Test #2, were performed in 1982

and 1987, respectively (Wyoming Fuel Company 1983; Resources Technologies Group 1987). Test #3 was conducted in September 1996 (Harlan & Associates, Inc. 1996). Test #4 was conducted in August 2002 (PetroTek 2002). Results from those tests are summarized in **Table G.3-1**.

Pumping tests on the Basal Chadron Sandstone aquifer were conducted in the NTEA between 2004 and 2006 (**Appendix 5**). Testing activities and findings from pumping test activities in the NTEA are summarized below.

Results from the initial testing activities conducted in 2004 to 2005 (Tests #1 through #5) were not definitive as a result of such problems including improperly abandoned old exploration holes, equipment problems, insufficient stress (drawdown) to provide usable data and infiltration of surface water into observation wells. Prior to testing, CBR installed seven new wells in the Basal Chadron Sandstone (CPW-1, CPW-2, COW-1, COW-2, COW-3, COW-4, and COW-5) (**Figure H.2-8** of Chapter H). CPW-1 was installed specifically for use as a pumping well, but was subsequently abandoned due to casing problems, and CPW-2 was installed as a replacement. The remaining wells were used as observation wells. A pre-existing well that was screened in the Basal Chadron Sandstone (RC-2) was also used as a monitoring location. To assess the hydrogeologic isolation of the Basal Chadron Sandstone aquifer during testing, CBR also installed monitor wells in the overlying Upper/Middle Chadron (MCOW-1 and MCOW-2) and Brule Formation (BOW-1) (**Figure H.2-8** of Chapter H). Because the Basal Chadron Sandstone is underlain by the thick and relatively impermeable Pierre Shale (as discussed in Sections E.3 and G.4), no underlying monitor wells were installed.

A longer pumping test was conducted in June and July 2006 (Test #6) which included installing new monitor wells in the Upper/Middle Chadron (MCOW-3 and MCOW-4) and Brule Formation (BOW-2), and use of automated equipment. The pumping test was conducted in accordance with a Test Plan submitted by CBR to the NDEQ in June 2006. Well information for wells used during the 2006 pumping test is summarized in **Table G.3-2**. Locations of wells used during the 2006 pumping test are illustrated on **Figure H.2-8** of Chapter H.

The 2006 pumping test was designed to assess the following:

- degree of hydrologic communication between the Basal Chadron Sandstone pumping well and the surrounding Basal Chadron Sandstone monitor wells
- presence or absence of hydrologic boundaries within the Basal Chadron Sandstone aquifer over the test area
- hydrologic characteristic of the Basal Chadron Sandstone aquifer within the test area
- degree of hydrologic isolation between the Basal Chadron Sandstone aquifer and the overlying aquifers

The 2006 pumping test was conducted while pumping at COW-5 at 16.4 gpm for 357 hours (14.9 days). The radius of influence (ROI) was approximately 7,500 feet. More than 110 feet of drawdown was achieved during testing, and all wells monitored during the test indicated adequate drawdown (e.g., greater than 1.3 feet), confirming hydrologic communication with the Basal Chadron Sandstone aquifer.

Results of the 2006 pumping test indicate a mean hydraulic conductivity of 2.3 feet/day (8.1 x $10^{-4}$ centimeters per second [cm/sec]), a mean transmissivity of 60 square feet per day ($ft^2$/day; ranging from 42 to 75 $ft^2$/day), and a mean permeability of approximately 1,100 millidarcies (md) based on an assumed water viscosity of 1.35 centipoise (cP) (at 50 degrees Fahrenheit) and a density of 1 (**Table G.3-1**). The mean storativity was 5.3 x $10^{-5}$ (ranging from 2.3 x $10^{-5}$ to 8.4 x $10^{-5}$) (**Table G.3-1**). Estimated hydraulic parameters for individual well locations for the 2006 pumping test are summarized in **Table G.3-3**. No water level changes of concern were observed in any of the overlying wells during testing. The pumping test results demonstrate the following important conclusions:

- The Test #6 monitor well network is in hydraulic communication with the Basal Chadron Sandstone aquifer throughout the NTEA.
- Hydrogeologic conditions of the Basal Chadron Sandstone aquifer have been adequately characterized within the test area.
- There is adequate confinement between the Basal Chadron Sandstone aquifer and the overlying Upper/Middle Chadron and Brule Formation throughout the majority of the NTEA.
- Transmissivity of the Basal Chadron Sandstone in the NTEA is relatively consistent, but the thickness and hydraulic conductivity vary with direction and location.

These conclusions indicate that, though variance in thickness and hydraulic conductivity may impact mining operations (e.g., well spacing, completion interval, and injection/production rates), it is not anticipated to impact regulatory issues. It should be noted that cross-sections presented in the North Trend Hydrologic Testing Report - Test #6 (Petrotek 2006) differ from cross-sections presented in this application, which are revised interpretations based on a recent extensive review of available site-specific drilling logs and published literature.

The raw data from Test #6 was investigated for apparent boundary conditions as a result of structural folding of the Basal Chadron Sandstone. Extraction pumping at COW-5 produced drawdown in observation wells COW-2 and RC-2, which were used in this analysis due to their proximity to the fold structure. The data was imported into AQTESOLV and analyzed using the Theis solution to radial groundwater flow in a confined aquifer. Estimates of transmissivity and storage were similar and generally agreed with those provided by Petrotek (Petrotek, 2006).

A no-flow groundwater boundary was simulated in AQTESOLV at a distance of 7,000 feet from COW-5. This distance corresponds to the midpoint of the north-dipping fold limb south of the NTEA, which is approximately 1,000 feet south of RC-2. Simulated boundary conditions predict that increased drawdown should have been observed at RC-2. The simulated boundary condition was moved to a distance of 7,500 feet and similar results were observed. Though the 7,500 foot radius of influence (ROI) for Test #6 was adequate to recognize a hydraulic boundary between the top anticlinal axis of the fold structure and the pumping well, increased drawdown was not observed at RC-2 during Test #6. Therefore, a hydraulic boundary likely does not exist within the fold structure.

## G.4 Hydrologic Conceptual Model for the North Trend Expansion Area

**Tables E.1-1** and **E.1-2** of Chapter E present the regional and local stratigraphic columns within the NTEA. The water-bearing units within the stratigraphic section present at the NTEA include the Basal Chadron Sandstone, Upper/ Middle Chadron, permeable intervals in the Orella Member of the Brule Formation, and (rarely) alluvial deposits. Sections G.4.1, G.4.2, and G.4.3 describe the confining layers present at the NTEA, hydrologic conditions for the water-bearing intervals, and hydrological affects of tectonic folding.

### G.4.1 Confining Layers

Lower confinement for the Basal Chadron Sandstone is represented by approximately 1,200 to 1,500 feet of Pierre Shale in the NTEA, which hydraulically isolates the unit from underlying sandstone intervals. The Pierre Shale is not a water-bearing unit, exhibits very low permeability, and is considered a regional aquiclude. Regional estimates of hydraulic conductivity for the Pierre Shale range from $10^{-7}$ to $10^{-12}$ cm/sec (Neuzil and Bredehoeft 1980; Neuzil et al. 1984; Neuzil 1993). The Pierre Shale has a measured vertical hydraulic conductivity in the CSA of less than $1 \times 10^{-10}$ cm/sec (Wyoming Fuel Company 1983), which is consistent with other studies in the region. Particle grain size analysis of a sample collected from the Pierre Shale within the NTEA (borehole 775) indicates a silty clay composition (**Appendix 3**). Regional studies also indicate that there is no observed transmissivity between vertical fractures in the Pierre Shale, which appear to be short and not interconnected (Neuzil et al. 1984).

Upper confinement for the Basal Chadron Sandstone within the NTEA is represented by 200 to 300 feet of smectite-rich mudstones and claystones of the Middle Chadron (Figures F.2-3a through F.2-3d). Particle grain-size analyses of six samples collected from the Middle Chadron in the NTEA indicate that all samples were either silty claystone or clayey siltstone, with an even mixture of silt- and clay-sized particles (**Appendix 3**). X-ray diffraction and particle grain-size analyses indicate the compositions and particle size distributions of mudstone and claystone intervals of the Middle Chadron are highly similar to the Pierre Shale (**Appendix 3**). This would be expected if the Pierre Shale was a source of materials for the overlying Middle Chadron. Geophysical logs generally indicate a lack of formation water for the Middle Chadron (**Appendix 4**). All available data indicate an upward hydraulic gradient between the Basal Chadron Sandstone and the Upper/ Middle Chadron, with an average hydraulic head difference of approximately 90 feet between the two units. Coupled with no observed drawdown in the Upper/Middle Chadron related to pumping in the Basal Chadron Sandstone aquifer during the 2006 pumping test (see Section G.3), the magnitude of hydraulic head difference between Basal Chadron Sandstone and the Upper/Middle Chadron further indicates adequate hydraulic confinement and, therefore, hydraulic isolation between the two water-bearing units.

The Upper Chadron represents a second upper confining layer for both the Upper/Middle Chadron and the Basal Chadron Sandstone. This second upper confining layer represents 100 to 250 feet of laterally continuous bentonitic clay. Though minor interbedded tabular and lenticular sandstones occur in the Upper Chadron, the sandstones are thinly bedded, not laterally continuous, and are highly localized (Terry and LaGarry 1998). All available data indicate an upward hydraulic gradient between the Basal Chadron Sandstone and the Brule Formation, with an average hydraulic head difference of approximately 80 feet between the two units. Similar to

the Upper/Middle Chadron, no drawdown was observed in the Brule Formation related to pumping in the Basal Chadron Sandstone aquifer during the 2006 pumping test (see Section G.3). In addition, the large magnitude of hydraulic head difference between the Basal Chadron Sandstone and the Brule Formation, coupled with the observation that Brule Formation wells are often dry, further indicate adequate hydraulic confinement between the two water-bearing units. Though the Orella Member of the Brule Formation is composed of predominantly low-permeability clayey siltstones, discontinuous lenses of permeable facies (sandstone and siltstone units) create the possibility of permeability pathways in the Brule Formation. In addition, the primary groundwater supply in the vicinity of the NTEA is a sandy clay in the Brule Formation. Therefore, the upper confining unit represented by the Upper Chadron probably does not extend much above the contact between the Upper Chadron and overlying Brule Formation.

### G.4.2 Hydrologic Conditions

The Basal Chadron Sandstone outcrops approximately 10 miles north of the NTEA, where recharge occurs. A travel time of approximately 1,035 years was estimated between the recharge zone and the northernmost monitor well in the NTEA (COW-6) based on an average hydraulic gradient (0.00304 ft/ft) and gradient direction (N70°W) for the northern portion of the NTEA, estimated travel distance (10 miles), mean hydraulic conductivity from the 2006 pumping test (2.3 ft/day) and estimate of effective porosity (0.05) for a coarse-grained arkosic sandstone. A potentiometric map and cross-sections of the Basal Chadron Sandstone indicate confined groundwater flow (**Figures F.2-3a** through **F.2-3d** of Chapter F and **H.2-5** of Chapter H). Most wells screened in the Basal Chadron Sandstone in the NTEA flow as artesian wells at the surface. Elevations of the potentiometric surface within the NTEA indicate the recharge zone must be located above a minimum elevation of 3,720 feet amsl. Artesian conditions exist in the NTEA as a result of an elevated recharge zone north of the NTEA. The top of the Basal Chadron Sandstone occurs at much lower elevations within the NTEA (ranging from approximately 3,100 to 3,400 feet amsl), which is likely a flexural response to development of the fold to the south.

Groundwater flow in the Basal Chadron Sandstone aquifer is predominantly to the southeast within the NTEA, with an average hydraulic gradient of 0.0018 ft/ft (9.5 feet/mile). Groundwater flow south of the NTEA is predominantly to the southeast, with an average steepened hydraulic gradient of 0.0058 ft/ft (30.6 feet/mile), coincident with the north-dipping fold limb. The elevation of the Basal Chadron Sandstone within the NTEA is typically more than 500 feet below the base of the White River, with the exception of shallower locations within the fold structure and at the northern end of the NTEA (**Figures F.2-3a**, **F.2-3b** and **F.2-3d** of Chapter F).

Regional water level data for the Basal Chadron Sandstone are limited (**Figure H.2-6** of Chapter H). Based on the limited data available, the hydraulic gradient in the NTEA (to the east) is different from the hydraulic gradient in the CSA (generally to the north) (**Figures H.2-6** and **H.2-5** of Chapter H). Together, groundwater flow directions from the NTEA and CSA suggest a discharge point at an elevation of at least approximately 3,700 feet amsl (or below) located east of Crawford, presumably at a location where the Basal Chadron Sandstone is exposed. Additional investigations to be conducted during development of mining activities in the NTEA will provide additional information regarding the impact of the fold structure on regional and local flow in the Basal Chadron Sandstone.

The Upper/Middle Chadron is generally present within the NTEA, though it occurs intermittently in the northern portion of the NTEA and is completely absent in the vicinity of the fold structure south of the NTEA (**Figures F.2-3a** through F.**2-3d**, and F.**3-3b** of Chapter F). The resistivity curve for the Upper/Middle Chadron suggests this is a transmissive unit. The N-N curve generally reads lower cps, indicating that the unit is more saturated with higher porosity than overlying and underlying materials. Where present, available water level information from the 2006 pumping test (3,605 to 3,609 feet AMSL) indicates confined conditions. This also suggests that the Upper/Middle Chadron is hydraulically connected to a recharge zone that occurs at least vertically 200 feet higher than the elevation of the unit within the NTEA, presumably located to north. Results from the 2006 pumping test verify that this unit is not hydraulically connected to the Basal Chadron Sandstone. However, because wells screened in the Upper/Middle Chadron (MCOW-1, MCOW-2, MCOW-03, and MCOW-4) are generally dry, this unit is not considered a regional aquifer, at least not at the locations of the monitor wells (**Figure H.2-1** of Chapter H). It is possible that the Upper/Middle Chadron may produce recoverable water at other locations.

Available regional water level information for the Brule Formation indicates unconfined groundwater flow generally toward the White River (**Figures H.2-4** and **H.2-3** of Chapter H). Within the NTEA, groundwater generally flows to the southeast in the northern portion of the NTEA and to the northeast in the southern portion of the NTEA. Though the Brule Formation is the primary groundwater supply in the vicinity of the NTEA, low production rates indicate that the discontinuous sandstone lenses of the Orella Member may not be hydraulically well-connected. Recharge to this unit likely occurs directly within the NTEA, as the unit is unconformably overlain by 0 to 60 feet of unconsolidated alluvial and colluvial deposits (depending on local topography) and is exposed throughout the vicinity (Beins, W. 2008). This unit is likely in direct hydraulic communication with the White River, as indicated by apparent recharge to the Brule Formation in the vicinity of the White River (**Figures H.2-4** and **H.2-3** of Chapter H). In that context, gaining and losing conditions along the White River are probably seasonally influenced. A sufficient number of monitor wells will be installed in the Brule Formation in the vicinity of the White River to monitor water quality in the event of failure of an injection well or production well, and to prevent potential communication of mining fluids with surface water (see Section G.5 for a more detailed discussion). Alluvial deposits along the margins of the White River may offer limited groundwater storage depending on river levels.

The individual water-bearing units in the NTEA have distinct and differing water level elevations (**Table G.2-2**). The available water level data suggest hydrologic isolation of the Basal Chadron Sandstone with respect to the overlying water-bearing intervals in the NTEA. This inference is further supported by the difference in geochemical groundwater characteristics between the Basal Chadron Sandstone and the Brule Formation (see Section G.2.2) (**Table G.2-6**). At this time, data are currently unavailable for a comparison of water quality for the Basal Chadron Sandstone between the recharge area and the NTEA.

In summary, the following multiple lines of evidence indicate adequate hydrologic confinement of the Basal Chadron Sandstone within the NTEA:

- Results of the 2006 aquifer pumping test demonstrate no observed drawdown in observation wells screened in overlying water-bearing units throughout the majority of the NTEA (see Section G.3).
- Site-specific x-ray diffraction, particle grain-size distribution analyses, and geophysical logging confirm the presence of two upper confining units, each consisting of thick sequences (up to 250 and 300 feet) of low-permeability mudstone and claystone, and a thick (up to 1,500 feet), regionally extensive lower confining unit composed of very low-permeability black marine shale (see Section G.4.1).
- Large differences in hydraulic head (80 to 90 feet) were observed between the Basal Chadron Sandstone and two overlying water-bearing units (see Section G.4.1).
- Significant historical differences exist in geochemical groundwater characteristics between the Basal Chadron Sandstone and the Brule Formation (Section G.2.2).

### G.4.3 Hydrological Affects of Folding

The overall hydraulic gradient direction in the Basal Chadron Sandstone aquifer is generally to the southeast (**Figure H.2-5** of Chapter H). Steep folding of the Basal Chadron Sandstone associated with development of the fold structure immediately south of the NTEA boundary does not appear to effect the overall hydraulic gradient direction. However, there is a noticeable increase in hydraulic gradient south and east of well location COW-2, where the gradient is nearly three times steeper than the hydraulic gradient in the NTEA (**Figure H.2-5** of Chapter H). Several explanations for the increased hydraulic gradient are presented below:

- Based on the occurrence of increased hydraulic gradient coincident with the location of the fold structure and hydraulic head isolines that parallel the strike of the fold axis, it is feasible that development of the fold structure (e.g., jointing, fracturing, compression of the aquifer matrix) as a result of compressional stresses (i.e., reverse faulting) caused a change in pore connectivity, with a bulk decrease in permeability of the Basal Chadron Sandstone. Based on this observed change in gradient, transmissivity appears to be reduced by as much as 50 percent or more in the vicinity of the fold. The occurrence of hydraulic head iso lines that parallel the strike of the fold further support a reduction in transmissivity as a result of compressional folding, as one would expect a reduction in transmissivity to occur along the entire length of the fold.
- Flexural thinning of stratigraphic units located along the length of the fold limb resulted in reduced transmissivity in the Basal Chadron Sandstone aquifer. Though a reduction in hydraulic conductivity may have occurred, only flexural thinning is necessary to reduce transmissivity.
- Potential localized and distributed faulting within the Basal Chadron Sandstone may explain the observed increase in hydraulic gradient. However, hydraulic confinement demonstrated by the 2006 aquifer pump test within the NTEA indicates that even if distributed faulting were present, it currently does not significantly impact hydraulic confinement of the Basal Chadron Sandstone.Heterogeneity may exist within the Basal Chadron Sandstone, which reduces the transmissivity south of the NTEA.

- Any spatial variation in leakage through the upper confining layers could contribute to the observed gradient change. However, the rate of leakage required to produce the observed change in gradient would be minimal.
- Regional influence from pumping (e.g., ISL mining activities at the CSA to the south) may be affecting the observed gradient.
- Any combination of scenarios listed above.

Yecheili et al. (2007) concluded that steep hydraulic gradients associated with pressure-induced permeability reductions were due to compressional stresses on the steep limbs of the Ramallah and Hebron monoclines in a layered structure in the Judea Group Aquifer system in Israel. Their study is analogous to the effects of tectonic folding on the hydrologic conditions within the Basal Chadron Sandstone. However, without a quantitative basis or additional data with which to further evaluate these possible explanations, development of a comprehensive groundwater model with an integrated systems analysis could be used to choose the best quantitative solution, as well as optimize ISL mining scenarios from a cost perspective.

Based solely on the 2006 pumping test results, the existence of a discrete fault surface that cuts upsection into the White River Group (and the Basal Chadron Sandstone aquifer) cannot be ruled out. However, numerous lines of evidence (listed below) support the inference that the White River Fault does not offset the geologic contact between the Pierre Shale and Basal Chadron nor members of the Chadron Formation and, therefore, does not affect the hydraulic confinement of the Basal Chadron Sandstone aquifer:

- There is a lack of obvious linear features on the top surface of the Pierre Shale and Basal Chadron Sandstone that are typically associated with discrete fault displacement, which would indicate a fault rupture (**Figures F.3-3a** through **F.3-3d** of Chapter F).
- Based on geophysical logging, there is adequate spatial resolution of continuous geophysical signatures across the steep fold limb for two important marker beds (Pierre Shale and Basal Chadron Sandstone) that indicate the geologic beds are not offset due to faulting (**Figure F.3-3a** of Chapter F, lower right panel; **Figure F.3-3d** of Chapter F; **Appendix 4**).
- If a permeable fault boundary did exist south of the NTEA, one would expect to observe more dramatically decreased water levels near the fold structure (see **Figures F.2-3a, F.2-3b,** and **F.2-3d** of Chapter F). Significantly decreased water levels have not been observed, thereby indicating that the hydrologic effects of the fold structure are limited to reduced transmissivity within the Basal Chadron Sandstone aquifer).

Deposition of the Brule Formation likely post-dated most, if not all, deformation associated with the White River fold structure (see Section E.4.2). Though the Brule Formation may have experienced a very low magnitude of broad, concentric folding, tensile fracture development requires only very low strains (**Figure F.3-3**). A distinctive and pervasive tensile fracture set associated with even subtle fold development is possible. Such fractures could be due to continued deeper fault movement and shallower bending stresses or due to differential compaction, subsidence and diagenesis across a buried fault-fold structure. However, self-sealing (fracture annealing) due to wall-rock swelling clays should be expected. Additionally, an older

years after a well begins operation. In addition, all wells that have had rig work completed with the drill string entering the well casing, will be tested for mechanical integrity before being returned to service. Water quality sampling is conducted bi-weekly at all monitoring well locations, which would indicate an excursion (i.e., presence of mining solutions). Contingency plans in the event of well failure are also discussed in Chapter O, which may either include identifying and patching the leaking well casing or abandoning the well if the leak cannot be repaired. In addition, drilling under artesian conditions requires specific procedures to avoid leakage of production zone water to the surface, such as the use of drilling fluids of varying viscosity and weight, as well as bentonite-lined drilling pits where drilling fluids and formation water are contained and extracted for transport to evaporation ponds.

Planned procedures for monitoring the capture of injected mining solutions are discussed in Chapter M and Chapter Q. These procedures include routine water level measurements in the production zone and overlying water-bearing zones and water quality sampling at monitor wells every 2 weeks. Any changes in water levels or water quality within the production zone will be evaluated after sample collection to ensure that the system is operating properly and successfully. The proposed procedures will also allow for flow rate adjustments to ensure capture of mining fluids. An increase in pumping rates by land owners at water supply wells that are screened in the Basal Chadron Sandstone within the 2.25-mile AOR (i.e., Well 98, Well 5069 and Well 61) will not affect control of the migration of mining fluids. These 3 private wells have estimated pumping rates of 10 to 12 gallons per minute (gpm) and are located at distances between 6,500 and 9,500 feet downgradient from the NTEA permit boundary. The region of influence associated with these private wells at the estimated flow rates, coupled with the average thickness of the production zone within the NTEA, indicate that the effect of pumping at the private wells will be negligible. Conversely, In-situ Leach (ISL) mining at NTEA will be a closed system resulting from the over-production (or bleed) rates. Within the wellfield and its vicinity, there will be local changes in head and flow direction. However, beyond the NTEA permit boundary, the magnitude of regional groundwater flow will not be meaningfully affected and will resume to regional flow conditions within a few hundred feet outside the permit boundary. The procedures proposed in Chapter M and Chapter Q are considered an adequate trigger for hydraulic adjustments to the production system in response to increases in pumping by private wells screened in Basal Chadron Sandstone. The Basal Chadron Sandstone hydrological properties must be known to formulate the best injection/ extraction well arrays and for appropriate containment. Based on the pumping rate, test duration, and formation characteristics, the ROI (i.e., the area over which drawdown occurs) can also be determined for a given test. **Table G.3-1** presents relevant hydrologic information based on an aquifer test performed in the NTEA during 2006, compared with the same properties in the CSA. These data indicate that mean transmissivity and hydraulic conductivity of the NTEA are lower than the CSA, yet high enough such that successful development of the NTEA can be accomplished.

Potential impacts to groundwater resources from mining and restoration activities are discussed in Chapter I, Section I.5.2.5.

## G.6 Water Use Information

Water use is discussed in Chapter I, Section I.1.3.

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**Table G.1-1 Comparison of Mean Monthly Precipitation With Normal Mean Monthly Discharge of the White River at Crawford, Nebraska**

| Month | Mean Precipitation [1] | | Mean Discharge [2] | |
|---|---|---|---|---|
| | inches | centimeters | $Ft^3$/sec | $Meters^3$/sec |
| January | 0.61 | 1.55 | 21 | 0.59 |
| February | 0.76 | 1.93 | 23 | 0.65 |
| March | 1.74 | 4.42 | 27 | 0.76 |
| April | 2.65 | 6.73 | 25 | 0.71 |
| May | 3.11 | 7.9 | 27 | 0.76 |
| June | 2.42 | 6.15 | 22 | 0.62 |
| July | 2.77 | 7.04 | 16 | 0.45 |
| August | 1.21 | 3.07 | 13 | 0.37 |
| September | 1.38 | 3.51 | 14 | 0.4 |
| October | 1.66 | 4.22 | 17 | 0.48 |
| November | 0.82 | 2.08 | 19 | 0.54 |
| December | 0.79 | 2.01 | 20 | 0.57 |
| **Average** | **1.66** | **4.22** | **20.3** | **0.58** |

1 Climatology of the US No. 81, 1971-2000, NOAA, 25-Nebraska.
2 U.S. Department of the Interior, 1981, Period of Record 1931-2004.

**Table G.1-2 Normal Mean Monthly Discharge of the White River at Crawford, Nebraska, 1999 through 2006**

| Month | 1999 ($Ft^3$/sec) | 2000 ($Ft^3$/sec) | 2001 ($Ft^3$/sec) | 2002 ($Ft^3$/sec) | 2003 ($Ft^3$/sec) | 2004 ($Ft^3$/sec) | 2005 ($Ft^3$/sec) | 2006 ($Ft^3$/sec) |
|---|---|---|---|---|---|---|---|---|
| January | 22.6 | 21.7 | 21.0 | 22.9 | 22.6 | 23.0 | 23.9 | 24.1 |
| February | 22.4 | 24.1 | 24.3 | 23.6 | 24.0 | 24.8 | 23.3 | 24.5 |
| March | 23.1 | 25.5 | 27.0 | 26.8 | 26.4 | 25.9 | 24.5 | 26.4 |
| April | 26.1 | 29.1 | 26.4 | 25.3 | 26.5 | 22.7 | 25.3 | 25.9 |
| May | 23.7 | 10.0 | 24.7 | 23.9 | 25.9 | 21.1 | 26.5 | 23.2 |
| June | 27.1 | 20.5 | 18.6 | 16.6 | 23.2 | 17.1 | 26.5 | 17.8 |
| July | 21.4 | 15.4 | 14.4 | 10.3 | 13.2 | 17.4 | 17.6 | 11.0 |
| August | 15.0 | 11.5 | 12.5 | 10.1 | 11.7 | 11.3 | 18.1 | 10.0 |
| September | 17.0 | 12.1 | 12.9 | 13.7 | 23.3 | 17.8 | 14.8 | 14.8 |
| October | 19.4 | 17.4 | 17.2 | 18.1 | 17.5 | 20.8 | 18.5 | * |
| November | 20.8 | 20.1 | 22.0 | 22.3 | 22.6 | 21.3 | 21.0 | * |
| December | 21.4 | 20.7 | 22.2 | 22.2 | 23.1 | 22.1 | 23.1 | * |
| **Average** | **21.7** | **16.7** | **20.3** | **19.7** | **21.6** | **20.4** | **21.9** | **19.7** |

Source: Nebraska Department of Natural Resources (NDNR) 2008.
* Data not available for fourth quarter of 2006.

**Table G.1-3 Historic White River Water Quality Data, 1968 through 1994***

| PARAMETER | RESULTS | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 8/20/1968 | 5/6/1969 | 7/15/1969 | 5/24/1970 | 8/28/1970 | 8/5/1971 | 6/5/1972 | 10/2/1972 | 6/4/1973 | 9/23/1981 | 7/13/1994 |
| Number used in sample accounting procedure | 66 | 66 | 65 | 95 | 77 | 109 | no data | no data | no data | 1 | 1 |
| Temperature, water (degrees centigrade) | 21 | 18 | 28 | 18.5 | 21 | 19.5 | 22 | 12.5 | 17 | No data | 20 |
| Temperature, air (degrees centigrade) | 32 | 21 | 36 | 23 | 27 | 30 | 21 | 11.1 | 23 | No data | No data |
| Flow, stream, mean daily cfs | 10 | 22 | 10 | 22 | 21 | 12 | 19 | 12 | 24 | No data | No data |
| Turbidity, (jackson candle units) | 41 | 62 | 10 | 45 | 337 | 5 | 36 | 4 | 4 | No data | No data |
| Specific conductance (umhos/cm @ 25C) | 400 | 390 | 355 | 353 | 305 | 340 | 340 | 340 | 400 | 330 | 700 |
| Oxygen, dissolved mg/l | 7.4 | 8.5 | 6.9 | 7.8 | 7 | 8 | 8.1 | 9.6 | 7.9 | No data | 6.9 |
| Oxygen, dissolved, percent of saturation | 82.2321 | 89.4889 | 87.3453 | 82.106 | 77.7793 | 85.1096 | 92.0463 | 88.8907 | 81 .4491 | No data | 75 |
| pH (standard units) | 7.7 | 8.2 | 8.2 | 7.9 | 7 | 8.5 | 8.4 | 8.5 | 7.6 | no data | 8.3 |
| Alkalinity, total (mg/l as $CaCO_3$) | 208 | 108 | 180 | 184 | 168 | 176 | 192 | 200 | 189 | 188 | No data |
| Residue, total filtrable (dried at 105C),mg/l | 258 | 270 | 250 | 250 | 220 | 250 | 240 | 260 | No data | 288 | No data |
| Nitrite plus nitrate, total 1 det. (mg/l as N) | 0.1 | 0.1 | 1 | 0.1 | 0.6 | 0.1 | 0.2 | 0.1 | No data | No data | No data |
| Phosphate, total (mg/l as $PO_4$) | 0.8 | 0.1 | 0.5 | 0.2 | 0.3 | 0.1 | 0.2 | 0.1 | No data | No data | No data |
| Hardness, total (mg/l as $CaCO_3$) | 176 | 148 | 168 | 160 | 156 | 172 | 160 | 172 | 172 | No data | 159 |
| Calcium, dissolved (mg/l as Ca) | 39 | 35 | 51 | 50 | 52 | 46 | 51 | 56 | No data | No data | No data |
| Magnesium, dissolved (mg/l as Mg) | 10 | 1 | 10 | 9 | 6 | 14 | 8 | 8 | No data | No data | No data |
| Sodium, dissolved (mg/l as Na) | 36 | 24 | 43 | 24 | 22 | 16 | 15 | 15 | No data | No data | No data |
| Sodium adsorption ratio | 0.4 | 0.9 | 1.5 | 0.8 | 0.8 | 0.5 | 0.5 | 0.5 | No data | No data | No data |
| Potassium, dissolved (mg/l as K) | 6 | 8 | 13 | 8 | 9 | 9 | 10 | 9 | No data | No data | No data |
| Chloride,total in water mg/l | 12 | 18 | 4 | 1 | 2 | 4 | 1 | 2 | 7 | 5 | No data |
| Hardness, ca mg calculated (mg/l as $CaCO_3$) | 138.563 | 91.513 | 168.527 | 161.912 | 154.552 | 172.514 | 160.291 | 172.776 | No data | 174.528 | 159.437 |

* Data are summarized. See http://www.epa.gov/storet/updates.html, EPA's STORET database, for full data sets (USEPA 2008)

**Table G.1-4 Water Quality Data for the White River at Crawford [Station WH1WHITE208], 2003***

| PARAMETER | 1/13 | 02/01 | 03/03 | 04/08 | 05/06 | 06/03 | 07/09 | 08/04 | 09/09 | 10/06 | 11/03 | 12/01 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Flow, cfs | 22E | 24 | 25 | 28 | 25 | 23 | 15 | 12 | 18 | 17 | 24 | 23 |
| Temperature, °C | 0.81 | 6.42 | 5.08 | 9.32 | 13.34 | 18.33 | 21.5 | 12.2 | No data | 12.17 | 4.45 | 4.31 |
| pH, Std. Units | 8.11 | 7.95 | 8.19 | 8.48 | 8.22 | 8.30 | 8.25 | 8.05 | No data | 8.37 | 8.06 | 8.25 |
| Dissolved Oxygen, mg/l | 14.20 | 10.9 | 11.51 | 10.92 | 9.56 | 8.5 | 8.83 | 7.85 | No data | 10.44 | 10.71 | 10.48 |
| Turbidity, NTU | 0.9 | 7.5 | 4.9 | 4.8 | 23.6 | 20.7 | 11.9 | 12.2 | 2711 | 3.4 | 4.4 | 3.8 |
| Specific Conductance, umho/cm | 386 | 368 | 367 | 381 | 383 | 372 | 374 | 349 | No data | 375 | 375 | 379 |
| Solids, Fixed (Total), mg/l | No data | No data | No data | 30 | 48 | 49 | 22 | 14 | 2900 | No data | No data | No data |
| Nitrogen, Ammonia ($NH_3$) as $NH_3$, Total, mg/l | No data | No data | No data | 0.05 | 0.06 | 0.05 | 0.05 | 0.05 | 0.23 | No data | No data | No data |
| Nitrogen, Kjeldahl, Total, mg/l | No data | No data | No data | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 8.35 | No data | No data | No data |
| Nitrogen, Nitrite ($NO_2$) + Nitrate ($NO_3$) | No data | No data | No data | 0.38 | 0.35 | 0.28 | 0.18 | 0.20 | 0.61 | No data | No data | No data |
| Chloride, mg/l | No data | No data | No data | 3.59 | 3.67 | 3.61 | 3.04 | 3.65 | 4.68 | No data | No data | No data |
| Phosphorus as P, Total, mg/l | No data | No data | No data | 0.04 | 0.07 | 0.08 | 0.07 | 0.06 | 2.44 | No data | No data | No data |

* Water quality data are summarized. See http://www.epa.gov/storet/updates.html, USEPA' STORET database, for full data sets [Data source: Nebraska Department of Environmental Quality]. Flow data (NDNR 2008a).
E = Estimated flow

**Table G.1-5 Preoperational Water Quality Data for White River at Crow Butte Sample Points W-1, W-2 and W-3 (1982 – 1985)**

| Parameter | Minimum | Maximum | Mean | SD | Minimum | Maximum | Mean | SD | Minimum | Maximum | Mean | SD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mg/l unless noted | | | | | | | | | | | |
| | W-1[a] | | | | W-2[b] | | | | W-3[c] | | | |
| Calcium | 46 | 57 | 53 | 3.70 | 52 | 57 | 55 | 2.2 | 32.2 | 63 | 49 | 10.7 |
| Magnesium | 6.8 | 8.0 | 7.5 | 0.43 | 7.7 | 8.0 | 7.8 | 0.13 | 6.7 | 9.3 | 8.15 | 0.93 |
| Sodium | 12.7 | 15.9 | 14.2 | 0.89 | 16 | 20 | 17.8 | 1.7 | 24 | 109 | 64 | 35.9 |
| Potassium | 6.1 | 7.8 | 7.13 | 0.54 | 6.5 | 7.9 | 7.2 | 0.68 | 4.0 | 18 | 11.7 | 4.4 |
| Carbonate | <1.0 | <2.0 | 1.5 | 0.54 | <2.0 | <2.0 | 2.0 | 0 | <1.0 | 24 | 6.7 | 9.6 |
| Bicarbonate | 215 | 235 | 226 | 6.0 | 230 | 230 | 230 | 0 | 257 | 383 | 309 | 48.2 |
| Sulfate | <5.0 | 20 | 10.5 | 4.4 | <5.0 | 16.0 | 11.5 | 4.7 | 16 | 53 | 28.8 | 12.5 |
| Chloride | <2.0 | 4.7 | 3.4 | 0.79 | 4.0 | 6.0 | 5.0 | 1.2 | 5.6 | 18 | 12.6 | 4.8 |
| Ammonia – N | 0.05 | 0.05 | 0.05 | 0 | <0.05 | <0.05 | 0.05 | 0 | <0.05 | 0.26 | 0.113 | 0.08 |
| Nitrite – N | 0.001 | 0.02 | 9E-03 | 7E-03 | 0.01 | 0.01 | 0.01 | 0 | <0.001 | 0.01 | 6E-03 | 4E-03 |
| Nitrate – N | 0.24 | 0.78 | 0.49 | 0.18 | 0.4 | 0.62 | .50 | 0.114 | 0.08 | 0.8 | 0.424 | 0.25 |
| Fluoride | 0.3 | 0.6 | 0.50 | 0.10 | 0.4 | 0.6 | .48 | 0.10 | 0.4 | 0.9 | 0.69 | 0.17 |
| Silica (as $SiO_2$) | 51 | 59 | 54 | 2.4 | 52 | 56 | 54 | 1.63 | 45.8 | 55 | 51 | 3.6 |
| TDS – 180°C | 230 | 302 | 266 | 23.2 | 230 | 300 | 270 | 29.4 | 306 | 460 | 376 | 60 |
| Conductivity (umhos) | 329 | 400 | 366 | 22.0 | 377 | 420 | 401 | 19.4 | 470 | 709 | 565 | 97 |
| Alkalinity (as CaCo3) | 173 | 201 | 188 | 9.17 | 190 | 200 | 195 | 5.8 | 222 | 314 | 263 | 36 |
| pH (Standard Units) | 7.74 | 8.05 | 7.91 | 0.12 | 7.5 | 8.2 | 7.83 | 0.30 | 7.6 | 8.84 | 8.13 | -.363 |
| | | | | | | | | | | | | |
| | ug/l unless noted | | | | | | | | | | | |
| Aluminum | <100 | <100 | 100 | 0 | <100 | <100 | 100 | 0 | <100 | <100 | 100 | 0 |
| Arsenic | 2 | 2 | 2 | 0 | 2 | 2 | 2 | 0 | 11 | 11 | 11 | 0 |
| Barium | 100 | 100 | 100 | 0 | <100 | <100 | 100 | 0 | <100 | <100 | 100 | 0 |
| Boron | <500 | <500 | 500 | 0 | <5 | <500 | 500 | 0 | 10 | 10 | 10 | 0 |
| Cadmium | <1 | <1 | 1 | 0 | <1 | <1 | 1 | 0 | <1 | <1 | 1 | 0 |
| Chromium | <1 | <1 | 1 | 0 | <1 | <1 | 1 | 0 | <5 | <5 | 5 | 0 |
| Cobalt | <1 | <1 | 1 | 0 | <1 | <1 | 1 | 0 | - | - | - | - |
| Copper | <1 | <1 | 1 | 0 | <1 | <1 | 1 | 0 | <10 | <10 | 10 | 0 |

[a]Eleven (11) samples from February 1982 to October 1985
[b]Four (4) samples from February 1982 to October 1982
[c]Eight (8) samples from March 1983 to October 1985

**Table G.1-6 Radiological Surface Water Monitoring – White River**

| Location | Radionuclide | Date | Concentration µCi/ml x $10^{-9}$ | Error Estimate µCi/ml x $10^{-9}$ | LLD µCi/ml x $10^{-9}$ |
|---|---|---|---|---|---|
| **Third Quarter 2004** | | | | | |
| W-1 | U-Nat | 7/30/2004 | 3.6 | | 0.2 |
| | Th-230 | | <0.2 | | 0.2 |
| | Ra-226 | | <0.2 | | 0.2 |
| | Pb-210 | | <1.0 | | 1.0 |
| | Po-210 | | <1.0 | | 1.0 |
| W-2 | U-Nat | 7/30/2004 | 4.2 | | 0.2 |
| | Th-230 | | <0.2 | | 0.2 |
| | Ra-226 | | 1.0 | 0.7 | 0.2 |
| | Pb-210 | | <1.0 | | 1.0 |
| | Po-210 | | <1.0 | | 1.0 |
| **Fourth Quarter 2004** | | | | | |
| W-1 | U-Nat | 11/11/2004 | 4.0 | | 0.2 |
| | Th-230 | | <0.2 | | 0.2 |
| | Ra-226 | | <0.2 | | 0.2 |
| | Pb-210 | | <1.0 | | 1.0 |
| | Po-210 | | <1.0 | | 1.0 |
| W-2 | U-Nat | 11/11/2004 | 4.3 | | 0.2 |
| | Th-230 | | <0.2 | | 0.2 |
| | Ra-226 | | <0.2 | | 0.2 |
| | Pb-210 | | <1.0 | | 1.0 |
| | Po-210 | | <1.0 | | 1.0 |
| **First Quarter 2005** | | | | | |
| W-1 | U-Nat | 3/4/2005 | 5.0 | | 0.2 |
| | Ra-226 | | <0.2 | | 0.2 |
| W-2 | U-Nat | 3/4/2005 | 5.0 | | 0.2 |
| | Ra-226 | | <0.2 | | 0.2 |
| **Second Quarter 2005** | | | | | |
| W-1 | U-Nat | 5/27/2005 | 4.5 | | 0.2 |
| | Th-230 | | <0.2 | | 0.2 |
| | Ra-226 | | <0.2 | | 0.2 |
| | Pb-210 | | <1.0 | | 1.0 |
| | Po-210 | | <1.0 | | 1.0 |
| W-2 | U-Nat | 5/27/2005 | 4.7 | | 0.2 |
| | Th-230 | | <0.2 | | 0.2 |
| | Ra-226 | | <0.2 | | 0.2 |
| | Pb-210 | | <1.0 | | 1.0 |
| | Po-210 | | <1.0 | | 1.0 |
| **Third Quarter 2005** | | | | | |
| W-1 | U-Nat | 9/16/2005 | 4.6 | | 0.2 |
| | Ra-226 | | <0.2 | | 0.2 |
| W-2 | U-Nat | 9/16/2005 | 4.9 | | 0.2 |
| | Ra-226 | | <0.2 | | 0.2 |

Note: Due to an error on the chain of custody, the groundwater samples for the first quarter 2005 were not analyzed for thorium-230, lead-210, and polonium-210.
µCi/ml = microCuries per milliliter
LLD = Lowest Level of Detection

**Table G.1-7 Water Quality Summary - Quarterly Monitoring In Brule Formation And Basal Chadron Sandstone (1996-1997 And 2004-2005)**

| Location | Radionuclide | Date | Concentration pCi/L | Error Estimate pCi/L | LLD pCi/L |
|---|---|---|---|---|---|
| **Third Quarter 1996** | | | | | |
| *Basal Chadron Sandstone* | | | | | |
| W-81 | U-Nat | 9/5/1996 | 8.8 | | 0.2 |
| | Th-230 | | 10.8 | 1 | 0.2 |
| | Ra-226 | | <0.2 | | 0.2 |
| | Pb-210 | | <1.0 | | 1 |
| | Po-210 | | <1.0 | | 1 |
| *Brule Formation* | | | | | |
| W-77 | U-Nat | 9/9/1996 | 31.1 | | 0.2 |
| | Th-230 | | <0.2 | | 0.2 |
| | Ra-226 | | <0.2 | | 0.2 |
| | Pb-210 | | <1.0 | | 1 |
| | Po-210 | | <1.0 | | 1 |
| W-78 | U-Nat | 9/5/1996 | 16.2 | | 0.2 |
| | Th-230 | | <0.2 | | 0.2 |
| | Ra-226 | | <0.2 | | 0.2 |
| | Pb-210 | | 13.5 | 1.2 | 1 |
| | Po-210 | | <1.0 | | 1 |
| W-83 | U-Nat | 9/9/1996 | 19.5 | | 0.2 |
| | Th-230 | | <0.2 | | 0.2 |
| | Ra-226 | | <0.2 | | 0.2 |
| | Pb-210 | | <1.0 | | 1 |
| | Po-210 | | <1.0 | | 1 |
| W-107 | U-Nat | 9/9/1996 | 10.8 | | 0.2 |
| | Th-230 | | <0.2 | | 0.2 |
| | Ra-226 | | <0.2 | | 0.2 |
| | Pb-210 | | <1.0 | | 1 |
| | Po-210 | | <1.0 | | 1 |
| **Fourth Quarter 1996** | | | | | |
| *Basal Chadron Sandstone* | | | | | |
| W-81 | U-Nat | 12/10/1996 | <0.2 | | 0.2 |
| | Th-230 | | <0.2 | | 0.2 |
| | Ra-226 | | 13.5 | 1.1 | 0.2 |
| | Pb-210 | | 12.9 | 4.5 | 1 |
| | Po-210 | | 3.3 | 0.7 | 1 |
| *Brule Formation* | | | | | |
| W-77 | U-Nat | 12/10/1996 | 15.6 | | 0.2 |
| | Th-230 | | <0.2 | | 0.2 |
| | Ra-226 | | <0.2 | | 0.2 |
| | Pb-210 | | <1.0 | | 1 |
| | Po-210 | | <1.0 | | 1 |
| W-78 | U-Nat | 12/10/1996 | 7.45 | | 0.2 |
| | Th-230 | | <0.2 | | 0.2 |
| | Ra-226 | | 0.4 | 0.2 | 0.2 |
| | Pb-210 | | <1.0 | | 1 |
| | Po-210 | | 1.4 | 0.4 | 1 |

**Table G.1-7 Water Quality Summary - Quarterly Monitoring In Brule Formation And Basal Chadron Sandstone (1996-1997 And 2004-2005)**

| Location | Radionuclide | Date | Concentration pCi/L | Error Estimate pCi/L | LLD pCi/L |
|---|---|---|---|---|---|
| W-83 | U-Nat | 12/10/1996 | 10.8 | | 0.2 |
| | Th-230 | | <0.2 | | 0.2 |
| | Ra-226 | | 0.4 | 0.2 | 0.2 |
| | Pb-210 | | 2.5 | 1.2 | 1 |
| | Po-210 | | <1.0 | | 1 |
| W-107 | U-Nat | 12/10/1996 | 8.12 | | 0.2 |
| | Th-230 | | <0.2 | | 0.2 |
| | Ra-226 | | <0.2 | | 0.2 |
| | Pb-210 | | <1.0 | | 1 |
| | Po-210 | | <1.0 | | 1 |
| **First Quarter 1997** | | | | | |
| | *Basal Chadron Sandstone* | | | | |
| W-81 | U-Nat | 3/11/1997 | <0.2 | | 0.2 |
| | Th-230 | | <0.2 | | 0.2 |
| | Ra-226 | | 10.9 | 1 | 0.2 |
| | Pb-210 | | 4.9 | 0.6 | 1 |
| | Po-210 | | <1.0 | | 1 |
| | *Brule Formation* | | | | |
| W-77 | U-Nat | 3/11/1997 | 18.3 | | 0.2 |
| | Th-230 | | 1.2 | 0.6 | 0.2 |
| | Ra-226 | | <0.2 | | 0.2 |
| | Pb-210 | | <1.0 | | 1 |
| | Po-210 | | <1.0 | | 1 |
| W-78 | U-Nat | 3/11/1997 | 10.2 | | 0.2 |
| | Th-230 | | <0.2 | | 0.2 |
| | Ra-226 | | <0.2 | | 0.2 |
| | Pb-210 | | <1.0 | | 1 |
| | Po-210 | | <1.0 | | 1 |
| W-83 | U-Nat | 3/11/1997 | 14.9 | | 0.2 |
| | Th-230 | | 1 | 0.5 | 0.2 |
| | Ra-226 | | <0.2 | | 0.2 |
| | Pb-210 | | <1.0 | | 1 |
| | Po-210 | | <1.0 | | 1 |
| W-107 | U-Nat | 3/12/1997 | 6.09 | | 0.2 |
| | Th-230 | | <0.2 | | 0.2 |
| | Ra-226 | | 0.5 | 0.1 | 0.2 |
| | Pb-210 | | <1.0 | | 1 |
| | Po-210 | | <1.0 | | 1 |
| **Second Quarter 1997** | | | | | |
| | *Basal Chadron Sandstone* | | | | |
| W-81 | U-Nat | 6/16/1997 | <0.2 | | 0.2 |
| | Th-230 | | <0.2 | | 0.2 |
| | Ra-226 | | 12.7 | 1.1 | 0.2 |
| | Pb-210 | | <1.0 | 1.2 | 1.2 |
| | Po-210 | | 12.4 | 1.2 | 1 |
| | *Brule Formation* | | | | |

**Table G.1-7 Water Quality Summary - Quarterly Monitoring In Brule Formation And Basal Chadron Sandstone (1996-1997 And 2004-2005)**

| Location | Radionuclide | Date | Concentration pCi/L | Error Estimate pCi/L | LLD pCi/L |
|---|---|---|---|---|---|
| W-77 | U-Nat | 6/16/1997 | 17.9 | | 0.2 |
| | Th-230 | | <0.2 | | 0.2 |
| | Ra-226 | | <0.2 | | 0.2 |
| | Pb-210 | | <1.0 | | 1 |
| | Po-210 | | 1.7 | 0.1 | 1 |
| W-78 | U-Nat | 6/16/1997 | 10.7 | | 0.2 |
| | Th-230 | | <0.2 | | 0.2 |
| | Ra-226 | | <0.2 | | 0.2 |
| | Pb-210 | | <1.0 | | 1 |
| | Po-210 | | 2 | 0.1 | 1 |
| W-83 | U-Nat | 6/16/1997 | 15.5 | | 0.2 |
| | Th-230 | | <0.2 | | 0.2 |
| | Ra-226 | | 1.3 | 0.2 | 0.2 |
| | Pb-210 | | <1.0 | | 1 |
| | Po-210 | | 5.2 | 0.2 | 1 |
| W-107 | U-Nat | 6/16/1997 | 8.9 | | 0.2 |
| | Th-230 | | <0.2 | | 0.2 |
| | Ra-226 | | <0.2 | | 0.2 |
| | Pb-210 | | <1.0 | | 1 |
| | Po-210 | | 8.6 | 0.3 | 1 |
| **Third Quarter 2004** | | | | | |
| | *Basal Chadron Sandstone* | | | | |
| W-81 | U-Nat | 7/30/2004 | 0.7 | | 0.2 |
| | Th-230 | | <0.2 | | 0.2 |
| | Ra-226 | | 10.6 | 1.7 | 0.2 |
| | Pb-210 | | <1.0 | | 1 |
| | Po-210 | | <2.7 | | 2.7 |
| | *Brule Formation* | | | | |
| W-77 | U-Nat | 7/30/2004 | 15 | | 0.2 |
| | Th-230 | | <0.2 | | 0.2 |
| | Ra-226 | | <0.2 | | 0.2 |
| | Pb-210 | | <1.0 | | 1 |
| | Po-210 | | <2.7 | | 2.7 |
| W-78 | U-Nat | 7/30/2004 | 9.6 | | 0.2 |
| | Th-230 | | <0.2 | | 0.2 |
| | Ra-226 | | <0.2 | | 0.2 |
| | Pb-210 | | 1.4 | 0.8 | 1 |
| | Po-210 | | <2.7 | | 2.7 |
| W-83 | U-Nat | 7/30/2004 | 16 | | 0.2 |
| | Th-230 | | <0.2 | | 0.2 |
| | Ra-226 | | 0.8 | 0.7 | 0.2 |
| | Pb-210 | | <1.0 | | 1 |
| | Po-210 | | <2.7 | | 2.7 |
| W-107 | U-Nat | 7/30/2004 | 8 | | 0.2 |
| | Th-230 | | <0.2 | | 0.2 |
| | Ra-226 | | <0.2 | | 0.2 |

**Table G.1-7 Water Quality Summary - Quarterly Monitoring In Brule Formation And Basal Chadron Sandstone (1996-1997 And 2004-2005)**

| Location | Radionuclide | Date | Concentration pCi/L | Error Estimate pCi/L | LLD pCi/L |
|---|---|---|---|---|---|
| | Pb-210 | | <1.0 | | 1 |
| | Po-210 | | <2.7 | | 2.7 |
| **Fourth Quarter 2004** | | | | | |
| *Basal Chadron Sandstone* | | | | | |
| W-81 | U-Nat | 11/17/2004 | 0.77 | | 0.2 |
| | Th-230 | | <0.2 | | 0.2 |
| | Ra-226 | | 11.4 | 1.2 | 0.2 |
| | Pb-210 | | <1.0 | | 1 |
| | Po-210 | | <1.0 | | 1 |
| *Brule Formation* | | | | | |
| W-77 | U-Nat | 11/17/2004 | 16 | | 0.2 |
| | Th-230 | | <0.2 | | 0.2 |
| | Ra-226 | | <0.2 | | 0.2 |
| | Pb-210 | | <1.0 | | 1 |
| | Po-210 | | <1.0 | | 1 |
| W-78 | U-Nat | 11/11/2004 | 9.3 | | 0.2 |
| | Th-230 | | <0.2 | | 0.2 |
| | Ra-226 | | <0.2 | | 0.2 |
| | Pb-210 | | <1.0 | | 1 |
| | Po-210 | | <1.0 | | 1 |
| W-83 | U-Nat | 11/17/2004 | 16 | | 0.2 |
| | Th-230 | | <0.2 | | 0.2 |
| | Ra-226 | | <0.2 | | 0.2 |
| | Pb-210 | | <1.0 | | 1 |
| | Po-210 | | <1.0 | | 1 |
| W-107 | U-Nat | 11/19/2004 | 8 | | 0.2 |
| | Th-230 | | <0.2 | | 0.2 |
| | Ra-226 | | 0.7 | 0.4 | 0.2 |
| | Pb-210 | | <1.0 | | 1 |
| | Po-210 | | <1.0 | | 1 |
| **First Quarter 2005** | | | | | |
| *Basal Chadron Sandstone* | | | | | |
| W-81 | U-Nat | 3/5/2005 | 0.7 | | 0.2 |
| | Ra-226 | | 11 | 1.2 | 0.2 |
| *Brule Formation* | | | | | |
| W-77 | U-Nat | 3/4/2005 | 20 | | 0.2 |
| | Ra-226 | | <0.2 | | 0.2 |
| W-78 | U-Nat | 3/4/2005 | 20 | | 0.2 |
| | Ra-226 | | <0.2 | | 0.2 |
| W-83 | U-Nat | 3/4/2005 | 20 | | 0.2 |
| | Ra-226 | | <0.2 | | 0.2 |
| W-107 | U-Nat | 3/4/2005 | 8 | | 0.2 |
| | Ra-226 | | <0.2 | | 0.2 |

Note: Due to an error on the chain of custody, the groundwater samples for the first quarter 2005 were not analyzed for thorium-230, lead-210, and polonium-210.

**Table G.1-7 Water Quality Summary - Quarterly Monitoring In Brule Formation And Basal Chadron Sandstone (1996-1997 And 2004-2005)**

| Location | Radionuclide | Date | Concentration pCi/L | Error Estimate pCi/L | LLD pCi/L |
|---|---|---|---|---|---|
| **Second Quarter 2005** | | | | | |
| *Basal Chadron Sandstone* | | | | | |
| W-81 | U-Nat | 5/27/2005 | 0.7 | | 0.2 |
| | Th-230 | | <0.2 | | 0.2 |
| | Ra-226 | | 9.2 | 1.6 | 0.2 |
| | Pb-210 | | <1.0 | | 1 |
| | Po-210 | | <1.0 | | 1 |
| *Brule Formation* | | | | | |
| W-77 | U-Nat | 5/27/2005 | 17 | | 0.2 |
| | Th-230 | | <0.2 | | 0.2 |
| | Ra-226 | | <0.2 | | 0.2 |
| | Pb-210 | | <1.0 | | 1 |
| | Po-210 | | <1.0 | | 1 |
| W-78 | U-Nat | 5/27/2005 | 12 | | 0.2 |
| | Th-230 | | <0.2 | | 0.2 |
| | Ra-226 | | 0.6 | 0.6 | 0.2 |
| | Pb-210 | | <1.0 | | 1 |
| | Po-210 | | <1.0 | | 1 |
| W-83 | U-Nat | 5/27/2005 | 18 | | 0.2 |
| | Th-230 | | <0.2 | | 0.2 |
| | Ra-226 | | 0.6 | 0.6 | 0.2 |
| | Pb-210 | | <1.0 | | 1 |
| | Po-210 | | <1.0 | | 1 |
| W-107 | U-Nat | 5/27/2005 | 8.7 | | 0.2 |
| | Th-230 | | <0.2 | | 0.2 |
| | Ra-226 | | <0.2 | | 0.2 |
| | Pb-210 | | <1.0 | | 1 |
| | Po-210 | | <1.0 | | 1 |
| **Third Quarter 2005** | | | | | |
| *Basal Chadron Sandstone* | | | | | |
| W-81 | U-Nat | 9/16/2005 | 1.2 | | 0.2 |
| | Ra-226 | | 10.2 | 1.2 | 0.2 |
| *Brule Formation* | | | | | |
| W-77 | U-Nat | 9/16/2005 | 18 | | 0.2 |
| | Ra-226 | | <0.2 | | 0.2 |
| W-78 | U-Nat | 9/16/2005 | 12 | | 0.2 |
| | Ra-226 | | <0.2 | | 0.2 |
| W-83 | U-Nat | 9/16/2005 | 19 | | 0.2 |
| | Ra-226 | | 0.2 | 0.4 | 0.2 |
| W-107 | U-Nat | 9/16/2005 | 8.9 | | 0.2 |
| | Ra-226 | | <0.2 | | 0.2 |

NOTES:
pCi/L = picoCuries per liter
LLD = Lowest Level of Detection

**Table G.2-1 Active, Inactive and Abandoned Water Supply Wells in the NTEA and 2.25-Mile Area Of Review**

| Well # | Estimated Depth (ft) | Formation | Well Use | Well Status | Within NTEA |
|---|---|---|---|---|---|
| 3 | 100 | Brule Fm | Agricultural | Active | No |
| 4 | 100 | Brule Fm | Domestic/Agricultural | Active | No |
| 20 | 50 | Brule Fm | Domestic/Agricultural | Active | No |
| 56 | 200 | Brule Fm | Domestic | Active | No |
| 66 | 60 | Brule Fm | Domestic/Agricultural | Active | No |
| 74 | 60 | Brule Fm | Agricultural | Active | No |
| 75 | 65 | Brule Fm | Agricultural | Active | Yes |
| 76 | 30 | Brule Fm | Agricultural | Inactive | Yes |
| 77 | 70 | Brule Fm | Domestic | Active | Yes |
| 78 | 98 | Brule Fm | Domestic | Active | Yes |
| 79 | 98 | Brule Fm | Agricultural | Inactive | No |
| 82 | 120 | Brule Fm | Agricultural | Inactive | Yes |
| 83 | 50 | Brule Fm | Domestic | Active | Yes |
| 84 | 50 | Brule Fm | Agricultural | Active | Yes |
| 85 | 80 | Brule Fm | Domestic | Active | No |
| 86 | 300 | Brule Fm | Agricultural | Inactive | No |
| 87 | 50 | Brule Fm | Agricultural | Active | No |
| 88 | 60 | Brule Fm | Domestic | Active | No |
| 89 | 35 | Brule Fm | Agricultural | Active | No |
| 90 | 35 | Brule Fm | Agricultural | Active | No |
| 91 | 80 | Brule Fm | Domestic/Agricultural | Active | No |
| 92 | 167 | Brule Fm | Domestic | Active | No |
| 93 | 85 | Brule Fm | Domestic | Active | No |
| 94 | 52 | Brule Fm | Domestic | Active | No |
| 95 | 100 | Brule Fm | Domestic | Active | No |
| 96 | 86 | Brule Fm | Domestic | Active | No |
| 99 | 50 | Brule Fm | Domestic | Active | No |
| 100 | 35 | Brule Fm | Agricultural | Active | No |
| 101 | 75 | Brule Fm | Domestic | Active | No |
| 102 | 100 | Brule Fm | Domestic | Active | No |
| 103 | 125 | Brule Fm | Agricultural | Active | No |
| 104 | 25 | Brule Fm | Domestic | Active | No |
| 105 | 70 | Brule Fm | Agricultural | Active | No |
| 106 | 100 | Brule Fm | Domestic | Active | No |
| 107 | 100 | Brule Fm | Domestic | Active | No |
| 108 | 75 | Brule Fm | Agricultural | Active | No |
| 109 | 55 | Brule Fm | Domestic | Active | No |
| 110 | 100 | Brule Fm | Domestic | Active | No |
| 111 | 90 | Brule Fm | Domestic | Active | No |
| 112 | 110 | Brule Fm | Domestic | Active | No |
| 113 | 110 | Brule Fm | Domestic | Active | No |
| 115 | 90 | Brule Fm | Domestic | Active | No |
| 116 | 35 | Brule Fm | Domestic | Active | No |
| 117 | 160 | Brule Fm | Agricultural | Active | No |
| 118 | 90 | Brule Fm | Agricultural | Active | No |
| 121 | 16 | Brule Fm | Agricultural | Active | No |
| 122 | 60 | Brule Fm | Agricultural | Active | No |
| 126 | 290 | Brule Fm | Agricultural | Active | No |

**Table G.2-1 Active, Inactive and Abandoned Water Supply Wells in the NTEA and 2.25-Mile Area Of Review**

| Well # | Estimated Depth (ft) | Formation | Well Use | Well Status | Within NTEA |
|---|---|---|---|---|---|
| 127 | 105 | Brule Fm | Domestic | Active | No |
| 149 | 175 | Brule Fm | Agricultural | Active | No |
| 161 | 60 | Brule Fm | Domestic | Active | No |
| 162 | * | Brule Fm | Domestic | Active | No |
| 168 | 65 | Brule Fm | Agricultural | Active | No |
| 172 | 20 | Brule Fm | Agricultural | Inactive | No |
| 173 | 30 | Brule Fm | Agricultural | Active | No |
| 174 | 30 | Brule Fm | Agricultural | Active | No |
| 175 | 25 | Brule Fm | Domestic/Agricultural | Active | No |
| 176 | 70 | Brule Fm | Domestic | Active | No |
| 184 | 60 | Brule Fm | Domestic | Active | No |
| 185 | 70 | Brule Fm | Domestic | Active | No |
| 186 | 20 | Brule Fm | Domestic | Active | No |
| 187 | 78 | Brule Fm | Agricultural | Active | No |
| 188 | 95 | Brule Fm | Domestic | Active | No |
| 189 | 30 | Brule Fm | Agricultural | Active | No |
| 190 | 30 | Brule Fm | Agricultural | Active | No |
| 197 | 70 | Brule Fm | Agricultural | Active | Yes |
| 198 | * | Brule Fm | Agricultural | Active | Yes |
| 199 | 21 | Brule Fm | Agricultural | Active | No |
| 200 | 30 | Brule Fm | Agricultural | Active | No |
| 201 | 30 | Brule Fm | Agricultural | Inactive | No |
| 206 | 60 | Brule Fm | Agricultural | Inactive | Yes |
| 207 | 30 | Brule Fm | Agricultural | Active | No |
| 208 | 30 | Brule Fm | Agricultural | Active | Yes |
| 209 | 100 | Brule Fm | Agricultural | Active | Yes |
| 210 | * | Brule Fm | Agricultural | Inactive | No |
| 211 | * | Brule Fm | Agricultural | Inactive | No |
| 212 | * | Brule Fm | Agricultural | Inactive | Yes |
| 213 | 30 | Brule Fm | Agricultural | Active | Yes |
| 214 | 37 | Brule Fm | Agricultural | Active | No |
| 215 | 50 | Brule Fm | Agricultural | Active | No |
| 216 | 37 | Brule Fm | Agricultural | Active | No |
| 217 | * | Brule Fm | Agricultural | Active | No |
| 218 | * | Brule Fm | Agricultural | Active | No |
| 220 | 35 | Brule Fm | Agricultural | Active | No |
| 221 | 35 | Brule Fm | Agricultural | Active | No |
| 222 | 35 | Brule Fm | Agricultural | Active | No |
| 223 | 35 | Brule Fm | Agricultural | Active | No |
| 224 | * | Brule Fm | Agricultural | Active | No |
| 227 | 30 | Brule Fm | Agricultural | Active | No |
| 228 | 30 | Brule Fm | Agricultural | Active | No |
| 229 | 30 | Brule Fm | Agricultural | Inactive | No |
| 230 | * | Brule Fm | Domestic/Agricultural | Active | No |
| 231 | * | Brule Fm | Agricultural | Active | No |
| 233 | 80 | Brule Fm | Domestic/Agricultural | Active | No |
| 235 | 30 | Brule Fm | Agricultural | Active | No |
| 237 | 50 | Brule Fm | Domestic/Agricultural | Active | No |
| 241 | 21 | Brule Fm | Domestic/Agricultural | Active | No |

**Table G.2-1 Active, Inactive and Abandoned Water Supply Wells in the NTEA and 2.25-Mile Area Of Review**

| Well # | Estimated Depth (ft) | Formation | Well Use | Well Status | Within NTEA |
|---|---|---|---|---|---|
| 243 | 30 | Brule Fm | Domestic/Agricultural | Active | No |
| 244 | 30 | Brule Fm | Domestic/Agricultural | Active | No |
| 245 | 25 | Brule Fm | Agricultural | Active | No |
| 246 | 40 | Brule Fm | Domestic/Agricultural | Active | No |
| 247 | 30 | Brule Fm | Agricultural | Active | No |
| 248 | 248 | Brule Fm | Agricultural | Active | No |
| 249 | 30 | Brule Fm | Agricultural | Active | No |
| 250 | 30 | Brule Fm | Domestic/Agricultural | Active | No |
| 251 | 100 | Brule Fm | Agricultural | Active | No |
| 252 | * | Brule Fm | Domestic/Agricultural | Active | No |
| 253 | * | Brule Fm | Agricultural | Active | No |
| 254 | * | Brule Fm | Domestic/Agricultural | Active | No |
| 255 | 30 | Brule Fm | Agricultural | Active | No |
| 256 | 40 | Brule Fm | Agricultural | Inactive | No |
| 257 | 50 | Brule Fm | Agricultural | Active | No |
| 258 | * | Brule Fm | Agricultural | Active | No |
| 259 | * | Brule Fm | Domestic/Agricultural | Active | No |
| 262 | 30 | Brule Fm | Domestic/Agricultural | Active | No |
| 263 | * | Brule Fm | Agricultural | Inactive | No |
| 436 | 37 | Brule Fm | Domestic | Active | No |
| 438 | 60 | Brule Fm | Agricultural | Active | Yes |
| 439 | 69 | Brule Fm | Agricultural | Active | No |
| 442 | 60 | Brule Fm | Agricultural | Active | No |
| 445 | 160 | Brule Fm | Agricultural | Active | No |
| 5002 | 25 | Brule Fm | Agricultural | Active | No |
| 5004 | 85 | Brule Fm | Agricultural | Abandoned | No |
| 5005 | 40 | Brule Fm | Domestic | Active | No |
| 5006 | 100 | Brule Fm | Domestic | Active | No |
| 5007 | 50 | Brule Fm | Agricultural | Active | No |
| 5008 | 48 | Brule Fm | Agricultural | Active | No |
| 5009 | 60 | Brule Fm | Domestic | Active | No |
| 5010 | 30 | Brule Fm | Agricultural | Inactive | No |
| 5011 | 110 | Brule Fm | Agricultural | Active | No |
| 5012 | 80 | Brule Fm | Agricultural | Active | No |
| 5013 | 45 | Brule Fm | Agricultural | Active | No |
| 5014 | 50 | Brule Fm | Agricultural | Active | No |
| 5015 | 50 | Brule Fm | Domestic | Active | No |
| 5016 | 38 | Brule Fm | Agricultural | Active | No |
| 5017 | 60 | Brule Fm | Agricultural | Active | No |
| 5018 | 40 | Brule Fm | Agricultural | Active | No |
| 5019 | 60 | Brule Fm | Domestic | Active | No |
| 5020 | 100 | Brule Fm | Domestic | Active | No |
| 5021 | 50 | Brule Fm | Agricultural | Active | No |
| 5022 | 50 | Brule Fm | Agricultural | Inactive | No |
| 5023 | 50 | Brule Fm | Domestic | Active | No |
| 5024 | 40 | Brule Fm | Agricultural | Active | No |
| 5025 | 60 | Brule Fm | Agricultural | Inactive | No |
| 5026 | 65 | Brule Fm | Domestic | Abandoned | No |
| 5027 | 60 | Brule Fm | Agricultural | Active | No |

**Table G.2-1 Active, Inactive and Abandoned Water Supply Wells in the NTEA and 2.25-Mile Area Of Review**

| Well # | Estimated Depth (ft) | Formation | Well Use | Well Status | Within NTEA |
|---|---|---|---|---|---|
| 5028 | 36 | Brule Fm | Agricultural | Inactive | No |
| 5029 | 80 | Brule Fm | Agricultural | Active | No |
| 5030 | 50 | Brule Fm | Agricultural | Inactive | No |
| 5031 | * | Brule Fm | Agricultural | Active | No |
| 5032 | 114 | Brule Fm | Domestic | Active | No |
| 5033 | 46 | Brule Fm | Agricultural | Active | No |
| 5034 | 55 | Brule Fm | Agricultural | Active | No |
| 5036 | 26 | Brule Fm | Agricultural | Inactive | No |
| 5037 | 63 | Brule Fm | Domestic | Active | No |
| 5038 | 105 | Brule Fm | Agricultural | Inactive | No |
| 5039 | 56 | Brule Fm | Agricultural | Active | No |
| 5040 | * | Brule Fm | Agricultural | Active | No |
| 5041 | 40 | Brule Fm | Agricultural | Active | No |
| 5042 | 90 | Brule Fm | Agricultural | Active | No |
| 5043 | 60 | Brule Fm | Agricultural | Active | No |
| 5045 | 50 | Brule Fm | Agricultural | Active | No |
| 5046 | 24 | Brule Fm | Agricultural | Inactive | No |
| 5047 | 140 | Brule Fm | Domestic | Active | No |
| 5048 | 50 | Brule Fm | Domestic | Active | No |
| 5049 | 40 | Brule Fm | Agricultural | Active | No |
| 5050 | 50 | Brule Fm | Agricultural | Inactive | No |
| 5052 | * | Brule Fm | Agricultural | Inactive | No |
| 5053 | 50 | Brule Fm | Agricultural | Active | No |
| 5054 | * | Brule Fm | Agricultural | Inactive | No |
| 5056 | * | Brule Fm | Agricultural | Active | No |
| 5057 | 26 | Brule Fm | Agricultural | Active | No |
| 5058 | 55 | Brule Fm | Agricultural | Active | No |
| 5059 | 60 | Brule Fm | Agricultural | Active | No |
| 5060 | * | Brule Fm | Agricultural | Inactive | No |
| 5062 | * | Brule Fm | Agricultural | Inactive | No |
| 5063 | 50 | Brule Fm | Agricultural | Inactive | No |
| 5064 | * | Brule Fm | Agricultural | Inactive | No |
| 5066 | 56 | Brule Fm | Domestic | Active | No |
| 5068 | 75 | Brule Fm | Domestic | Active | No |
| 52 | 420 | Chadron Fm | Agricultural | Abandoned | No |
| 55 | 320 | Chadron Fm | Agricultural | Active | No |
| 60 | 312 | Chadron Fm | Agricultural | Inactive | No |
| 61 | 280 | Chadron Fm | Domestic/Agricultural | Active | No |
| 65 | 260 | Chadron Fm | Agricultural | Abandoned | No |
| 81 | 630 | Chadron Fm | Agricultural | Abandoned | Yes |
| 97 | 380 | Chadron Fm | Agricultural | Active | No |
| 98 | 100 | Chadron Fm | Domestic/Agricultural | Active | No |
| 114 | 470 | Chadron Fm | Agricultural | Active | No |
| 123 | 280 | Chadron Fm | Agricultural | Active | No |
| 425 | 700 | Chadron Fm | Agricultural | Abandoned | No |
| 437† | 200 | Chadron Fm | Domestic | Active | No |
| 440† | 240 | Chadron Fm | Agricultural | Active | No |
| 441† | 240 | Chadron Fm | Agricultural | Active | No |
| 443† | 140 | Chadron Fm | Domestic | Active | No |

**Table G.2-1 Active, Inactive and Abandoned Water Supply Wells in the NTEA and 2.25-Mile Area Of Review**

| Well # | Estimated Depth (ft) | Formation | Well Use | Well Status | Within NTEA |
|---|---|---|---|---|---|
| 5001 | 280 | Chadron Fm | Agricultural | Active | No |
| 5003 | 280 | Chadron Fm | Agricultural | Active | No |
| 5035 | 285 | Chadron Fm | Agricultural | Active | No |
| 5044 | 400 | Chadron Fm | Agricultural | Inactive | No |
| 5069 | 360 | Chadron Fm | Domestic | Active | No |
| RC1 | 370 | Chadron Fm | Agricultural | Active | No |
| RC2 | 630 | Chadron Fm | Not Used | Active | Yes |
| RC3 | 293 | Chadron Fm | Not Used | Abandoned | No |

NOTES:

1) RC-1, RC-2 and RC-3 were originally installed as monitor wells. RC-1 is currently used as an agricultural water supply well. RC-2 is no longer used. RC-3 was abandoned.

2) Wells designated as completed in the Brule Formation, in many cases, are also included completed in the overlying alluvium.

† Indicates well is completed into Chadron clay only and is in hydraulic communication with Brule Fm.

* No Reported Depth

**Table G.2-2 Water Levels - Brule Formation And Basal Chadron Sandstone (Spring 2008)**

| Well | Point of Measurement (ft-msl) | 3/4/08 - 3/10/08 (psi) | 3/4/08 - 3/10/08 (ft-amsl) | 3/17/08 (psi) | 3/17/2008 (ft-amsl) | 3/28/08 (psi) | 3/28/2008 (ft-amsl) | 4/4/08 (psi) | 4/4/2008 (ft-amsl) | 4/16/08 (psi) | 4/16/2008 (ft-amsl) | 6/9/2008 (psi) | 6/9/2008 (ft-amsl) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **BASAL CHADRON SANDSTONE** | | | | | | | | | | | | | |
| RC-1 | 3650.20 | 17 | 3689.47 | 18 | 3691.78 | 11 | 3675.61 | 11 | 3675.61 | 20 | 3696.4 | NM | NM |
| RC-2 | 3651.75 | 22 | 3702.57 | 21 | 3700.26 | 22 | 3702.57 | 21 | 3700.26 | 21 | 3700.26 | NM | NM |
| COW-1 | 3635.61 | 31 | 3707.22 | 31 | 3707.22 | 31 | 3707.22 | 31 | 3707.22 | 31 | 3707.22 | NM | NM |
| COW-2 | 3656.40 | 21 | 3704.91 | 24 | 3711.84 | 23 | 3709.53 | 18 | 3697.98 | 23 | 3709.53 | NM | NM |
| COW-3 | 3687.54 | 12 | 3715.26 | 12 | 3715.26 | 12 | 3715.26 | 12 | 3715.26 | 13 | 3717.57 | NM | NM |
| COW-4 | 3691.09 | 10 | 3714.19 | 10 | 3714.19 | 10 | 3714.19 | 10 | 3714.19 | 10 | 3714.19 | NM | NM |
| COW-5 | 3670.64 | 16 | 3707.6 | 18 | 3712.22 | 18 | 3712.22 | 18 | 3712.22 | 18 | 3712.22 | NM | NM |
| COW-6 | 3671.22 | 20 | 3717.42 | 22 | 3722.04 | 21 | 3719.73 | 20 | 3717.42 | 21.5 | 3720.88 | NM | NM |
| CPW-2 | 3678.73 | 13 | 3708.76 | 17 | 3718 | 17 | 3718 | 23 | 3731.86 | 15 | 3713.38 | NM | NM |
| WELL 97 | 3658.38 | NM | NM | NM | NM | NM | NM | 18 | 3699.96 | 14 | 3690.72 | NM | NM |
| WELL 123 | 3660.56 | 4 | 3669.8 | 4 | 3669.8 | 7 | 3676.73 | 6 | 3674.42 | 5 | 3672.11 | NM | NM |
| **Well** | **Point of Measurement (ft-msl)** | **3/10/08 (ft)** | **3/10/08 (ft-amsl)** | **3/17/08 (ft)** | **3/17/2008 (ft-amsl)** | **3/28/08 (ft)** | **3/28/2008 (ft-amsl)** | **4/4/08 (ft)** | **4/4/2008 (ft-amsl)** | **4/16/08 (ft)** | **4/16/2008 (ft-amsl)** | **6/12/2008 (ft)** | **6/12/2008 (ft-amsl)** |
| **BRULE FORMATION** | | | | | | | | | | | | | |
| BOW-1 | 3,677.39 | 57.54 | 3,619.85 | 57.49 | 3,619.90 | 57.33 | 3,620.06 | 57.31 | 3,620.08 | NM | NM | 56.63 | 3,620.76 |
| BOW-2 | 3,668.73 | DRY | DRY | DRY | DRY | DRY | DRY | DRY | DRY | NM | NM | 59.89 | 3,615.57 |
| WELL 95 | 3,637.00 | NM | NM | NM | NM | NM | NM | NM | NM | NM | NM | 31.53 | 3,605.47 |
| WELL 118 | 3,653.00 | NM | NM | NM | NM | NM | NM | NM | NM | NM | NM | 64.22 | 3,588.78 |
| WELL 197 | 3,699.48 | NM | NM | NM | NM | NM | NM | NM | NM | NM | NM | 70.72 | 3,628.76 |
| WELL 208 | 3,708.50 | NM | NM | NM | NM | NM | NM | NM | NM | NM | NM | 72.77 | 3,635.73 |
| WELL 75 | 3,710.09 | NM | NM | NM | NM | NM | NM | NM | NM | NM | NM | 34.19 | 3,675.90 |
| WELL 108 | 3,675.79 | NM | NM | NM | NM | NM | NM | NM | NM | NM | NM | 45.09 | 3,630.70 |

NOTES:
1) Groundwater elevations are in feet above mean sea level (ft-amsl).
2) Groundwater elevations for the Basal Chadron Sandstone are based on pressure readings (psi).
3) Groundwater elevations for the Brule Formation are based on depth to water measurements.
NM - not measured

**Table G.2-3 Water Quality Summary For The Alluvium, Brule Formation, And Chadron Formation - CSA**

| Constituent[1)] | Brule Formation | | Chadron Formation | | Alluvium | |
|---|---|---|---|---|---|---|
| | Range | Mean | Range | Mean | Range | Mean |
| Calcium | 7.1 - 98 | 48 | 11 - 41 | 20 | 67 - 74 | 70.6 |
| Magnesium | 0.3 - 16 | 6.6 | 0.8 - 7.2 | 3.2 | 6.4 - 10 | 8.7 |
| Sodium | 12 - 340 | 104 | 340 - 540 | 411 | 34 - 41 | 36.5 |
| Potassium | 4.1 - 15.9 | 9.9 | 7.0 - 19.8 | 12.4 | 10.3 - 13 | 11.1 |
| Bicarbonate | 137 - 627 | 364 | 308 - 411 | 368 | 299 - 364 | 321 |
| Sulfate | 1 - 23 | 10 | 254 - 620 | 407 | 11 - 20 | 16.3 |
| Chloride | 1.6 - 192 | 48 | 134 - 250 | 176 | 5 - 10 | 6.7 |
| Specific Conductance (• mhos) | 246 - 1481 | 714 | 1500 - 2500 | 1932 | 507 - 614 | 548 |
| pH (pH units) | 6.80 - 8.50 | 7.80 | 7.60 - 8.70 | 8.20 | 7.10 - 8.40 | 7.70 |
| Uranium (mg/l) | 0.001 - 0.021 | 0.0064 | <0.001 - 2.40 | 0.092 | 0.006 - 0.022 | 0.015 |
| Radium-226 (pCi/l) | 0.1 - 3.0 | 0.7 | 0.1 - 619 | 53 | 0.4 - 18.3 | 2.5 |

NOTES:
[1] Concentrations in mg/l, unless otherwise noted.
mg/l = milligrams per liter
pCi/L = picoCuries per liter

**Table G.2-4 Water Quality Summary - Basal Chadron Sandstone Well W-007 (Well 81A)**

| Major Ions | Units | Detection Limit | 9/5/1996 | 12/13/1996 | 3/20/1997 | 6/26/1997 | Average Value |
|---|---|---|---|---|---|---|---|
| Calcium (Ca) | mg/L | 1.0 | 29.4 | 28.9 | 29.1 | 30.9 | 29.6 |
| Magnesium (Mg) | mg/L | 1.0 | 5.4 | 5.33 | 5.2 | 5.2 | 5.3 |
| Sodium (Na) | mg/L | 1.0 | 555 | 568 | 561 | 582 | 567 |
| Potassium (K) | mg/L | 1.0 | 15.0 | 14.7 | 15.1 | 15.1 | 15.0 |
| Carbonate (CO3) | mg/L | 0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |
| Bicarbonate (HCO3) | mg/L | 0.10 | 399 | 404 | 398 | 401 | 401 |
| Sulfate (SO4) | mg/L | 1.0 | 740 | 744 | 743 | 720 | 737 |
| Chloride (CI) | mg/L | 0.10 | 196 | 204 | 208 | 201 | 202 |
| Ammonium (NH4) as N | mg/L | 0.05 | 0.73 | 0.68 | 0.75 | 1 | 0.74 |
| Nitrite (NO2) as N | mg/L | 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | <0.10 |
| Nitrate (N03) as N | mg/L | 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | <0.10 |
| Fluoride (F) | mg/L | 0.10 | 1.24 | 1.21 | 1.22 | 1.24 | 1.23 |
| Silica (S102) | mg/L | 1.0 | 11.5 | 11.3 | 10.9 | 11.5 | 11.3 |
| **Non-Metals** | | | | | | | |
| Total Dissolved Solids (TDS) @ 180°C | mg/L | 1.0 | 1820 | 1810 | 1795 | 1790 | 1804 |
| Conductivity | pmho/cm | 1.0 | 2640 | 2750 | 2790 | 2710 | 2723 |
| Alkalinity (CaCO3) | mg/L | 1.0 | 327 | 331 | 326 | 329 | 328 |
| pH | std. units | 0.10 | 8.02 | 8.21 | 8 | 8.15 | 8.10 |
| **Trace Metals** | | | | | | | |
| Aluminum (Al) | mg/L | 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | <0.10 |
| Arsenic (As) | mg/L | 0.001 | < 0.001 | < 0.001 | 0.002 | < 0.001 | <0.002 |
| Barium (Ba) | mg/L | 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | <0.10 |
| Boron (B) | mg/L | 0.10 | 1.66 | 1.60 | 1.60 | 1.59 | 1.61 |
| Cadmium (Cd) | mg/L | 0.01 | < 0.01 | < 0.01 | < 0.01 | < 0.01 | <0.01 |
| Chromium (Cr) | mg/L | 0.05 | < 0.05 | < 0.05 | < 0.05 | < 0.05 | <0.05 |
| Copper (Cu) | mg/L | 0.01 | < 0.01 | < 0.01 | < 0.01 | < 0.01 | <0.01 |
| Iron (Fe) | mg/L | 0.05 | < 0.05 | < 0.05 | < 0.05 | < 0.05 | <0.05 |

**Table G.2-4 Water Quality Summary - Basal Chadron Sandstone Well W-007 (Well 81A)**

| Trace Metals | Units | Detection Limit | 9/5/1996 | 12/13/1996 | 3/20/1997 | 6/26/1997 | Average Value |
|---|---|---|---|---|---|---|---|
| Lead (Pb) | mg/L | 0.05 | < 0.05 | < 0.05 | < 0.05 | < 0.05 | <0.05 |
| Manganese (Mn) | mg/L | 0.01 | 0.02 | < 0.01 | 0.01 | 0.01 | 0.01 |
| Mercury (Hg) | mg/L | 0.001 | < 0.001 | < 0.001 | < 0.001 | < 0.001 | <0.001 |
| Molybdenum (Mo) | mg/L | 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | <0.10 |
| Nickel (Ni) | mg/L | 0.05 | < 0.05 | < 0.05 | < 0.05 | < 0.05 | <0.05 |
| Selenium (Se) | mg/L | 0.001 | < 0.001 | 0.175 | < 0.001 | < 0:001 | <0.175 |
| Vanadium (V) | mg/L | 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | <0.10 |
| Zinc (Zn) | mg/L | 0.01 | 0.02 | 0.01 | 0.02 | < 0.01 | <0.02 |
| **Radiometric** | | | | | | | |
| Uranium (UNat) | mg/L | 0.0003 | < 0.0003 | 0.0060 | <0.0003 | 0.0003 | <0.0032 |
| Radium 226 (Ra226) | pCi/L | 0.2 | 10.5 | 11.9 | 10.3 | 14.7 | 11.9 |
| Radium Precision ± | | | 0.4 | 0.6 | 0.6 | 1.3 | |
| **Qualty Assurance Data** | | target range | | | | | |
| Anion | meq | | 27.55 | 27.94 | 27.93 | 27.31 | 27.68 |
| Cation | meq | | 26.45 | 27.02 | 26.74 | 27.74 | 26.99 |
| WYDEQ A/C Balance | % | -5 - +5 | -2.04 | -1.66 | -2.18 | 0.77 | -1.28 |
| Calc TDS | mg/L | | 1754 | 1780 | 1773 | 1768 | 1769 |
| TDS A/C Balance | dec. % | 0.80 - 1.20 | 1.04 | 1.02 | 1.01 | 1.01 | 1.02 |

NOTES:
mg/L = milligrams per liter
pCi/L = picoCuries per liter
meq = milliequivalents
pmho/cm = picomhos per centimeter
dec. % = decimal percent

**Table G.2-5 Water Quality Summary - Brule Formation Well W-008 (Well 78)**

| Major Ions | Units | Detection Limit | 10/11/1996 | 12/13/1996 | 3/20/1997 | 7/17/1997 | Average Value |
|---|---|---|---|---|---|---|---|
| Calcium (Ca) | mg/L | 1.0 | 67.6 | 67.6 | 67.4 | 77.0 | 69.9 |
| Magnesium (Mg) | mg/L | 1.0 | 9.2 | 9.2 | 9.0 | 9.8 | 9.3 |
| Sodium (Na) | mg/L | 1.0 | 41.8 | 43.9 | 41.0 | 46.3 | 43.3 |
| Potassium (K) | mg/L | 1.0 | 16.6 | 16.7 | 16.1 | 16.9 | 16.6 |
| Carbonate (CO3) | mg/L | 0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |
| Bicarbonate (HCO3) | mg/L | 0.10 | 244 | 248 | 245 | 248 | 246 |
| Sulfate (SO4) | mg/L | 1.0 | 52.2 | 51.0 | 51.3 | 66.5 | 55.3 |
| Chloride (Cl) | mg/L | 0.10 | 26.9 | 27.0 | 27.2 | 31.9 | 28.3 |
| Ammonium (NH4) as N | mg/L | 0.05 | < 0.05 | < 0.05 | < 0.05 | < 0.05 | <0.05 |
| Nitrite (NO2) as N | mg/L | 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | <0.10 |
| Nitrate (N03) as N | mg/L | 0.10 | 6.12 | 5.66 | 5.76 | 5.47 | 5.75 |
| Fluoride (F) | mg/L | 0.10 | 0.38 | 0.35 | 0.38 | 0.35 | 0.37 |
| Silica (S102) | mg/L | 1.0 | 68.0 | 68.0 | 64.9 | 68.0 | 67.2 |
| **Non-Metals** | | | | | | | |
| Total Dissolved Solids (TDS) @ 180°C | mg/L | 1.0 | 436 | 423 | 432 | 479 | 443 |
| Conductivity | pmho/cm | 1.0 | 606 | 622 | 618 | 650 | 624 |
| Alkalinity (CaCO3) | mg/L | 1.0 | 200 | 203 | 201 | 203 | 202 |
| pH | std. units | 0.10 | 7.89 | 8.22 | 7.91 | 7.90 | 7.98 |
| **Trace Metals** | | | | | | | |
| Aluminum (Al) | mg/L | 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | <0.10 |
| Arsenic (As) | mg/L | 0.001 | 0.005 | 0.003 | 0.006 | 0.007 | 0.005 |
| Barium (Ba) | mg/L | 0.10 | 0.20 | 0.20 | 0.19 | 0.20 | 0.20 |
| Boron (B) | mg/L | 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | <0.10 |
| Cadmium (Cd) | mg/L | 0.01 | < 0.01 | < 0.01 | < 0.01 | < 0.01 | <0.01 |
| Chromium (Cr) | mg/L | 0.05 | < 0.05 | < 0.05 | < 0.05 | < 0.05 | <0.05 |
| Copper (Cu) | mg/L | 0.01 | < 0.01 | < 0.01 | < 0.01 | < 0.01 | <0.01 |

**Table G.2-5 Water Quality Summary - Brule Formation Well W-008 (Well 78)**

| Trace Metals | Units | Detection Limit | 10/11/1996 | 12/13/1996 | 3/20/1997 | 7/17/1997 | Average Value |
|---|---|---|---|---|---|---|---|
| Iron (Fe) | mg/L | 0.05 | < 0.05 | < 0.05 | < 0.05 | < 0.05 | <0.05 |
| Lead (Pb) | mg/L | 0.05 | < 0.05 | < 0.05 | < 0.05 | < 0.05 | <0.05 |
| Manganese (Mn) | mg/L | 0.01 | < 0.01 | < 0.01 | < 0.01 | < 0.01 | <0.01 |
| Mercury (Hg) | mg/L | 0.001 | < 0.001 | < 0.001 | < 0.001 | < 0.001 | <0.001 |
| Molybdenum (Mo) | mg/L | 0.10 | < 0.10 | < 0.10 | _< 0.10 | < 0.10 | <0.10 |
| Nickel (Ni) | mg/L | 0.05 | < 0.05 | < 0.05 | < 0.05 | < 0.05 | <0.05 |
| Selenium (Se) | mg/L | 0.001 | 0.018 | 0.018 | 0.015 | 0.017 | 0.017 |
| Vanadium (V) | mg/L | 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | <0.10 |
| Zinc (Zn) | mg/L | 0.01 | 0.04 | 0.02 | 0.02 | 0.03 | 0.02 |
| **Radiometric** | | | | | | | |
| Uranium (UNat) | mg/L | 0.0003 | 0.0123 | 0.0069 | 0.014 | 0.016 | 0.0123 |
| Radium 226 (Ra226) | pCi/L | 0.2 | <0.2 | 0.5 | 0.3 | <0.2 | 0.4 |
| Radium Precision ± | | | | 0.1 | 0.2 | | |
| **Quality Assurance Data** | | **target range** | | | | | |
| Anion | meq | | 6.30 | 6.31 | 6.29 | 6.75 | 6.41 |
| Cation | meq | | 6.41 | 6.50 | 6.33 | 7.13 | 6.59 |
| WYDEQ A/C Balance | % | -5 - +5 | 0.81 | 1.53 | 0.38 | 2.73 | 1.36 |
| Calc TDS | mg/L | | 432 | 433 | 425 | 465 | 439 |
| TDS A/C Balance | dec. % | 0.80 - 1.20 | 1.01 | 0.98 | 1.02 | 1.03 | 1.01 |

NOTES:
mg/L = milligrams per liter
pCi/L = picoCuries per liter
meq = milliequivalents
pmho/cm = picomhos per centimeter
dec. % = decimal percent

**Table G.2-6 Water Quality Summary - Brule Formation And Basal Chadron Sandstone (March-April 2008)**

| Location ID<br>Date Collected<br>Formation | Units | Bow 1<br>03/07/08<br>Brule | Bow 1<br>03/24/08<br>Brule | Bow 1<br>04/07/08<br>Brule | Cow 1<br>03/04/08<br>Chadron | Cow 1<br>03/18/08<br>Chadron | Cow 1<br>04/01/08<br>Chadron | Cow 2<br>03/05/08<br>Chadron | Cow 2<br>03/19/08<br>Chadron | Cow 2<br>04/03/08<br>Chadron | Cow 3<br>03/04/08<br>Chadron | Cow 3<br>03/18/08<br>Chadron |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Major Ions** | | | | | | | | | | | | |
| Bicarbonate as HCO3 | mg/L | 252 | 253 | 255 | 357 | 355 | 359 | 387 | 392 | 392 | 391 | 396 |
| Calcium | mg/L | 61 | 67 | 57 | 55 | 58 | 57 | 8 | 9 | 11 | 9 | 10 |
| Carbonate as CO3 | mg/L | <1 | <1 | <1 | <1 | <1 | <1 | 11 | 11 | 12 | 10 | 10 |
| Chloride | mg/L | 35 | 35 | 35 | 259 | 260 | 257 | 149 | 157 | 160 | 163 | 164 |
| Fluoride | mg/L | 0.3 | 0.3 | 0.3 | 1.1 | 1 | 0.9 | 1.5 | 1.4 | 1.3 | 1.6 | 1.4 |
| Magnesium | mg/L | 7 | 9 | 7 | 6 | 7 | 7 | <1 | 1 | 2 | 2 | 2 |
| Nitrogen, Ammonia as N | mg/L | <0.05 | <0.05 | <0.1 | 0.99 | 0.98 | 0.99 | 0.48 | 0.53 | 0.49 | 0.76 | 0.56 |
| Nitrogen, Nitrate+Nitrite as N | mg/L | 7.5 | 7.8 | 8.02 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Nitrogen, Nitrite as N | mg/L | <0.1 H | <0.1 H | <0.1 H | <0.1 H | <0.1 H | <0.1 H | <0.1 H | <0.1 H | <0.1 H | <0.1 H | <0.1 H |
| Potassium | mg/L | 19 | 18 | 21 | 26 | 27 | 24 | 18 | 18 | 19 | 20 | 20 |
| Silica | mg/L | 68.1 D | 93 | 65.3 | 11.7 | 11.5 | 12 D | 13 | 13.1 | 14.4 | 12.5 | 12.7 |
| Sodium | mg/L | 65 | 65 | 62 | 775 D | 800 D | 708 | 496 D | 487 D | 505 | 519 D | 538 D |
| Sulfate | mg/L | 62 | 59 | 63 | 1,180 D | 1,180 D | 1,130 D | 566 D | 596 D | 599 D | 588 D | 612 D |
| **Non-Metals** | | | | | | | | | | | | |
| Alkalinity, Total as CaCO3 | mg/L | 207 | 208 | 209 | 292 | 291 | 294 | 336 | 340 | 341 | 337 | 340 |
| Conductivity | umhos/cm | 691 | 676 | 678 | 3,810 | 3,600 | 3,590 | 2,410 | 2,260 | 2,280 | 2,520 | 2,400 |
| pH | SU | 7.77 | 7.92 | 7.75 | 7.92 | 8.38 H | 7.76 | 8.45 | 8.49 | 8.37 | 8.03 | 8.62 H |
| Solids, Total Dissolved TDS @ 180 C | mg/L | 472 H | 429 H | 474 | 2,300 | 2,290 H | 2,440 | 1,400 | 1,470 H | 1,500 | 1,430 | 1,460 H |
| **Trace Metals** | | | | | | | | | | | | |
| Aluminum | mg/L | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Arsenic | mg/L | 0.01 | 0.01 | <0.1 D | 0.002 | <0.001 | <0.001 | 0.002 | <0.001 | <0.001 | 0.002 | 0.002 |
| Barium | mg/L | 0.1 | 0.1 | 0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Boron | mg/L | <0.1 | <0.1 | <0.1 | 2 | 1.9 | 1.6 | 1.9 | 1.8 | 1.6 | 1.9 | 1.9 |
| Cadmium | mg/L | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |
| Chromium | mg/L | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Copper | mg/L | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Iron | mg/L | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 |
| Lead | mg/L | 0.003 | 0.001 | <0.05 D | <0.001 | 0.002 | <0.001 | <0.001 | <0.001 | <0.001 | 0.001 | <0.001 |
| Manganese | mg/L | <0.01 | <0.01 | <0.01 | 0.03 | 0.03 | 0.03 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Mercury | mg/L | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Molybdenum | mg/L | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Nickel | mg/L | <0.05 | <0.05 | 0.07 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |

**Table G.2-6 Water Quality Summary - Brule Formation And Basal Chadron Sandstone (March-April 2008)**

| Location ID<br>Date Collected<br>Formation | Units | Bow 1<br>03/07/08<br>Brule | Bow 1<br>03/24/08<br>Brule | Bow 1<br>04/07/08<br>Brule | Cow 1<br>03/04/08<br>Chadron | Cow 1<br>03/18/08<br>Chadron | Cow 1<br>04/01/08<br>Chadron | Cow 2<br>03/05/08<br>Chadron | Cow 2<br>03/19/08<br>Chadron | Cow 2<br>04/03/08<br>Chadron | Cow 3<br>03/04/08<br>Chadron | Cow 3<br>03/18/08<br>Chadron |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Selenium | mg/L | **0.027** | **0.028** | **0.027** | **0.008** | **0.004** | <0.001 | **0.005** | **0.002** | <0.001 | **0.004** | **0.002** |
| Vanadium | mg/L | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Zinc | mg/L | **0.48** | **0.32** | **0.25** | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| **Radiometric** | | | | | | | | | | | | |
| Lead 210 | pCi/L | <0.3 | <1.4 | <0.9 | <1.1 | <2.2 | <1 | <1.9 | <1.6 | <1.4 | <1.4 | <1.8 |
| Polonium 210 | pCi/L | <0.5 | **0.9** | **1** | NA | **5.4** | **1** | <0.8 | <1 | **1.6** | **1.4** | **4.4** |
| Radium 226 | pCi/L | <0.1 | <0.2 | <0.17 | **22.5** | **21.8** | **23.3** | **7.7** | **8.1** | **9.7** | **0.5** | **0.6** |
| Thorium 230 | pCi/L | <0.1 | <0.08 | <0.1 | <0.2 | <0.1 | <0.1 | <0.1 | <0.1 | <0.06 | <0.1 | <0.2 |
| Uranium | mg/L | 0.0256 | 0.025 | 0.024 | **0.0008** | **0.0004** | **0.0003** | **0.0133** | **0.0146** | **0.0125** | **0.0087** | **0.009** |
| **Quality Assurance** | | | | | | | | | | | | |
| A/C Balance (± 5) | % | 0.001 | 2.97 | 2.87 | 0.011 | 1.59 | 2.55 | 0.626 | 3.18 | 1.51 | 0.107 | 0.903 |
| Anions | meq/L | 6.94 | 6.93 | 7.06 | 37.7 | 37.8 | 36.8 | 22.8 | 23.7 | 23.9 | 23.7 | 24.2 |
| Cations | meq/L | 6.94 | 7.36 | 6.66 | 37.7 | 39 | 34.9 | 22.5 | 22.2 | 23.2 | 23.7 | 24.7 |
| Solids, Total Dissolved Calculated | mg/L | 473 | 505 | 471 | 2,480 | 2,520 | 2,380 | 1,450 | 1,490 | 1,520 | 1,520 | 1,560 |
| TDS Balance (0.80 - 1.20) | dec. % | 1 | 0.85 | 1.01 | 0.93 | 0.91 | 1.03 | 0.97 | 0.99 | 0.99 | 0.94 | 0.94 |

## Table G.2-6 Water Quality Summary - Brule Formation And Basal Chadron Sandstone (March-April 2008) *(continued)*

| Location ID<br>Date Collected<br>Formation | Units | Cow 4<br>03/04/08<br>Chadron | Cow 4<br>03/18/08<br>Chadron | Cow 4<br>04/01/08<br>Chadron | Cow 5<br>03/05/08<br>Chadron | Cow 5<br>03/19/08<br>Chadron | Cow 5<br>04/03/08<br>Chadron | Cow 6<br>03/06/08<br>Chadron | Cow 6<br>03/20/08<br>Chadron | Cow 6<br>04/03/08<br>Chadron | CPW-2<br>03/05/08<br>Chadron | CPW-2<br>03/19/08<br>Chadron | CPW-2<br>04/03/08<br>Chadron |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Major Ions** | | | | | | | | | | | | | |
| Bicarbonate as HCO3 | mg/L | 329 | 334 | 335 | 403 | 429 | 403 | 378 | 396 | 376 | 414 | 416 | 410 |
| Calcium | mg/L | 31 | 30 | 30 | 30 | 30 | 32 | 58 | 55 | 60 | 22 | 21 | 22 |
| Carbonate as CO3 | mg/L | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | 4 |
| Chloride | mg/L | 227 | 228 | 236 | 227 | 213 | 226 | 305 | 338 | 306 | 156 | 157 | 163 |
| Fluoride | mg/L | 1.2 | 1.1 | 1.1 | 1.2 | 1.2 | 1.2 | 0.8 | 0.7 | 0.7 | 1.5 | 1.5 | 1.4 |
| Magnesium | mg/L | 6 | 6 | 7 | 5 | 6 | 6 | 11 | 11 | 12 | 4 | 4 | 4 |
| Nitrogen, Ammonia as N | mg/L | 0.93 | 0.77 | 0.8 | 0.74 | 0.72 | 0.78 | 1.09 | 1.02 | 1.06 | 0.84 | 0.59 | 0.55 |
| Nitrogen, Nitrate+Nitrite as N | mg/L | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Nitrogen, Nitrite as N | mg/L | <0.1 H | <0.1 H | <0.1 H | <0.1 H | <0.1 H | <0.1 H | <0.1 H | <0.1 H | <0.1 H | <0.1 H | <0.1 H | <0.1 H |
| Potassium | mg/L | 17 | 19 | 18 | 13 | 13 | 14 | 30 | 30 | 31 | 14 | 13 | 14 |
| Silica | mg/L | 12.2 | 12.1 | 13.6 | 12.1 | 12.5 | 13.7 | 12.2 | 12.5 | 13.7 | 11.9 | 12.2 | 13.4 |
| Sodium | mg/L | 670 D | 694 D | 671 | 643 D | 607 D | 654 | 826 D | 773 D | 848 | 546 D | 500 D | 530 |
| Sulfate | mg/L | 947 D | 979 D | 962 D | 832 D | 858 D | 859 D | 1,190 D | 628 D | 1,200 D | 631 D | 649 D | 648 D |
| **Non-Metals** | | | | | | | | | | | | | |
| Alkalinity, Total as CaCO3 | mg/L | 270 | 273 | 275 | 331 | 352 | 331 | 310 | 325 | 308 | 339 | 341 | 342 |
| Conductivity | umhos /cm | 3,290 | 3,160 | 3,110 | 3,160 | 2,930 | 2,950 | 2,560 | 3,860 | 3,840 | 2,560 | 2,370 | 2,390 |
| pH | SU | 8.08 | 8.16 H | 7.95 | 8 | 8.17 | 7.97 | 8.05 | 8.12 | 7.73 | 8.06 | 8.24 | 8.02 |
| Solids, Total Dissolved TDS @ 180 C | mg/L | 2,020 | 1,950 H | 2,000 | 1,890 | 1,880 | 1,840 | 2,550 | 2,440 H | 2,510 | 1,510 | 1,530 | 1,510 |
| **Trace Metals** | | | | | | | | | | | | | |
| Aluminum | mg/L | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Arsenic | mg/L | 0.002 | <0.001 | <0.001 | 0.001 | <0.001 | <0.001 | 0.003 | 0.002 | <0.001 | 0.002 | 0.001 | <0.001 |
| Barium | mg/L | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Boron | mg/L | 1.8 | 1.8 | 1.6 | 2 | 1.9 | 1.8 | 1.7 | 1.7 | 1.6 | 1.7 | 1.8 | 1.7 |
| Cadmium | mg/L | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |
| Chromium | mg/L | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Copper | mg/L | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |

## Table G.2-6 Water Quality Summary - Brule Formation And Basal Chadron Sandstone (March-April 2008) *(continued)*

| Location ID<br>Date Collected<br>Formation | Units | Cow 4<br>03/04/08<br>Chadron | Cow 4<br>03/18/08<br>Chadron | Cow 4<br>04/01/08<br>Chadron | Cow 5<br>03/05/08<br>Chadron | Cow 5<br>03/19/08<br>Chadron | Cow 5<br>04/03/08<br>Chadron | Cow 6<br>03/06/08<br>Chadron | Cow 6<br>03/20/08<br>Chadron | Cow 6<br>04/03/08<br>Chadron | CPW-2<br>03/05/08<br>Chadron | CPW-2<br>03/19/08<br>Chadron | CPW-2<br>04/03/08<br>Chadron |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Iron | mg/L | **0.04** | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | **0.08** | <0.03 | <0.03 | **0.16** | <0.03 | <0.03 |
| Lead | mg/L | **0.005** | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | **0.006** | <0.001 | **0.004** | **0.001** | <0.001 | <0.001 |
| Manganese | mg/L | **0.02** | **0.01** | **0.01** | **0.01** | **0.02** | **0.02** | **0.02** | **0.03** | **0.04** | <0.01 | <0.01 | <0.01 |
| Mercury | mg/L | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Molybdenum | mg/L | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Nickel | mg/L | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Selenium | mg/L | **0.007** | **0.003** | <0.001 | **0.006** | **0.003** | <0.001 | **0.009** | **0.004** | <0.001 | **0.005** | **0.002** | <0.001 |
| Vanadium | mg/L | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Zinc | mg/L | **0.01** | <0.01 | <0.01 | **0.01** | <0.01 | <0.01 | **0.04** | **0.02** | **0.02** | <0.01 | <0.01 | <0.01 |
| **Radiometric** | | | | | | | | | | | | | |
| Lead 210 | pCi/L | **23.3** | **17.2** | <1.2 | <2 | **20.1** | <0.6 | <0.5 | <0.4 | <1.9 | <2.7 | <1.6 | <0.7 |
| Polonium 210 | pCi/L | <1.2 | **1.1** | <1 | **1.6** | **1.3** | <0.9 | **1.4** | **7.6** | **1** | **1.7** | **1.3** | **1.4** |
| Radium 226 | pCi/L | **38.8** | **25.1** | **19.3** | **38.7** | **42** | **44.6** | **1.8** | **1** | **1.9** | **11.7** | **12.5** | **12.8** |
| Thorium 230 | pCi/L | <0.1 | **0.1** | <0.1 | <0.1 | **0.2** | <0.2 | <0.1 | <0.1 | <0.09 | <0.1 | <0.1 | <0.2 |
| Uranium | mg/L | **0.0348** | **0.0355** | **0.0305** | **0.0149** | **0.0172** | **0.0155** | **0.0017** | **0.0018** | **0.0014** | **0.0361** | **0.0341** | **0.0355** |
| **Quality Assurance** | | | | | | | | | | | | | |
| A/C Balance (± 5) | % | 0.197 | 0.613 | 0.745 | 0.143 | 3.72 | 0.093 | 1.11 | 13.3 | 2.32 | 2.32 | 2.81 | 0.211 |
| Anions | meq/L | 31.6 | 32.3 | 32.2 | 30.4 | 31 | 30.9 | 39.6 | 29.1 | 39.8 | 24.4 | 24.8 | 25 |
| Cations | meq/L | 31.7 | 32.7 | 31.8 | 30.3 | 28.8 | 31 | 40.5 | 38.1 | 41.7 | 25.6 | 23.5 | 24.9 |
| Solids, Total Dissolved Calculated | mg/L | 2,070 | 2,130 | 2,100 | 1,960 | 1,950 | 2,000 | 2,620 | 2,040 | 2,660 | 1,590 | 1,560 | 1,600 |
| TDS Balance (0.80 - 1.20) | dec. % | 0.98 | 0.92 | 0.95 | 0.96 | 0.96 | 0.92 | 0.97 | 1.2 | 0.94 | 0.95 | 0.98 | 0.94 |

## Table G.2-6 Water Quality Summary - Brule Formation And Basal Chadron Sandstone (March-April 2008) (continued)

| Location ID<br>Date Collected<br>Formation | Units | RC-1<br>03/04/08<br>Chadron | RC-1<br>03/19/08<br>Chadron | RC-1<br>04/03/08<br>Chadron | RC-2<br>03/04/08<br>Chadron | RC-2<br>03/18/08<br>Chadron | RC-2<br>04/01/08<br>Chadron | Well 97<br>03/03/08<br>Chadron | Well 97<br>03/17/08<br>Chadron | Well 97<br>03/31/08<br>Chadron | Well 123<br>03/03/08<br>Chadron | Well 123<br>03/17/08<br>Chadron | Well 123<br>03/31/08<br>Chadron |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Major Ions** | | | | | | | | | | | | | |
| Bicarbonate as HCO3 | mg/L | | | | | | | | | | | | |
| Calcium | mg/L | | | | | | | | | | | | |
| Carbonate as CO3 | mg/L | | 382 | 372 | 381 | 373 | 368 | 384 | 531 | 373 | 375 | 367 | 361 |
| Chloride | mg/L | 20 | 19 | 20 | 13 | 14 | 14 | 17 | 18 | 18 | 10 | 11 | 11 |
| Fluoride | mg/L | <1 | <1 | 6 | <1 | 5 | 7 | <1 | 2 | 7 | 3 | 5 | 9 |
| Magnesium | mg/L | | 185 | 181 | 142 | 142 | 153 | 152 | 157 | 167 | 170 | 160 | 181 |
| Nitrogen, Ammonia as N | mg/L | | 0.9 | 0.9 | 1.4 | 1.3 | 1.3 | 1.1 | 1 | 1 | 0.8 | 0.7 | 0.7 |
| Nitrogen, Nitrate+Nitrite as N | mg/L | 384 | 2 | 3 | <1 | 1 | 2 | 1 | 2 | 2 | <1 | 1 | 2 |
| Nitrogen, Nitrite as N | mg/L | 0.4 | 0.36 | 0.4 | 0.52 | 0.59 | 0.47 | 0.39 | 0.36 | 0.4 | 0.27 | 0.26 | 0.28 |
| Potassium | mg/L | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Silica | mg/L | <0.1 H | <0.1 H | <0.1 H | <0.1 H | <0.1 H | <0.1 H | <0.1 H | <0.1 H | <0.1 H | <0.1 H | <0.1 H | <0.1 H |
| Sodium | mg/L | 17 | 17 | 17 | 15 | 15 | 15 | 15 | 14 | 14 | 10 | 11 | 9 |
| Sulfate | mg/L | 10.3 | 10.1 | 11.1 | 11.8 | 11.7 | 13 | 10 | 10.2 | 10.8 | 10.6 | 10.4 | 11 D |
| **Non-Metals** | | 502 D | 486 D | 509 | 494 D | 508 D | 496 | 502 D | 498 D | 484 | 452 D | 462 D | 422 |
| Alkalinity, Total as CaCO3 | mg/L | 590 D | 604 D | 631 D | 579 D | 602 D | 600 D | 576 D | 595 D | 595 D | 435 D | 460 D | 466 D |
| Conductivity | umhos/cm | | | | | | | | | | | | |
| pH | SU | 315 | 313 | 314 | 312 | 313 | 314 | 315 | 438 | 318 | 313 | 310 | 311 |
| Solids, Total Dissolved TDS @ 180 C | mg/L | 2,480 | 2,340 | 2,320 | 2,370 | 2,270 | 2,250 | 2,410 | 2,270 | 2,260 | 2,170 | 2,070 | 2,050 |
| **Trace Metals** | | 8.1 | 8.35 | 8.02 | 8.18 | 8.53 H | 8.25 | 8.17 H | 8.52 H | 8.22 | 8.26 H | 8.65 H | 8.35 |
| Aluminum | mg/L | 1,420 | 1,550 H | 1,500 | 1,360 | 1,400 H | 1,390 | 1,390 H | 1,370 H | 1,400 | 1,200 H | 1,250 H | 1,240 |
| Arsenic | mg/L | | | | | | | | | | | | |
| Barium | mg/L | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Boron | mg/L | <0.001 | <0.001 | <0.001 | 0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | 0.002 | <0.001 |
| Cadmium | mg/L | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |

## Table G.2-6 Water Quality Summary - Brule Formation And Basal Chadron Sandstone (March-April 2008) (continued)

| Location ID<br>Date Collected<br>Formation | Units | RC-1<br>03/04/08<br>Chadron | RC-1<br>03/19/08<br>Chadron | RC-1<br>04/03/08<br>Chadron | RC-2<br>03/04/08<br>Chadron | RC-2<br>03/18/08<br>Chadron | RC-2<br>04/01/08<br>Chadron | Well 97<br>03/03/08<br>Chadron | Well 97<br>03/17/08<br>Chadron | Well 97<br>03/31/08<br>Chadron | Well 123<br>03/03/08<br>Chadron | Well 123<br>03/17/08<br>Chadron | Well 123<br>03/31/08<br>Chadron |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Chromium | mg/L | **1.4** | **1.3** | **1.1** | **1.8** | **1.8** | **1.6** | **1.5** | **1.6** | **1.2** | **1.4** | **1.3** | **1.2** |
| Copper | mg/L | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |
| Iron | mg/L | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Lead | mg/L | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Manganese | mg/L | <0.03 | <0.03 | <0.03 | **0.07** | <0.03 | **0.06** | <0.03 | <0.03 | <0.03 | <0.03 | **0.72** | <0.03 |
| Mercury | mg/L | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | **0.001** | <0.001 | <0.001 | **0.001** | <0.001 |
| Molybdenum | mg/L | <0.01 | **0.01** | <0.01 | **0.02** | **0.01** | **0.01** | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Nickel | mg/L | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Selenium | mg/L | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Vanadium | mg/L | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Zinc | mg/L | **0.005** | **0.002** | <0.001 | **0.005** | **0.002** | <0.001 | **0.005** | **0.002** | <0.001 | **0.005** | **0.002** | <0.001 |
| **Radiometric** | | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Lead 210 | pCi/L | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Polonium 210 | pCi/L | | | | | | | | | | | | |
| Radium 226 | pCi/L | <1.6 | <1.2 | <1.2 | <1.2 | <2 | <1.9 | <1.8 | **17.8** | <2.1 | <2 | **39.2** | <2 |
| Thorium 230 | pCi/L | **1.3** | <0.9 | **1.1** | <0.8 | **4.6** | <0.7 | <0.8 | **1.6** | **2.1** | <0.4 | <0.5 | **1.2** |
| Uranium | mg/L | **0.9** | **0.8** | **1.3** | **1** | **1.4** | **1.5** | **0.4** | **0.3** | **1.6** | <0.2 | <0.2 | **0.6** |
| **Quality Assurance** | | <0.1 | **0.1** | <0.05 | <0.2 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.2 | <0.1 | <0.05 |
| A/C Balance (± 5) | % | <0.0003 | <0.0003 | <0.0003 | **0.0029** | **0.0032** | **0.0028** | <0.0003 | <0.0003 | <0.0003 | <0.0003 | <0.0003 | <0.0003 |
| Anions | meq/L | | | | | | | | | | | | |
| Cations | meq/L | 0.029 | 3.01 | 1.5 | 0.538 | 1.02 | 0.686 | 1.2 | 5.24 | 2.25 | 0.94 | 1.79 | 4.37 |
| Solids, Total Dissolved Calculated | mg/L | 23.4 | 24.1 | 24.6 | 22.4 | 22.9 | 23.2 | 22.6 | 25.6 | 23.5 | 20.2 | 20.3 | 21.1 |
| TDS Balance (0.80 - 1.20) | dec. % | 23.4 | 22.7 | 23.8 | 22.6 | 23.3 | 22.8 | 23.2 | 23.1 | 22.5 | 20.5 | 21.1 | 19.3 |
| | | 1,500 | 1,510 | 1,560 | 1,440 | 1,480 | 1,480 | 1,460 | 1,560 | 1,480 | 1,280 | 1,300 | 1,290 |
| | | 0.95 | 1.03 | 0.96 | 0.94 | 0.95 | 0.94 | 0.95 | 0.88 | 0.95 | 0.94 | 0.96 | 0.96 |

NOTES: 1) Detections are bolded.
D - reporting limit increased due to sample matrix interference
H - analysis performed past recommended holding time
meq/L - milliequivalents per liter
mg/L - milligrams per liter
pCi/L - picoCuries per liter
dec. % - decimal percent
umhos/cm - micromhos per centimeter
SU - standard units

**Table G.3-1 Summary of 2006 North Trend Pumping Test Results Vs. Existing Permit Area**

| | Tests #1-#4 Existing Class III Permit Area (mean) | Test #5 North Trend 2004 & 2005 (mean) | Test #6 North Trend 2006 (mean) |
|---|---|---|---|
| Transmissivity ($ft^2$/day) | 363 | 103 | 60 |
| Formation Thickness (feet) | 39.0 | 19.8 | 26 |
| Hyd. Cond. (ft/day) | 9.3 | 5.2 | 2.3 |
| Storativity | 9.7E-05 | 7.1E-05 | 5.3E-05 |

**Table G.3-2 Summary Of 2006 North Trend Pumping Test Well Information**

| Well | Distance to Pumping Well | North | East | Township and Range | Section | TOC Elev. (ft-amsl) | Surface Elevation (ft-amsl) |
|---|---|---|---|---|---|---|---|
| **Basal Chadron Sandstone Pumping Well** | | | | | | | |
| COW-5 (PW) | 0.00 | 523,541.90 | 1,082,946.00 | T32N R52W | 27 | 3,669.05 | 3,667.65 |
| | | | | | | | |
| **Basal Chadron Sandstone Observation Wells** | | | | | | | |
| COW-1 | 3,614.28 | 525,991.00 | 1,085,604.00 | T32N R52W | 27 | 3,633.77 | 3,632.57 |
| COW-2 | 4,001.38 | 519,632.50 | 1,083,799.00 | T32N R52W | 34 | 3,654.52 | 3,653.22 |
| COW-3 | 3,315.00 | 521,315.40 | 1,080,490.00 | T32N R52W | 27 | 3,685.33 | 3,684.63 |
| COW-4 | 3,609.34 | 526,204.30 | 1,080,509.00 | T32N R52W | 27 | 3,689.04 | 3,687.94 |
| CPW-2 | 2,291.19 | 521,626.30 | 1,081,689.00 | T32N R52W | 27 | 3,676.92 | 3,675.82 |
| RC-2 | 6,634.66 | 516,911.30 | 1,082,714.00 | T32N R52W | 34 | 3,651.22 | 3,648.42 |
| | | | | | | | |
| **Brule Formation Observation Wells** | | | | | | | |
| BOW-1 | 2,301.76 | 521,642.20 | 1,081,644.00 | T32N R52W | 27 | 3,677.39 | 3,675.49 |
| BOW-2 | 31.78 | 523,534.20 | 1,082,915.00 | T32N R52W | 27 | 3,668.73 | 3,667.93 |
| | | | | | | | |
| **Upper/Middle Chadron Observation Wells** | | | | | | | |
| MCOW-1 | 2,268.07 | 521,627.10 | 1,081,729.00 | T32N R52W | 27 | 3,676.80 | 3,675.50 |
| MCOW-2 | 2,323.47 | 521,681.10 | 1,081,552.00 | T32N R52W | 27 | 3,678.82 | 3,677.52 |
| MCOW-3 | 43.45 | 523,582.40 | 1,082,951.00 | T32N R52W | 27 | 3,668.85 | 3,667.65 |
| MCOW-4 | 1,280.16 | 523,634.60 | 1,081,671.00 | T32N R52W | 27 | 3,681.66 | 3,679.86 |

**Table G.3-2 Summary Of 2006 North Trend Pumping Test Well Information *(continued)***

| Casing Stickup (ft) | Hole Depth (ft; bgs) | Casing Depth (ft; bgs) | Top Screen (ft; bgs) | Bottom Screen (ft; bgs) | Screen Length (ft) | Screen Interval (feet) | Casing O.D. (in.) | 06/28/06 Static Water Elevation (ft; AMSL) |
|---|---|---|---|---|---|---|---|---|
| 1.40 | 740 | 708 | 653 | 708 | 55 | 22 | 4.5 | 3,704.85 |
| | | | | | | | | |
| | | | | | | | | |
| 1.20 | 580 | 557 | 537 | 557 | 20 | 10 | 4.5 | 3,699.81 |
| 1.30 | 620 | 594 | 569 | 594 | 25 | 15 | 4.5 | 3,704.41 |
| 0.70 | 670 | 646 | 596 | 646 | 50 | 33 | 4.5 | 3,710.59 |
| 1.10 | 670 | 645 | 585 | 645 | 60 | 41 | 4.5 | 3,705.30 |
| 1.10 | 710 | 685 | 615 | 685 | 70 | 35 | 4.5 | 3,705.99 |
| 2.80 | 630 | 630 | 572 | 630 | 58 | 25 | 4.5 | 3,703.93 |
| | | | | | | | | |
| | | | | | | | | |
| 1.90 | 65 | 65 | 45 | 65 | 20 | 5 | 4.5 | 3,620.68 |
| 0.80 | 59 | 59 | 22 | 59 | 37 | 10 | 4.5 | 3,608.57 |
| | | | | | | | | |
| | | | | | | | | |
| 1.30 | 380 | 350 | 305 | 350 | 45 | 5 | 4.5 | 3,607.29 |
| 1.30 | 370 | 360 | 315 | 360 | 45 | 7 | 4.5 | 3,606.83 |
| 1.20 | 390 | 391 | 325 | 391 | 66 | 17 | 4.5 | 3,606.14 |
| 1.80 | 371 | 371 | 290 | 371 | 81 | 19 | 4.5 | 3,608.27 |

**Table G.3-3 Summary Of 2006 North Trend Pumping Test Results**

| Well | Distance from Pumping Well (feet) | Analytical Results | Test #6 Analytical Method | |
|---|---|---|---|---|
| | | | Theis | Theis Recovery |
| COW-5 (PW) | 0.00 | Transmissivity ($ft^2$/day) | NA | * |
| | | Hyd. Cond. (ft/day) | NA | * |
| | | Storativity | NA | * |
| COW-1 | 3,614.28 | Transmissivity ($ft^2$/day) | 42.0 | NA |
| | | Hyd. Cond. (ft/day) | 1.6 | NA |
| | | Storativity | 2.30E-05 | NA |
| COW-2 | 4,001.38 | Transmissivity ($ft^2$/day) | 74.8 | NA |
| | | Hyd. Cond. (ft/day) | 2.9 | NA |
| | | Storativity | 7.05E-05 | NA |
| COW-3 | 3,315.00 | Transmissivity ($ft^2$/day) | 71.5 | NA |
| | | Hyd. Cond. (ft/day) | 2.8 | NA |
| | | Storativity | 8.40E-05 | NA |
| COW-4 | 3,609.34 | Transmissivity ($ft^2$/day) | 51.7 | NA |
| | | Hyd. Cond. (ft/day) | 2.0 | NA |
| | | Storativity | 3.43E-05 | NA |
| CPW-2 | 2,291.19 | Transmissivity ($ft^2$/day) | 60.7 | NA |
| | | Hyd. Cond. (ft/day) | 2.3 | NA |
| | | Storativity | 4.55E-05 | NA |
| RC-2 | 6,634.66 | Transmissivity ($ft^2$/day) | 58.2 | NA |
| | | Hyd. Cond. (ft/day) | 2.2 | NA |
| | | Storativity | 6.18E-05 | NA |

NA - Data not analyzed; pumping data were sufficient for analysis.
* Unable to analyze recovery data due to lack of check valve on top of pump.

**Table G.5-1 Anticipated Changes in Water Quality during Mining**

| Average Ore Zone Water Quality | | | |
|---|---|---|---|
| **Analyte** | **Units** | **Pre-Mining (Well W-007)** | **Typical Water Quality During Mining at CSA** |
| Alkalinity, Total as CaCO3 | mg/L | 328 | 1,600 |
| Carbonate as CO3 | mg/L | 0 | <1.0 |
| Bicarbonate as HCO3 | mg/L | 401 | 2,050 |
| Calcium | mg/L | 29.6 | 77 |
| Chloride | mg/L | 202 | 600 |
| Fluoride | mg/L | 1.23 | 0.6 |
| Magnesium | mg/L | 5.3 | 23 |
| Ammonia as N | mg/L | 0.74 | <0.05 |
| Nitrate+Nitrite as N | mg/L | | 0.46 |
| Potassium | mg/L | 15.0 | 35 |
| Silica | mg/L | 11.3 | 21 |
| Sodium | mg/L | 567 | 1,310 |
| Sulfate | mg/L | 737 | 900 |
| Conductivity | umhos/cm | 2,723 | 6,000 |
| pH | s.u. | 8.1 | 7.8 |
| TDS | mg/L | 1,804 | 4,080 |
| Aluminum | mg/L | <0.10 | <0.1 |
| Arsenic | mg/L | <0.002 | 0.06 |
| Barium | mg/L | <0.10 | <0.1 |
| Boron | mg/L | 1.61 | 1.1 |
| Cadmium | mg/L | <0.01 | <0.005 |
| Chromium | mg/L | <0.05 | <0.05 |
| Copper | mg/L | <0.01 | 0.04 |
| Iron | mg/L | <0.05 | <0.030 |
| Lead | mg/L | <0.05 | <0.05 |
| Manganese | mg/L | 0.01 | 0.05 |
| Mercury | mg/L | <0.001 | <0.001 |
| Molybdenum | mg/L | <0.10 | 0.5 |
| Nickel | mg/L | <0.05 | <0.05 |
| Selenium | mg/L | <0.175 | 0.07 |
| Uranium | mg/L | <0.0032 | 44 |
| Vanadium | mg/L | <0.10 | 2.5 |
| Zinc | mg/L | <0.02 | 0.02 |
| Radium 226 | pCi/L | 11.9 | 1,090 |

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# CHAPTER H. HYDROLOGIC MAPS AND DRAWINGS

The maps and drawings in this section are referenced in Chapter G – Hydrology. The numbers of the figures correspond to the number of the different sections in Chapter G.

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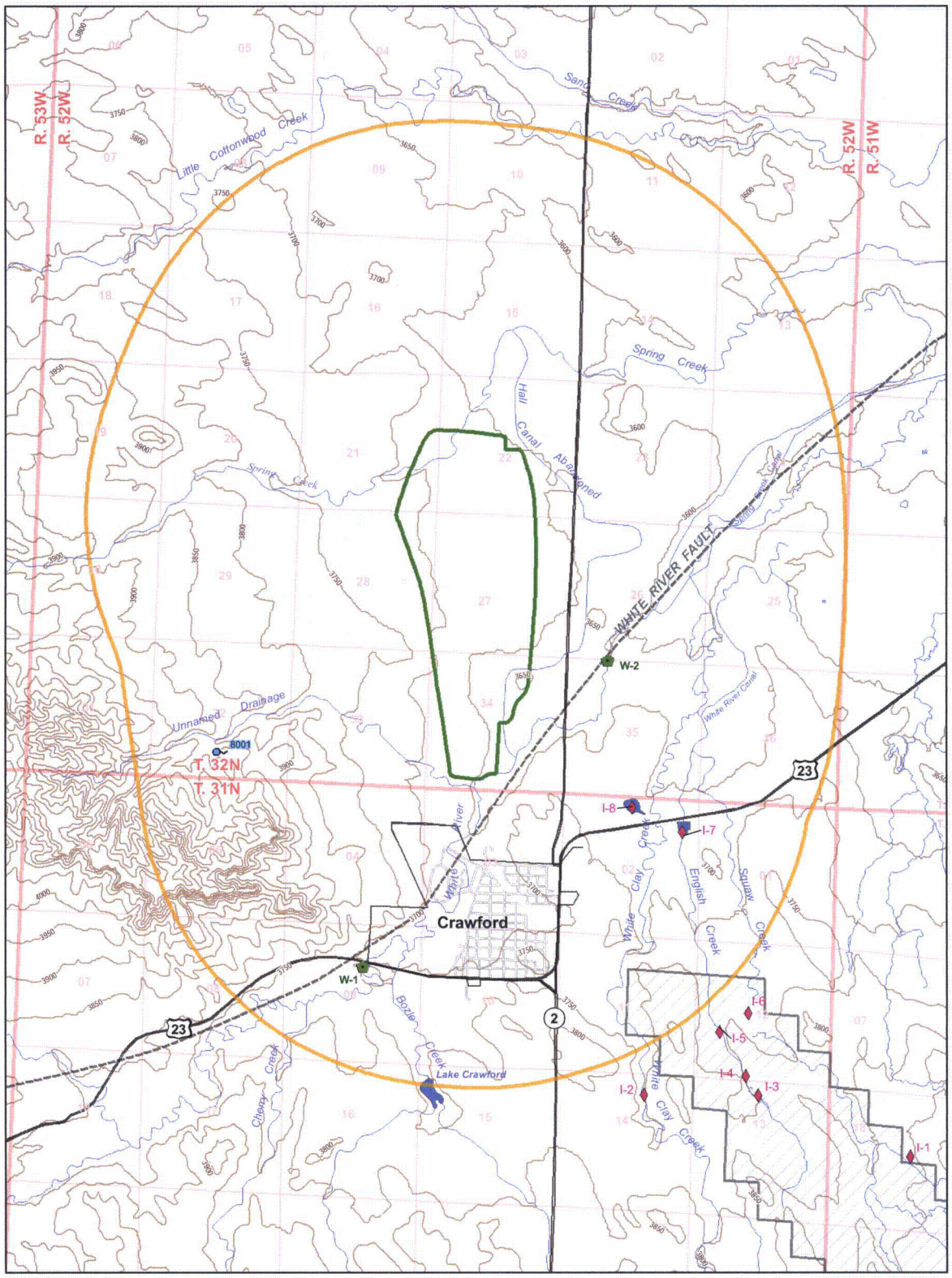


## LEGEND

- Surface Water Monitor
- Surface Water Impoundment
- Spring
- Streams
- White River Fault
- Elevation Contours (in Feet)
- Lake/Spring
- Proposed North Trend Expansion Area (NTEA)
- Current License Area
- 2.25-Mile Buffer of Proposed NTEA Boundary

N
W E

0 3,000 6,000
Scale in Feet

CROW BUTTE RESOURCES, INC.

FIGURE H.1-1
NORTH TREND
SURFACE WATER FEATURES

PROJECT: CO001322 MAPPED: JC CHECKED: MS

FILE: _H_1-1_NTSurfaceWater.mxd - 1/4/2010 @ 3:40:25 PM

ARCADIS
630 Plaza Drive, Ste. 100
Highlands Ranch, CO 80129
P: 720-344-3500 F: 720-344-3535
www.arcadis-us.com

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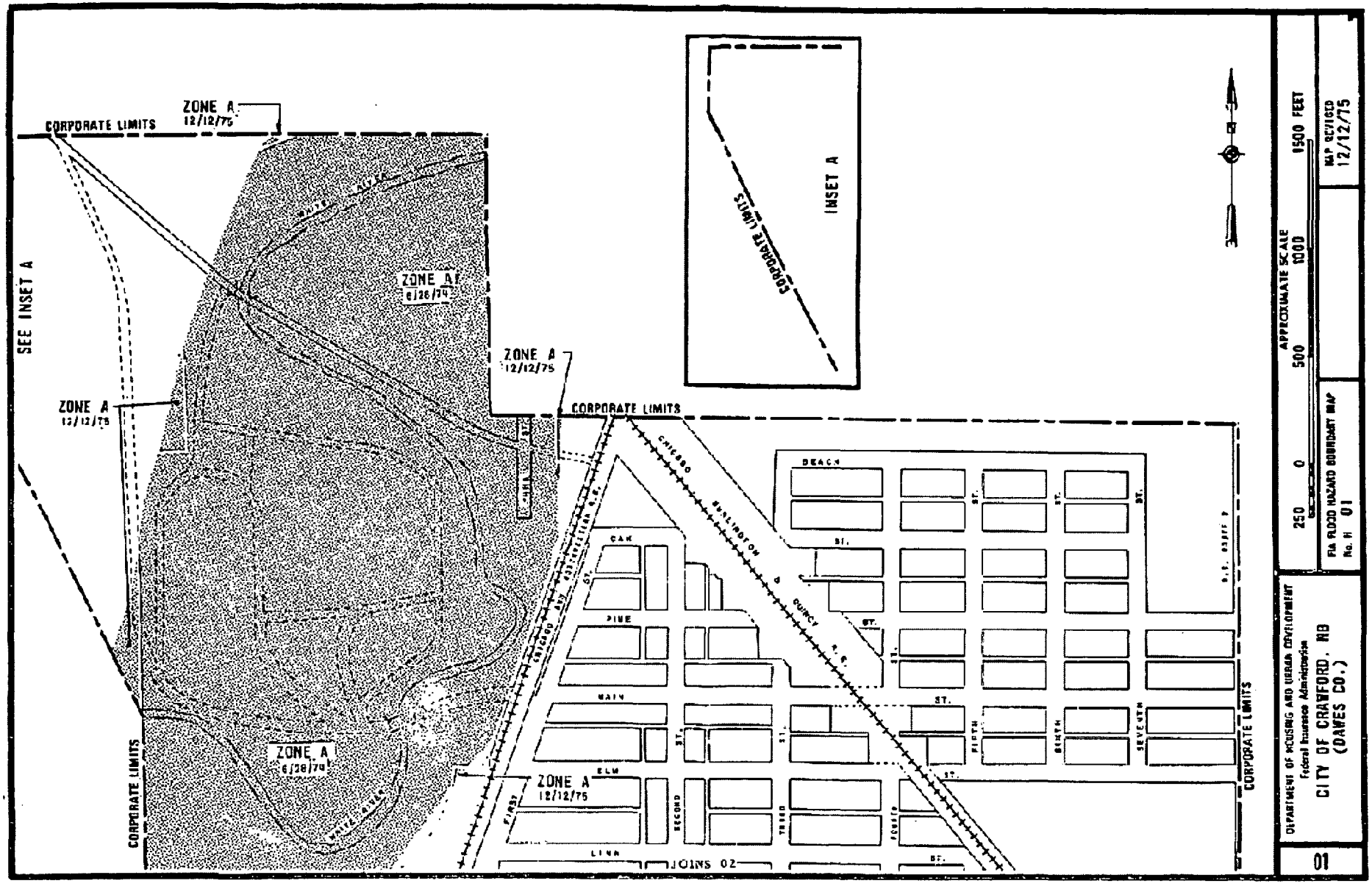
## FIGURE H.1-2 FEMA ZONE A FLOOD MAP

CROW BUTTE RESOURCES, INC.



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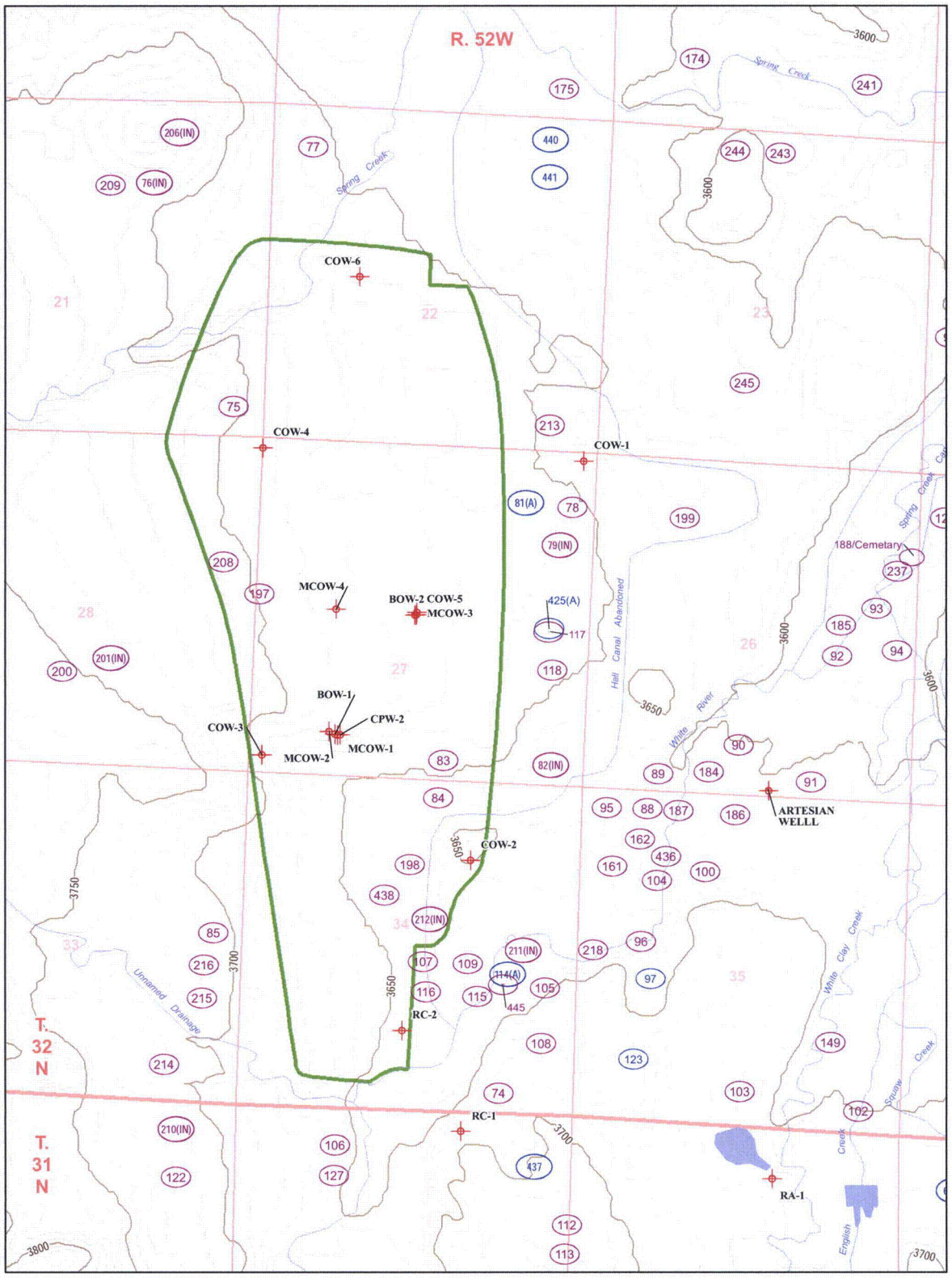


## LEGEND

- Monitoring Well
- 83 Brule Water Well (Active)
- 299(A) Brule Water Well (Abandoned)
- 76(IN) Brule Water Well (Inactive)
- 65 Chadron Water Well (Active)
- 81(A) Chadron Water Well (Abandoned)
- 298(IN) Chadron Water Well (Inactive)
- Elevation Contours (in Feet)
- Proposed North Trend Expansion Area

0 1,500 3,000
Scale in Feet

N
W E

CROW BUTTE RESOURCES, INC.

FIGURE H.2-1
LOCATION OF GROUNDWATER WELLS
IN NORTH TREND EXPANSION AREA

PROJECT: CO001322 MAPPED: JC CHECKED: MS

FILE: UIC_H_2-1_LocOfGWwells.mxd -12/11/09

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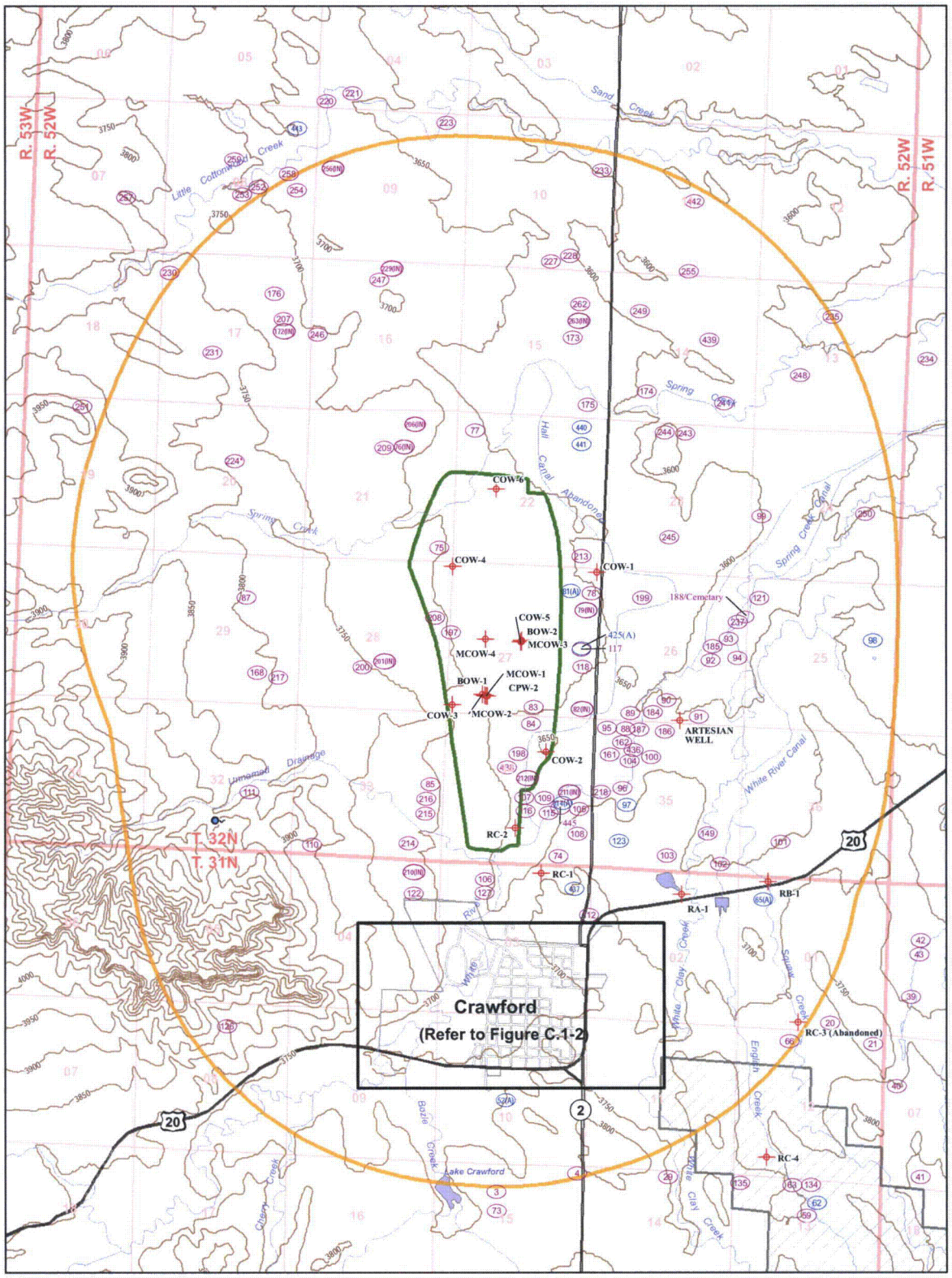


## LEGEND

- Monitoring Well
- Brule Water Well (Active)
- Brule Water Well (Abandoned)
- Brule Water Well (Inactive)
- Chadron Water Well (Active)
- Chadron Water Well (Abandoned)
- Chadron Water Well (Inactive)
- Spring
- Lakes
- Streams
- Elevation Contours (in Feet)
- Proposed North Trend Expansion Area (NTEA)
- Class III Permit Boundary
- 2.25-Mile Buffer of Proposed NTEA Boundary

* Locations of some wells are approximate and are based on available information.

0 3,000 6,000
Scale in Feet

N
W — E

CROW BUTTE RESOURCES, INC.

FIGURE H.2-2
LOCATION OF GROUNDWATER WELLS WITHIN 2 1/4 MILES OF NORTH TREND EXPANSION AREA

PROJECT: CO001322 MAPPED: JC CHECKED: MS

FILE: UIC_H_2-2_LocOfGWwells_2mB.mxd - 12/11/09

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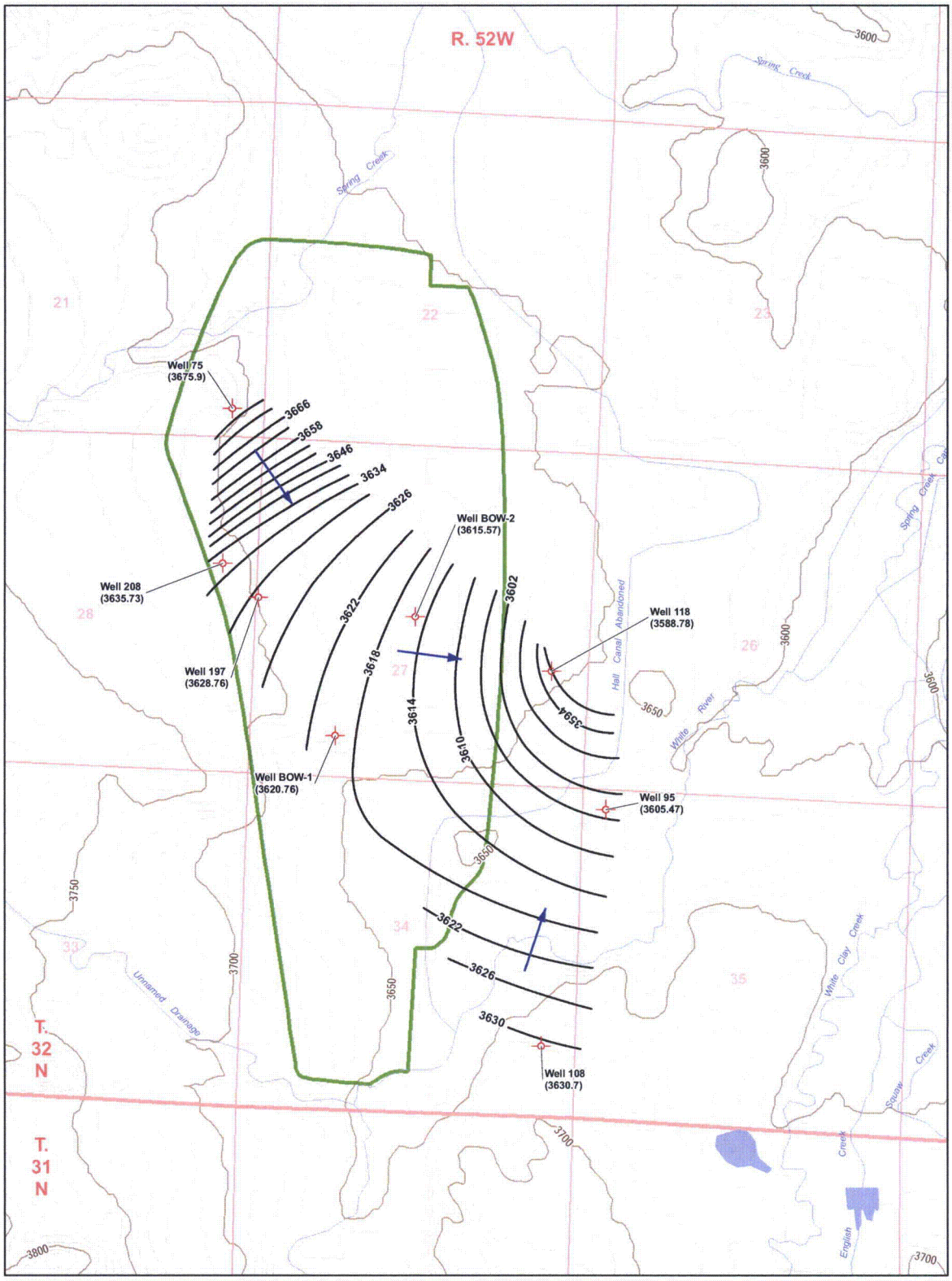


## LEGEND

- North Trend Monitoring Well
- Elevation Contours (FT-AMSL)
- Groundwater Elevation Contour (FT-AMSL, 4-FT Interval)
- (3560.17) Groundwater Elevation (FT-AMSL)
- Stream or Canal
- Direction of Groundwater Flow
- Lake
- Proposed North Trend Expansion Area (NTEA)

0 1,500 3,000
Scale in Feet

N
W E

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FIGURE H.2-3
NORTH TREND EXPANSION AREA
WATER LEVEL MAP
BRULE FORMATION (06/09/08)

PROJECT: CO001322 MAPPED: JC CHECKED: MS

FILE: _H_2-3_NT_WL_Brule.mxd - 1/4/2010 @ 4:36:02 PM

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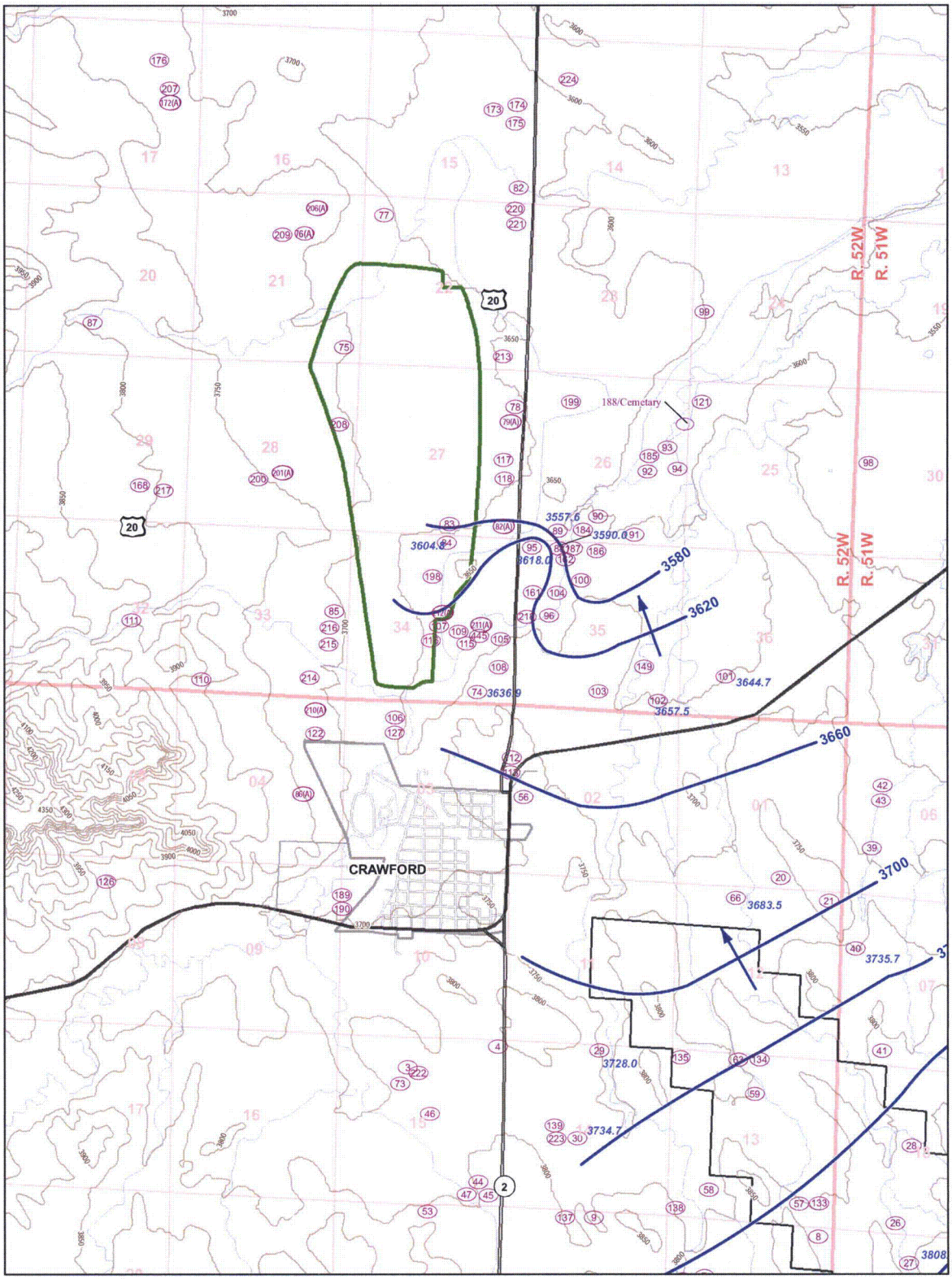


## LEGEND

- Groundwater Elevation (Brule Formation, FT-AMSL)
- Elevation Contours (FT-AMSL, 40-Ft Interval)
- (129) Brule Formation Water Well
  3968.8 and Water Level Elevation (FT-AMSL)
- Proposed North Trend Expansion Area (NTEA)
- Class III Permit Boundary
- Groundwater Flow Direction

0 3,000 6,000
Scale in Feet

N
W — E

CROW BUTTE RESOURCES, INC.

FIGURE H.2-4
REGIONAL WATER LEVEL MAP
BRULE FORMATION 1982-1983

PROJECT: CO001322 MAPPED: JC CHECKED: MS

FILE: _H_2-4_Regional_WL_Brule.mxd - 1/4/2010 @ 4:21:12 PM

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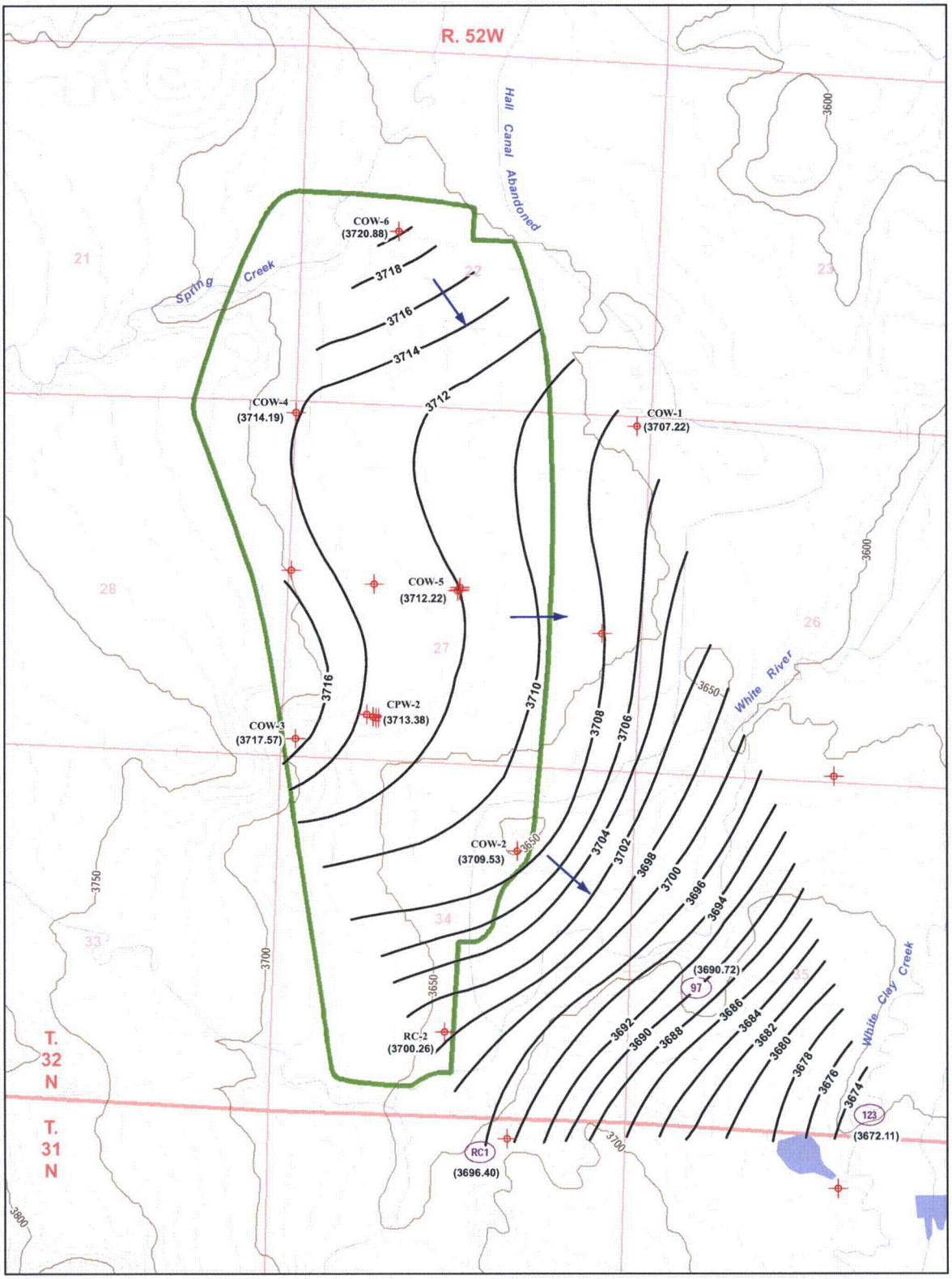


## LEGEND

- North Trend Monitoring Well
- 65 Basal Chadron Sandstone Water Well
- Elevation Contours (FT-AMSL)
- Groundwater Potentiometric Surface (FT-AMSL)
- (3700.26) Groundwater Elevation (FT-AMSL)
- Stream or Canal
- Lake
- Direction of Groundwater Flow
- Proposed North Trend Expansion Area (NTEA)

0 1,500 3,000
Scale in Feet

N
W E

CROW BUTTE RESOURCES, INC.

FIGURE H.2-5
NORTH TREND EXPANSION AREA
POTENTIOMETRIC SURFACE
BASAL CHADRON SANDSTONE (4/16/08)

PROJECT: CO001322 MAPPED: JC CHECKED: MS

FILE: _H_2-5_GW_BasalChadron.mxd - 12/30/2009 @ 1:12:51 PM

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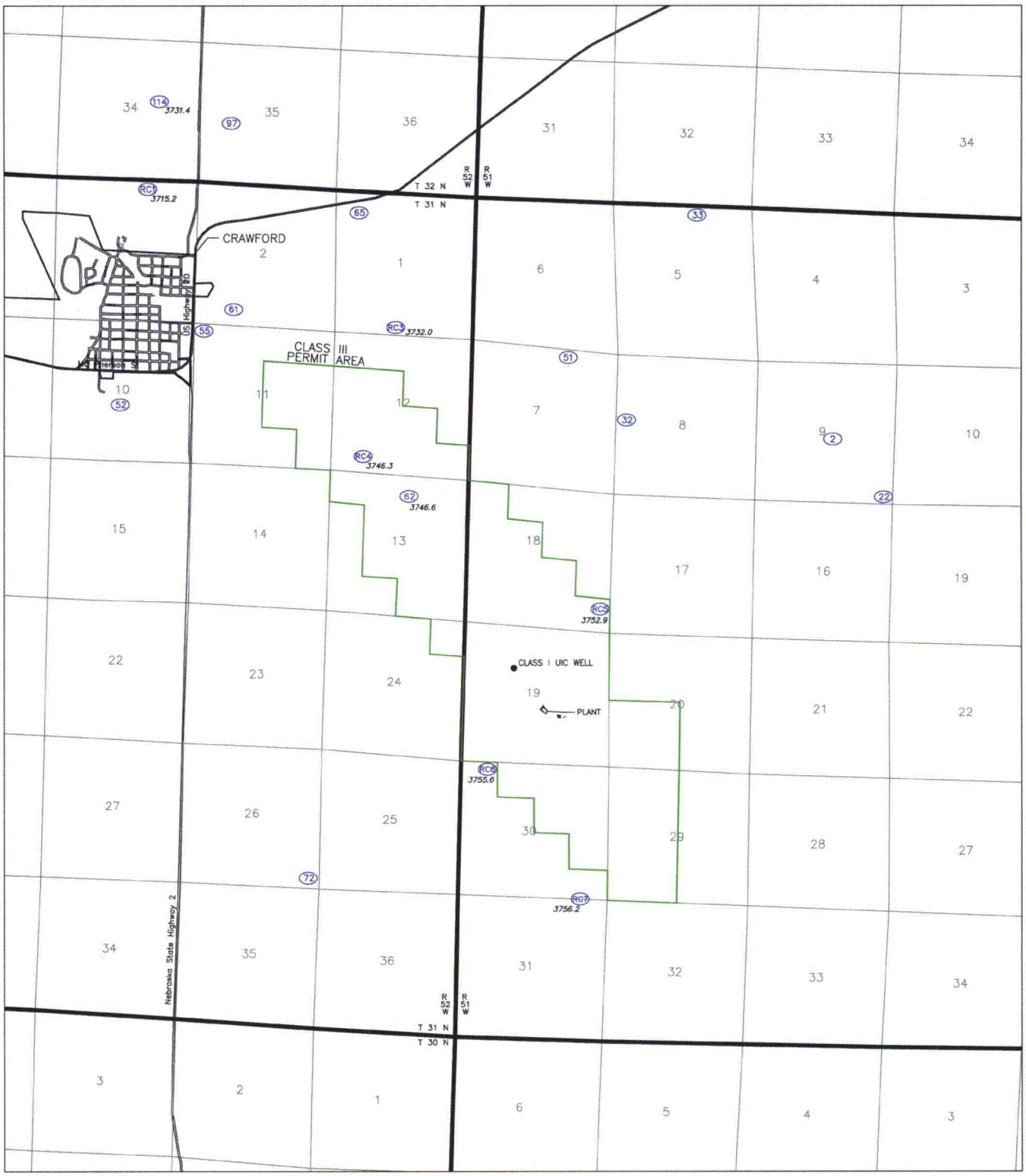


LEGEND

(129) Chadron Formation Water Level Elevation (amsl)
*3968.8*

0 0.5 1.0 2.0
SCALE IN FEET 1" = 1 MILE

N
W — E

CROW BUTTE RESOURCES, INC.

FIGURE H.2-6
REGIONAL WATER LEVEL MAP
BASAL CHADRON SANDSTONE 1982-1983

PROJECT: CO001322 MAPPED: JC CHECKED: MS

FILE: _H_2-6_pdf @06/18/2008

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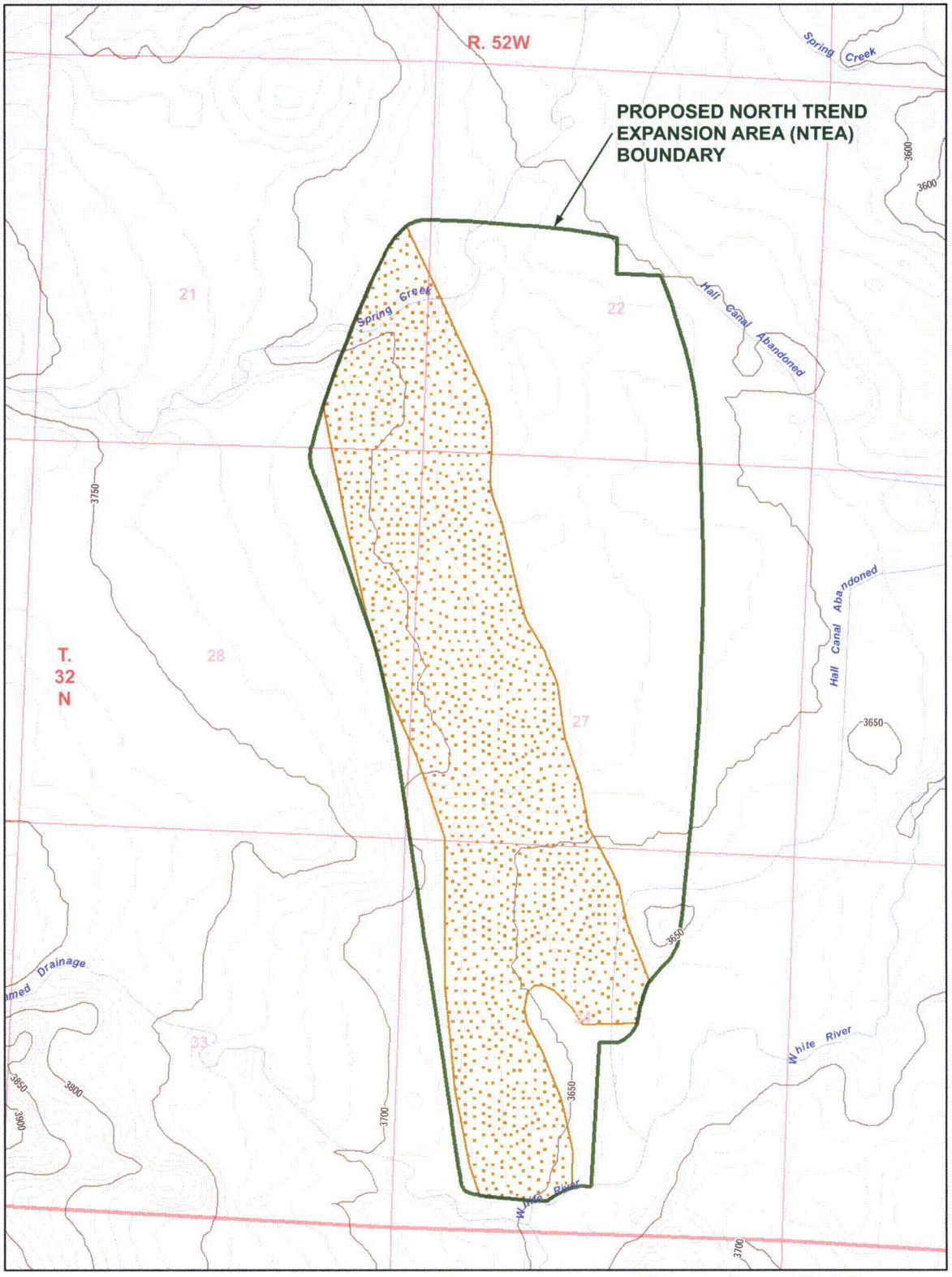


**LEGEND**

- Streams
- Proposed North Trend Expansion Area (NTEA)
- Ore Trend
- Elevation Contours (in Feet)

N
W — E

0 1,500 3,000
Scale in Feet

CROW BUTTE RESOURCES, INC.

FIGURE H.2-7
NORTH TREND ORE BODY

PROJECT: CO001322 MAPPED: JC CHECKED: MS

FILE: K:\CBR..UIC\ _H_2-7_Ore_Body.mxd - 1/4/2010 @ 3:31:35 PM

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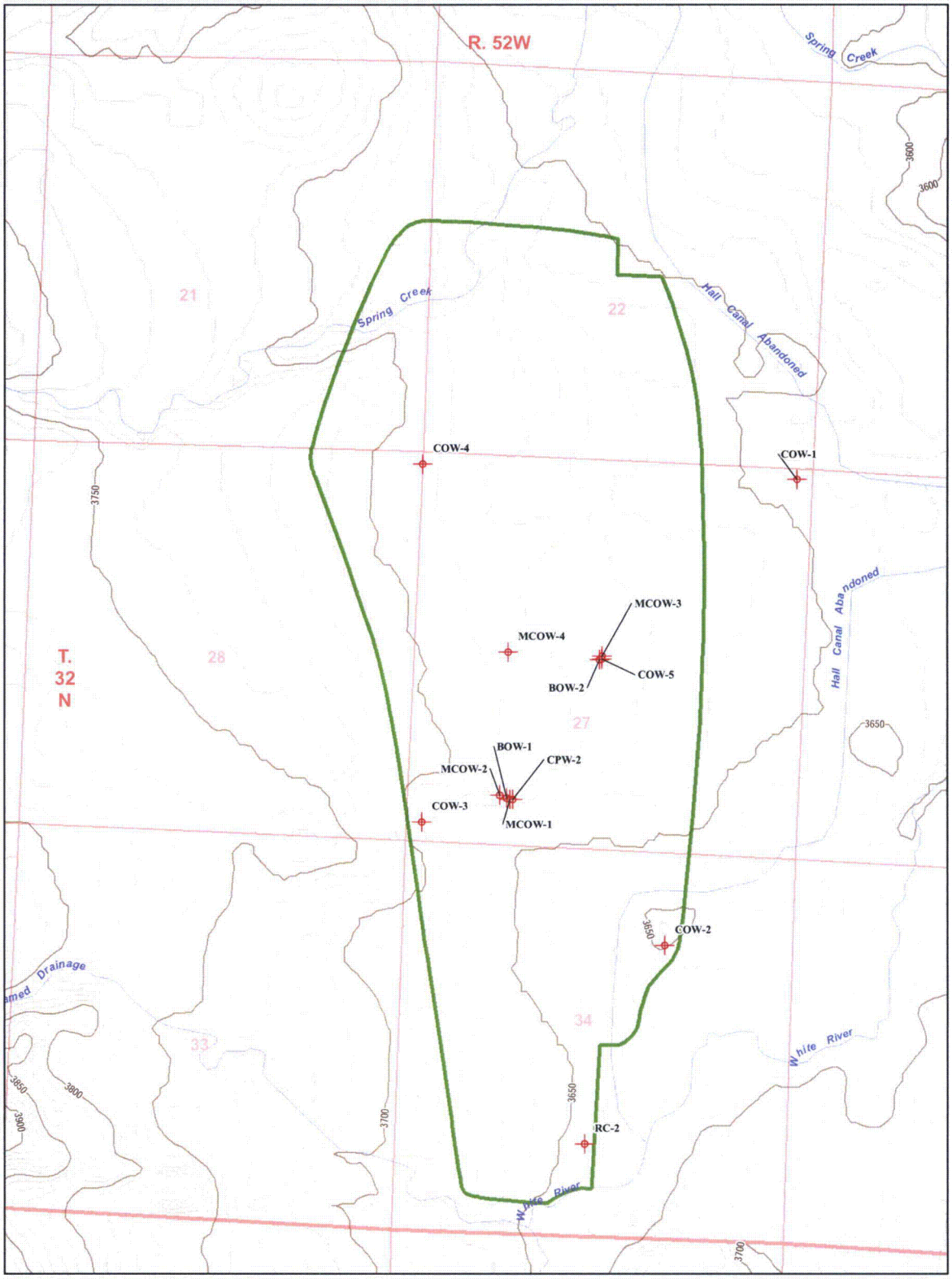


**LEGEND**

- North Trend Monitoring Well
- Elevation Contours (in Feet)
- Proposed North Trend Expansion Area (NTEA)

N
W — E

0 1,500 3,
Scale in Feet

CROW BUTTE RESOURCES, INC.

FIGURE H.2-8
LOCATION OF NORTH TREND PUMPING TEST MONITORING WELLS

PROJECT: CO001322 MAPPED: JC CHECKED: MS

FILE: K:\...UIC\ArcMaps_H_2-8_PumpTestMW.mxd @ 11/11/09

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Figure H.3-1
Drawdown at COW-2 (2006 Pumping Test)

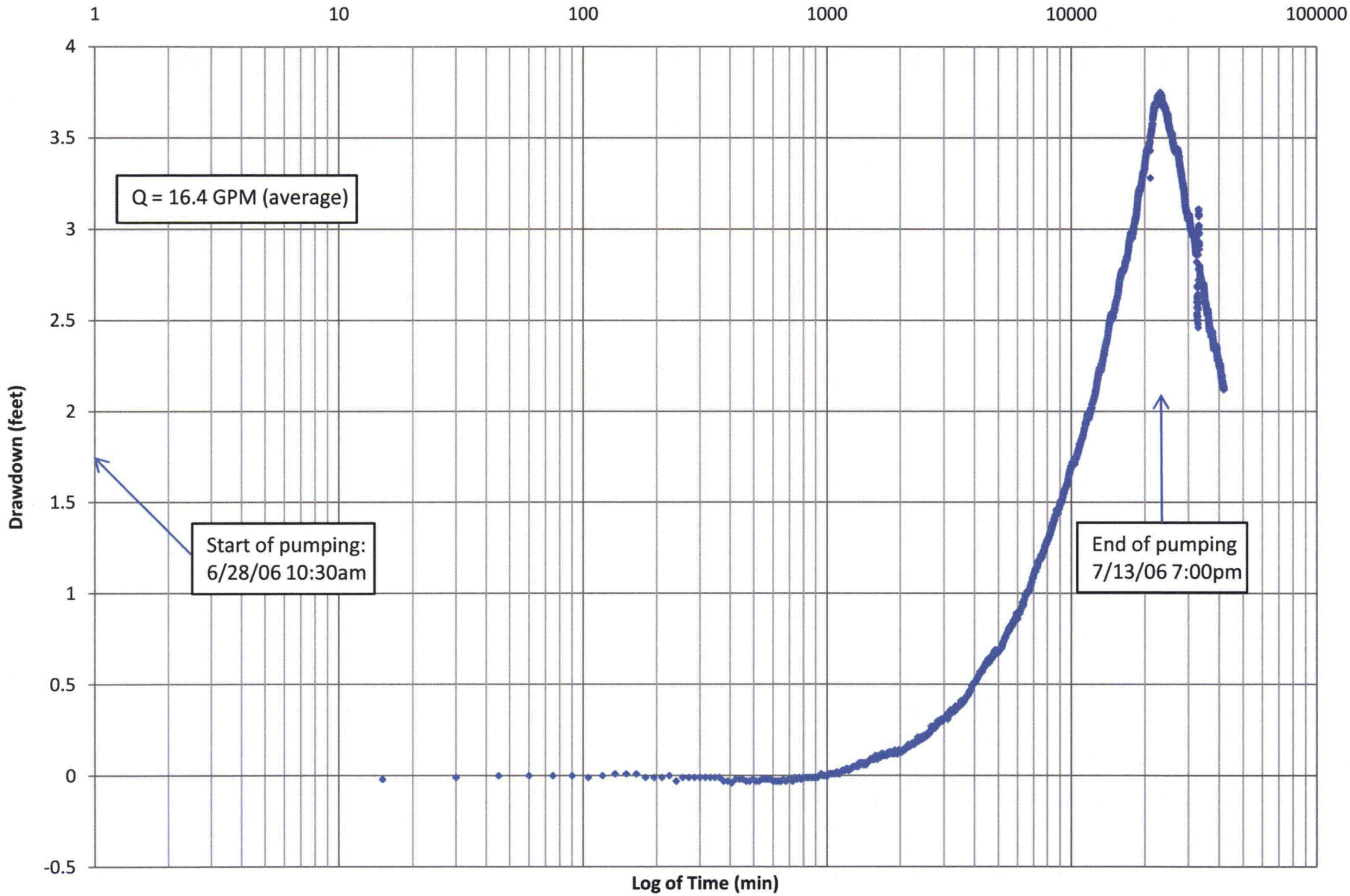

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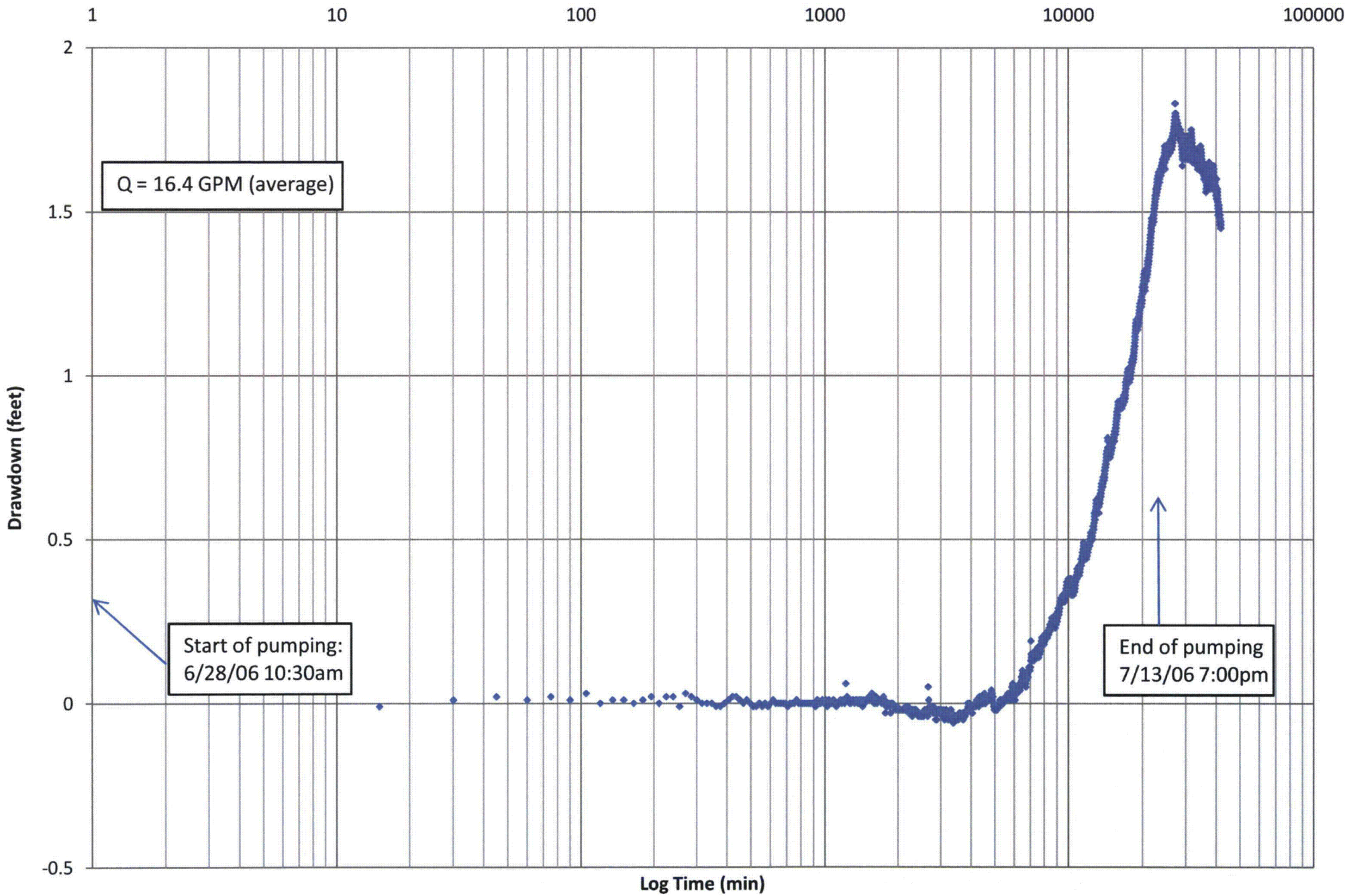
Figure H.3-2
Drawdown at RC-2 (2006 Pumping Test)



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