

CIMARRON CORPORATION

**LICENSE AMENDMENT REQUEST
LICENSE NO. SNM-928; DOCKET NO. 70-925**

**SITE DECOMMISSIONING PLAN
GROUNDWATER DECOMMISSIONING AMENDMENT**

**ARCADIS WORK PLAN FOR IN-SITU
BIOREMEDIATION OF GROUNDWATER**

Geochemical Modeling Evaluation

ENSR GROUNDWATER FLOW MODELING REPORT

DECEMBER 2006

CIMARRON CORPORATION

P.O. BOX 315 • CRESCENT, OK 73028

December 11, 2006

Mr. Kenneth Kalman
Office of Nuclear Materials Safety & Safeguards
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Re: Docket No. 70-925; License No. SNM-928
License Amendment Request – License Conditions and Groundwater Decommissioning

Dear Mr. Kalman:

Cimarron Corporation (Cimarron) submits this license amendment request to amend the Site Decommissioning Plan to address groundwater decommissioning, including needed changes to license SNM-928, Conditions 10, 26, 27(a), and 27(b). Decommissioning of soils and buildings has been demonstrated complete to NRC's acceptance in all areas excluding subsurface soil in Burial Area #1. Subsurface soil in this area will be addressed in a separate submittal as a response to NRC comments on the Final Status Survey Report for Subarea F. Groundwater is the only remaining media still requiring decommissioning. These license amendments will provide for the completion of all remaining decommissioning activities.

Recent submittals present a better understanding of the nature and extent of licensed material impact in groundwater than was possible when existing license conditions were issued. These proposed license amendments will modify the license to accurately reflect:

- Requirements still relevant after decommissioning of soil and buildings is complete,
- Remediation of groundwater in areas exceeding release limits,
- Requirements for post-remediation monitoring programs to demonstrate compliance,
- Methodology to demonstrate compliance, and
- Approval to abandon groundwater monitoring wells in areas for which continued monitoring is not needed.

This license amendment request includes three attachments. One of those attachments is Site Decommissioning Plan – Groundwater Decommissioning Amendment, which itself contains two attachments prepared by consultants retained by Cimarron. To eliminate confusion, the attachments to this license amendment request are labeled, "LAR Attachment 1", "LAR Attachment 2", and "LAR Attachment 3". Attachments to the Site Decommissioning Plan – Groundwater Decommissioning Amendment are labeled "SDP Attachment 1" and "SDP Attachment 2".

The following sections of this letter summarize the requested amendments to the License Conditions.

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License Condition 10

Condition 10 references thirty-nine (39) documents. Sixteen (16) of these documents address decommissioning activities now complete or no longer relevant. Twelve (12) address final status surveys for which NRC has already performed confirmatory surveys and either released the areas or agreed that the areas are releasable. Six (6) address a previous version of the radiation protection program or the designation of the Radiation Safety Officer.

LAR Attachment 1 is a table listing the documents cited in License Condition 10, with a brief description of the content of each document and Cimarron's recommendations to delete or retain the document, or to supersede it with another. Cimarron requests that License Condition 10 be amended to read,

For use in accordance with statements, representations, and conditions contained in letters dated September 14, 1990; July 25, 1995; January 28, 1997; and February 10, 1998.

License Condition 26

License Condition 26 references the original Radiation Protection Plan (RPP), at that time submitted as Annex A to the Site Decommissioning Plan, subsequent responses to NRC comments on the RPP, and subsequent versions of the RPP. Since this condition was added to the license, NRC has established a program for revision of the RPP in License Condition 27(e). Cimarron has made numerous revisions to the RPP in accordance with that condition. NRC has received copies of all the changes made to the RPP, along with the evaluation forms documenting the ALARA committee's evaluation of those changes, and providing assurance that those changes are in conformance with criteria specified in License Condition 27(e). These previous versions of the RPP are no longer relevant. Cimarron therefore proposes that License Condition 26 be amended to read,

Cimarron shall conduct a radiation protection program in accordance with statements, representations, and conditions contained in the Radiation Protection Plan submitted February 9, 2006, and subsequent revisions thereof as authorized by License Condition 27(e).

License Condition 27(a)

License Condition 27(a) references twelve (12) documents providing the basis for decommissioning the site. As with Condition 10, several relate to completed work, or to documents which should be superseded by more recent documents. For instance, four of the documents cited in this condition relate to the surveys of concrete rubble, which was demonstrated to be releasable to NRC's satisfaction as per a letter dated March 1, 1999.

Condition 27(a) should also be amended to reflect additional information obtained and reported to NRC. This license condition identifies documents which address the decommissioning of groundwater at the site. LAR Attachment 2 is a table listing the documents cited in License Condition 27(a), with a brief description of the content of the document and recommendations to delete or retain it, to supersede it with another, or to add a new document. LAR Attachment 3 is

the Site Decommissioning Plan – Groundwater Decommissioning Amendment. This document addresses groundwater remediation, post-decommissioning monitoring, and other groundwater decommissioning issues that must be addressed before the site can be released for unrestricted use. Cimarron anticipates revision of this document in accordance with NRC comments; the dates referenced in this and the requested wording for license condition 27(b) reference this version – the final amended language should reflect the submittal date of the NRC-approved revision of this document. Cimarron requests that license Condition 27(a) be amended to read,

The licensee is authorized to remediate the Cimarron facility in accordance with statements, representations, and conditions contained in submittals dated April 19, 1995; July 30, 1998; March 4, 1999; January 29, 2003; December 30, 2003; August 10, 2005; August 11, 2005, and October 26, 2006, December 11, 2006, and subsequent revisions of these documents as amended in accordance with Condition 27(e).

License Condition 27(b)

License Condition 27(b) establishes the criterion of 6.7 Bq/l (180 pCi/l) total uranium as the groundwater release criterion for uranium at the Cimarron site. It also specifies the following means of demonstrating compliance with the limit in the statement,

“... NRC will not terminate Radioactive Materials License SNM-928 until Cimarron demonstrates that the total uranium concentrations in all wells have been below the groundwater release criteria for eight consecutive quarterly samples (the past 2 years).”

Since this license condition was issued, Cimarron has installed numerous groundwater monitoring wells to identify areas of groundwater impact and to characterize the hydrogeology and geochemistry of impacted areas. We understand it was never NRC’s intent that Cimarron sample *every well* on the site for eight consecutive quarters to demonstrate compliance with the release criterion. NRC intended that each well used to demonstrate compliance must yield groundwater below the limit – i.e., Cimarron will not employ “averaging” for groundwater. However, strict interpretation of this license condition would require that Cimarron sample over 160 wells during eight successive quarters to satisfy this criterion. This is an unreasonable burden, and this license condition should be amended to reflect NRC’s original intent.

The existing environmental monitoring program, Section 15 of Radiation Protection Program (RPP), is no longer necessary for assessment purposes, nor is it appropriate for groundwater decommissioning. This program, in which numerous wells are sampled on an annual basis, requires the expenditure of effort and expense with no benefit to either Cimarron or NRC. The attached Site Decommissioning Plan – Groundwater Decommissioning Amendment includes justification for termination of monitoring in areas not requiring remediation, as well as a post-decommissioning monitoring plan for areas still requiring remediation. The post-decommissioning monitoring plan provided in Section 8 of the Site Decommissioning Plan – Groundwater Decommissioning Amendment (LAR Attachment 3) is intended to replace the environmental monitoring program.

Cimarron believes it is authorized to eliminate the environmental monitoring program in accordance with license Condition 27(e). However, because groundwater remediation and post-

decommissioning monitoring are all that remain to complete site decommissioning, Cimarron requests NRC concurrence to delete Section 15 of the RPP and to terminate the environmental monitoring program.

Cimarron requests that license Condition 27(b) be amended to read,

The release criterion for groundwater at the Cimarron site is 6.7 Bq/l (180 pCi/l) total uranium. Cimarron must confirm that groundwater complies with the criterion in accordance with NRC-approved Post-Decommissioning Monitoring Plans for each area exceeding the criterion. Cimarron will retain control of all licensed property exceeding the release criterion and/or hydrologically downgradient from property exceeding the release criterion until post-decommissioning monitoring demonstrates that the groundwater release criterion is met. The Oklahoma Department of Environmental Quality may require continued groundwater monitoring for non-radioactive components under its authority.


Summary

In this license amendment request, Cimarron is requesting:

- Amendment of license Condition 10
- Amendment of license Condition 27(a)
- Concurrence to delete Section 15 of the RPP
- Amendment of license Condition 27(b)
- Approval of Site Decommissioning Plan – Groundwater Decommissioning Amendment

Cimarron included the requests for amendment of license conditions 10 and 27(a), as well as deletion of Section 15 of the RPP in this letter at NRC's request, because these proposed amendments are related to the groundwater issues still remaining at the site. Cimarron recognizes that NRC may address those license amendments separately from the Site Decommissioning Plan – Groundwater Decommissioning Amendment for administrative reasons. If you have any questions regarding this license amendment request, please call me at 405-775-5194 (OKC) or 405-642-5152 (mobile).

Sincerely,



Jeff Lux
Project Manager

Cc: Blair Spitzberg, NRC Region IV
David Cates, DEQ
Mike Broderick, DEQ

LAR ATTACHMENT 1
CIMARRON LICENSE SNM-928 - CONDITION 10 REFERENCES

Document Date	Description	Recommendation
11/19/1985	Request to possess 6,000 kg Thorium	License Item 6(D) authorizes possession of 6,000 kg Thorium - delete from license.
3/3/1986	Request to increase authorized quantity of <5% U-235 from 1,200 g to 6,000 g	License Item 6(A) authorizes possession of 1,200 g of U-235 - delete from license.
9/4/1987	Request to bury Option 2 material on site	Disposal of Option 2 material is complete - delete from license.
11/2/1989	Final release survey for Pu plant	Subarea I, in which the Pu plant resides, has been released for unrestricted use - delete from license.
8/22/1990	Request to discontinue filing 70.59 reports	9/14/90 letter from NRC (next citation) approves request - delete from license.
9/14/1990	NRC approval to discontinue 70.59 reports	See 8/22/90 above - Retain in condition 10
6/24/1992	Request for information from NRC - Organization chart, detail on invoice, status of Pu plant license termination, status of on site disposal cell approval, status of adequacy of disposal area and lagoon cleanup (Subarea L).	Organization has changed multiple times since this submittal, financial detail was provided, Subarea with Pu plant was released for unrestricted use, disposal is complete and Subarea L was released for unrestricted use - delete from license.
2/25/1993	Response to 1/8/93 RAI on disposal cell - Subsidence, Wind and water erosion, Deed notice and location markers, Commitment to complete decommissioning	Disposal and associated work is complete, condition 23 still requires continuing inspections - delete from license.
4/19/1994	Onsite Disposal Plan - Responsibilities, Definitions, Precautions, Characterization, Transportation, Disposal, Determination of activity in cell, Run-on and run-off control, Cap placement, Record of disposal	Decommissioning and disposal of soils is complete - delete from license.
5/31/1994	Response to 4/19/94 RAIs - Final survey of material in cell, Average concentration determination, Reg Guide 1.86 criteria, Option 2 limit, Hot spot averaging, Final survey of excavations, Final survey of cap, Use of NUREG/CR-5849	Decommissioning and disposal of soils is complete, issues addressed. Subarea N demonstrated releasable, but not released due to groundwater in Subarea K - delete from license.
7/20/1994	Response to 7/18/94 RAI - How to sample and analyze for Kd of soil in disposal cell	Decommissioning and disposal of soils is complete - delete from license.
9/21/1994	Response to 8/12/94 RAIs - Hot spot averaging of soil in disposal cell, QC samples, NUREG/CR-5849 calculations, Soil counter calibration	Disposal is complete, soil counter calibration has changed since this time and has been inspected repeatedly - delete from license

LAR ATTACHMENT 1
CIMARRON LICENSE SNM-928 - CONDITION 10 REFERENCES

Document Date	Description	Recommendation
11/3/1994	Follow up on telephone conversation - Exposure to workers placing soil in disposal cell	Decommissioning and disposal of soils is complete - delete from license.
11/15/1994	License Amendment Request - Changes to Appendix A and Annex A	Appendix A and Annex A have changed substantially since this submittal. This submittal is no longer relevant - delete from license.
12/16/1994	License Amendment Request - Cimarron desires to designate Karen Morgan as RSO	License Condition 24 designates Karen Morgan as RSO - no longer needed - delete from license.
4/12/1995	Soil density test results for waste in and cap on disposal cell, Cell 2	Decommissioning and disposal of soils is complete - delete from license.
6/5/1995	Resume for Karen Morgan	License Condition 24 designates Karen Morgan as RSO - no longer needed - delete from license.
7/5/1995	Response to telephone inquiry on hot spot averaging in South Uranium Yard	The subject area (Subarea K) has been released for unrestricted use - delete from license.
7/25/1995	Submittal of Final Status Survey Plan for Phase II Areas	FSSR for Subarea F, a Phase II area, is in NRC review - retain in Condition 10.
8/9/1995	Submittal of Final Status Survey Report for Unaffected Areas (Phase I)	All Phase I areas have been released for unrestricted use -delete from license.
11/13/1995	Response to NRC comments on Final Status Survey Report for Phase I Areas	All Phase I areas have been released for unrestricted use -delete from license.
1/23/1996	License Amendment Request - Organization Change	Organization has changed since this submittal - it is no longer appropriate - delete from license
4/25/1996 (Listed twice)	Option 2 material disposal procedure change from stockpiling to direct transportation to cell	Decommissioning and disposal of soils is complete - delete from license.
6/10/1996	RAIs regarding 4/25/96 proposal	Decommissioning and disposal of soils is complete - delete from license.
8/28/1996	Hot spot averaging in stockpiles and cell - not performed in five pond areas	Decommissioning and disposal of soils is complete - delete from license.
9/20/1996	Response to 8/16/96 RAIs - License Amendment Request - Changes to Appendix A and Annex A	Appendix A and Annex A have changed substantially since this submittal - delete from license.
11/20/1996	Proposed lung fluid solubility test	Decommissioning and disposal of soils is complete - delete from license.

LAR ATTACHMENT 1
CIMARRON LICENSE SNM-928 - CONDITION 10 REFERENCES

Document Date	Description	Recommendation
1/2/1997	Response to 12/2/96 RAIs on Annex A	Appendix A and Annex A have changed substantially since this submittal - delete from license.
1/28/1997	Response to 10/31/96 NRC Comments on Final Status Survey Plan for Phase II Areas	FSSR for Subarea F, a Phase II area, is in NRC review - retain in Condition 10.
5/6/1997	Response to 2/25/97 NRC Comments - Volumetric averaging and groundwater contamination at Ponds 1 and 2, Averaging of paved areas, concrete in drainageways.	Issues all addressed except groundwater. Groundwater is addressed in Condition 27(b) - delete from license.
5/16/1997	Response to 3/5/97 NRC Comments on RPP -	Appendix A and Annex A have changed substantially since this submittal - delete from license.
12/5/1997	Response to 10/3/97 NRC Comments on Phase III Final Status Survey Plan	FSSRs for all Phase III areas have been approved by NRC. This is no longer needed - delete from license.
2/10/1998	Agenda for 2/17/98 Meeting w/ NRC - includes information on dose calculations	Provides basis for limits now stipulated in the license. Includes information on dose calculations - retain in Condition 10.
6/26/1998	Response to 2/9/98 NRC Comments on Phase III Final Status Survey Plan	FSSRs for all Phase III areas have been approved by NRC. This is no longer needed - delete from license.
7/2/1998	Responses to 7/1/98 Conference Call - Resolving questions about inspection report #70-925/97-02 - soil counter "traceability" and typographical error	Issues raised during conference call have been addressed - delete from license.
2/15/2000	Submittal of Final Status Survey Report for Phase III, Subarea K	Subarea K has been released from license - delete from license.
2/20/2001	Response to 1/29/01 NRC Comments on FSSR for Phase III, Subarea K - Hot spot averaging, revise Table 4.1	Subarea K has been released from license - delete from license.
4/17/2002	Decommissioning Schedule	Schedule no longer relevant - delete from license.
5/10/2002	Revised Decommissioning Schedule	Schedule no longer relevant - delete from license.

LAR ATTACHMENT 2
CIMARRON LICENSE SNM-928 - CONDITION 27(a) REFERENCES

Document Date	Description	Recommendation
4/19/1995	Decommissioning Plan for Cimarron Corporation's Former Nuclear Fuel Fabrication Facility at Crescent, Oklahoma	Foundational document for decommissioning - retain in Condition 27(a).
9/10/1996	Response to 7/11/96 NRC Comments on Decommissioning Plan	Work completed for all media except groundwater. Groundwater issues addressed more fully in later documents - delete from license.
5/6/1997	Response to 2/25/97 NRC Comments on Cimarron's 9/10/97 Response	Work completed for all media except groundwater. Groundwater issues addressed more fully in later documents - delete from license.
8/26/1997	Response to 7/1/97 NRC Comments on Decommissioning Plan - Waste Ponds #1 and #2, Concrete rubble	Waste Ponds released. Rubble addressed as per March 1, 1999 NRC letter - delete from license.
3/10/1998	Final Status Survey Report for Concrete Rubble in Sub-Area "F"	Rubble addressed as per March 1, 1999 NRC letter - delete from license.
3/12/1998	Final Status Survey Report for Phase III Sub Area "O" Uranium Waste Ponds #1 and #2 (Subsurface)	Waste Ponds released - delete from license.
6/15/1998	Response to 5/20/98 NRC Comments on Final Status Survey Report for Concrete Rubble in Sub-Area "F"	Rubble addressed as per March 1, 1999 NRC letter - delete from license.
7/30/1998	Decommissioning Plan Ground Water Evaluation Report	Amends 4/19/95 decommissioning to address groundwater issues identified since 1995 - add to Condition 27(a).
10/6/1998	Response to 9/10/98 NRC Comments Regarding Residential Inhalation Dose from Concrete Rubble in Sub-Area "F"	Rubble addressed as per March 1, 1999 NRC letter - delete from license.
3/4/1999	Response to 1/19/99 NRC Comments on "Decommissioning Plan Groundwater Evaluation Report"	Retain in Condition 27(a).
1/29/2003	Burial Area #1 Groundwater Assessment Report	Reports hydrogeology and delineates groundwater impact in Burial Area #1. - add to Condition 27(a).
12/30/2003	Tc-99 Groundwater Assessment Report	Demonstrates that Tc-99 does not require remediation - add to Condition 27(a).
12/30/2003	Assessment Report for Well 1319 Area	Delineates groundwater impact in Well 1319 Area - add to Condition 27(a).

LAR ATTACHMENT 2
CIMARRON LICENSE SNM-928 - CONDITION 27(a) REFERENCES

8/10/2005	Site-Wide Groundwater Assessment Review	Provides description of site-wide source identification and investigation, and delineates areas requiring monitoring and/or remediation - add to Condition 27(a).
8/11/2005	Refined Conceptual Site Model	Provides site-wide hydrogeologic information and area-specific hydrogeological and geochemical information for areas requiring groundwater remediation - add to Condition 27(a).

CIMARRON CORPORATION
LICENSE SNM-928; DOCKET NUMBER 70-925
SITE DECOMMISSIONING PLAN
GROUNDWATER DECOMMISSIONING AMENDMENT
DECEMBER, 2006

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ATTACHMENTS

Attachment 1 – Work Plan for In-Situ Bioremediation of Groundwater at the Cimarron Site (ARCADIS, 2006)

Attachment 2 – Groundwater Flow Modeling Report, Cimarron Site, (ENSR, 2006)

1.0 Executive Summary

Cimarron Corporation (Cimarron) owns a former nuclear fuel production facility near Crescent, Oklahoma. The Cimarron site was closed in 1975, and is being decommissioned in accordance with an NRC-approved decommissioning plan under License SNM-928. The license now addresses the decommissioning of the facility, which is complete for all environmental media except groundwater. Cimarron plans to decommission the site for release for unrestricted use. Cimarron proposed a release criterion for uranium in groundwater using site-specific parameters. NRC stipulated release criteria of 180 pCi/l for total uranium in groundwater and 3,790 pCi/l for Tc-99 in groundwater.

In the NRC-approved site decommissioning plan, Cimarron maintained that natural attenuation may reduce groundwater to concentrations below the stipulated criteria without “active” remediation. It stated that, should continued monitoring indicate that this is not the case, additional assessment or more aggressive remedial methods would be employed. This groundwater decommissioning amendment is being submitted as a license amendment request to fulfill that commitment.

This submittal addresses the active remediation of groundwater in areas exceeding groundwater release criteria, and establishes a post-decommissioning monitoring program for those areas. This submittal also provides monitoring results for specific areas that demonstrates that those areas now comply with groundwater release criteria. In summary, this amendment to the existing decommissioning plan:

- Proves that groundwater in most of the site is releasable for unrestricted use,
- Provides for groundwater remediation in areas exceeding release criteria,
- Modifies a license condition, and
- Replaces the existing environmental monitoring program with a post-decommissioning monitoring program.

2.0 Facility Operating History

2.1 License Number/Status

The Cimarron facility was operated as a nuclear fuel production facility under License SNM-928 until it was closed in 1975. Facility decommissioning began in 1976; decommissioning continues in accordance with a decommissioning plan approved by NRC in August 1999. The site is one of the former Site Decommissioning Management Program (SDMP) sites referenced in 10 CFR 70.38a(3)iii. The decommissioning and final status survey of buildings and soils is complete. Groundwater exceeds license criteria in three areas. This amendment to the existing Site Decommissioning Plan (SDP) addresses the remediation of groundwater in these three areas.

2.2 License History

The licensing history of the site, from issuance through April 1995, is presented in Section 1 of Site Decommissioning Plan (Chase Environmental Group, April 1995). The SDP was supplemented by Site Decommissioning Plan – Groundwater Evaluation Report (GER, Chase Environmental Group, 1998). NRC approved the SDP on August 23, 1999.

The SDP and GER presented information indicating that natural attenuation may reduce the concentration of licensed material in groundwater sufficiently that active groundwater remediation may not be needed. The GER stated that, should information indicate that natural attenuation may not achieve this, additional assessment and/or remediation may be needed. Additional assessment has been performed, and this amendment to the SDP provides for active remediation in the three areas in which groundwater continues to exceed license criteria.

Radiological Characterization Report for Cimarron Corporation's Former Nuclear Fuel Fabrication Facility (Chase Environmental Group, 1994) divided the Cimarron site into Subareas A through O (Figure 1.1). These Subareas were grouped into three "Phases". Phase I Subareas (A through E) were surveyed as unimpacted areas. The final status

survey plan for Phase I Subareas was approved by NRC in May 1995. Phase II Subareas (F through J) and Phase III Subareas (K through O) were surveyed as impacted areas. Final status survey plans for Phase II and Phase III Subareas were approved in March 1997 and September 1998, respectively.

Cimarron submitted Final Status Survey reports for each subarea of the site from 1996 to 2005. Table 1.1, taken from Final Status Survey Report, Subarea F (Nextep Environmental, Inc., 2005) provides a listing of the dates of final status survey plans and reports, status of confirmatory surveys, and the dates of release for the fifteen Subareas. NRC released all but three subareas in License Conditions 25 and 28 through 30. Remaining subareas will not be released until groundwater remediation is complete.

This amendment to the existing Site Decommissioning Plan is one portion of a license amendment request intended to bring the license up to date and provide for the remaining decommissioning work required to obtain release for unrestricted use.

2.3 Previous Decommissioning Activities

Previous decommissioning activities include the decontamination and removal/disposal of all equipment used in the processing of feed material and the production of uranium fuel, as well as the decontamination of the process buildings. A portion of the uranium building has been dismantled and removed from the site. All remaining buildings were released for unrestricted use in License Conditions 29 and 30.

Soil yielding greater than the 30 pCi/g total uranium criterion specified in License Condition 27(c) was excavated. Soil exceeding 100 pCi/g total uranium was packaged and shipped to a licensed disposal facility. Soil yielding between 30 and 100 pCi/g total uranium was buried in an onsite disposal cell in accordance with License Condition 27(a). Decommissioning of soils is complete at the Cimarron site. Final status survey reports were submitted for all areas of the site between 1996 and 2005. Three subareas have not yet been released for unrestricted use: Subareas F, G, and N. The remaining subareas were released for unrestricted use in License Conditions 25, 28, 29, and 30.

Groundwater which exceeds or recently exceeded NRC-stipulated criteria was identified in six areas. In three areas, natural attenuation or extraction reduced the concentration of radionuclides to less than the NRC-stipulated criteria.

2.4 Spills

During operating years, a pipeline carried wastewater from lagoons to the Cimarron River. During decommissioning activities, it was discovered that the pipeline had historically leaked into alluvial materials near the bluff overlooking the Cimarron River. The pipeline was removed, and soil exceeding the criteria specified in License Condition 17(c) was removed for disposal. The trench was then backfilled. Site-Wide Groundwater Assessment Review (Cimarron, 2005) identifies this area as an area in which groundwater remediation is required. Groundwater exceeding the total uranium criterion of 180 pCi/l has been delineated, and the hydrogeology and geochemistry of the area was reported in Conceptual Site Model, rev. 1 (ENSR, 2006). This amendment to the SDP addresses the remediation of groundwater in this area.

2.5 Prior On-Site Burials

Licensed material was buried in trenches in three areas, historically referred to as Burial Grounds #1, #2, and #3. All materials exceeding criteria for soils specified in License Condition 27(c) were removed from the trenches during previous decommissioning activities. Groundwater impacted by licensed material at concentrations exceeding the release criteria specified in License Condition 27(b) has been identified downgradient from two of these areas: Burial Ground #1 and Burial Ground #3.

Site-Wide Groundwater Assessment Review (Cimarron, 2005) identifies these areas as areas in which groundwater remediation is required. Groundwater exceeding the total uranium criterion of 180 pCi/l has been delineated, and the hydrogeology and geochemistry of the areas were reported in Conceptual Site Model, rev. 1 (ENSR, 2006). This amendment to the SDP addresses the remediation of groundwater in these areas.

3.0 Facility Description

The Cimarron site is located near Crescent, Oklahoma. Detailed information concerning the facility, climate, land use, and radiological characterization of the site are presented in the SDP and the GER. Detailed information on the geology and surface and ground water hydrology are presented in Conceptual Site Model, rev. 1 (ENSR, 2006). Relevant information from these reports will be presented in subsequent sections of this amendment to the SDP.

4.0 Radiological Status of Facility

4.1 Structures, Equipment, Soil, and Surface Water

Cimarron has completed the decommissioning of all structures, equipment, and soils. NRC has performed confirmatory surveys for all areas except Subarea F. All Subareas except Subareas F, G, and N have been released for unrestricted use.

4.2 Ground Water

The Cimarron facility is underlain by sandstone bedrock in the southern two-thirds of the site or alluvium in the northern third. The Cimarron River floodplain contains alluvial material, and represents the most permeable water-bearing zone on site. Upland areas are underlain by three sandstones of relatively low permeability, which are referred to as Sandstones A, B, and C, from higher to lower elevation. These three sandstone layers are separated by low-permeability mudstones, which function as aquitards, severely limiting groundwater flow between permeable zones. The hydrogeology of the site is described in detail in Conceptual Site Model, rev. 1 (ENSR, 2006).

NRC has established release criteria of 180 pCi/l for total uranium and 3,790 pCi/l for Technitium-99 in groundwater. Cimarron identified all potential sources of groundwater contamination and installed groundwater monitoring wells as needed to determine if licensed material had migrated from any of these potential sources, causing groundwater to exceed the criteria. In addition, historical groundwater data was reviewed to identify areas which may have exceeded the criteria in the past.

Site-Wide Groundwater Assessment Review (Cimarron, 2005) describes this groundwater assessment and divides the site into four categories of areas, termed "Phases". Phase I areas are hydrologically isolated from former production or disposal activities; groundwater in these areas is unimpacted. Phase II areas are potentially impacted areas in which groundwater monitoring has demonstrated impact is below release criteria. Phase III areas are areas which have been impacted above release criteria, but for which groundwater monitoring indicates impact no longer exceeds

release criteria. Phase IIIa areas are areas for which monitoring demonstrating compliance was long ago obtained and is no longer needed. Phase IIIb areas are areas for which needed monitoring data is presented in Section 8 of this document. Phase IV areas are areas in which groundwater monitoring indicates impact still exceeds release criteria. Phase IV areas require groundwater remediation, and are addressed in this amendment to the SDP.

Site-Wide Groundwater Assessment Review (Cimarron, 2005) identifies six areas in which groundwater has at some time exceeded license criteria. Three of these areas were identified as Phase IIIb areas, and three were identified as Phase IV areas. Figure 4.1 shows how the site has been divided into the four “phase” categories, as well as the location of the six areas addressed in this amendment to the SDP.

Tc-99 was believed to have exceeded the 3,790 pCi/l criterion in groundwater in two areas: the U-Pond #1 and U-Pond #2 areas. Section 8 of this amendment to the SDP, Environmental Monitoring and Control, describes the monitoring that has been performed in these areas, demonstrates that groundwater no longer exceeds applicable criteria, and proposes that monitoring be terminated for these areas.

In the Well 1319 area, uranium exceeded the 180 pCi/l release criterion in groundwater in Sandstones B and C. Cimarron extracted groundwater exceeding the release criterion, pumping the impacted groundwater from Wells 1319B-1 and 1319C-1. Section 9, Environmental Monitoring and Control, describes the monitoring that has been performed in this area, demonstrates that groundwater no longer exceeds applicable criteria, and proposes that monitoring be terminated for this area.

Uranium exceeds the 180 pCi/l release criterion in groundwater in three areas, which are referred to as:

- Western Upland Area
- Western Alluvial Area
- Burial Area #1

This amendment addresses the remediation of groundwater in these three areas. Section 5 of this amendment to the SDP, Planned Decommissioning Activities, describes the program that will be implemented to remediate groundwater. Section 8 of this amendment to the SDP, Environmental Monitoring and Control, describes the post-decommissioning monitoring program that will be implemented after groundwater remediation to demonstrate compliance with the license criteria.

5.0 *Planned Decommissioning Activities*

5.1 Overview

Decommissioning is proposed herein for those portions of the site identified on Figure 4.1 as Phase IV areas. Cimarron intends to remediate groundwater in all three areas by immobilizing dissolved uranium through biological reduction, with the creation of geochemical conditions that will prevent re-mobilization of uranium at concentrations above the license criterion. The following paragraphs provide an overview of the approach for groundwater remediation. More detailed descriptions of these plans are provided in subsequent sections.

ARCADIS G&M, Incorporated (ARCADIS) will contract with Cimarron to remediate groundwater in Burial Area #1, the Western Alluvial area, and the Western Upland area. Cimarron provides herein the groundwater flow model originally generated by ENSR to evaluate pump-and-treat methodology as an alternative to in situ bioremediation. ENSR then augmented and calibrated the model to provide the basis for designing an in-situ bioremediation program. ARCADIS used the model to utilize its output as input parameters for the development of its work plan. This model is provided to NRC to enable NRC staff to evaluate ARCADIS' work plan. Cimarron also provides the geochemical model input with which ARCADIS demonstrates that uranium will be immobilized, and cannot later remobilize at concentrations above the license criterion. The creation of these geochemical conditions will be the goal of the groundwater remediation effort.

ARCADIS will begin by creating a forward in situ reactive zone (IRZ) beyond the downgradient edge of the plume in Burial Area #1. This will enable ARCADIS to determine the quantity and concentration of reagents required to develop the geochemical conditions essential to immobilize dissolved. It will also create a reactive barrier to prevent uranium in groundwater upgradient of the forward IRZ from migrating past the area of treatment.

Based on information gained from the development of the forward IRZ, ARCADIS will inject reagents in all three areas to create the same geochemical conditions as in the forward IRZ. Groundwater samples and soil samples collected from both the saturated zone and the vadose zone will define the geochemical conditions created by the reagent injections. Attachment 1 is a detailed work plan prepared by ARCADIS G&M, Inc. for groundwater remediation in all three areas.

5.2 Geochemical Parameters to Demonstrate Compliance

A numerical groundwater flow model was prepared by ENSR when considering pump and treat technology as a remedial option for the site. As described briefly above, this groundwater flow model was based on the geologic, hydrogeologic, and geochemical characteristics of the site as presented in Conceptual Site Model, rev. 1 (ENSR, 2006). The groundwater flow model was refined as additional information was collected. The creation, calibration, and justification of this numerical model is presented as Attachment 2 to this amendment to the SDP.

ARCADIS used information from the groundwater flow model to generate estimates of the amount of reagent needed, the spacing of injection points, rates of injection, and other factors that will determine the success of the proposed treatment. ARCADIS plans to create specific geochemical conditions which will provide several "layers of protection". The first and most fundamental layer of protection is the creation of a "bank" of iron sulfide in the saturated zone throughout the extent of the plume. The abundance of iron sulfide will maintain a strongly reducing environment, preventing the re-mobilization of uranium. NRC can modify various input parameters to the groundwater flow model (e.g., hydraulic gradient or hydraulic conductivity) to test the conservatism of ARCADIS' assertion that all water-bearing zones will maintain a strongly reducing environment.

However, Cimarron recognizes that hydrogeologic models assume more homogeneous and isotropic conditions than actually exist in most water-bearing units. ARCADIS' inputs to Geochemists Work Bench, a widely used geochemical model, are provided to NRC in an appendix to Attachment 1. This information is provided to NRC to "test" the

response of the formation to the introduction of oxidizing groundwater into the water-bearing zones. Both ARCADIS' geochemical model and column tests referenced in Section 4.1.1 of the work plan show that the "bank" of iron sulfides ARCADIS proposes to create will also prevent the re-mobilization of uranium at concentrations exceeding the license criterion.

Finally, assuming that at some point in the future, uranium is introduced into groundwater within the plume areas, the geochemical model demonstrates that the iron oxide formed by the reaction of iron sulfide and oxidizing groundwater has such an affinity to uranium that even this newly-introduced uranium would precipitate. There are therefore two "layers of protection" for groundwater after immobilization is complete.

5.3 Creation of a Forward In-Situ Reactive Zone

Figure 5.1 presents Burial Area #1, showing the area within which ARCADIS will create an in situ reactive zone (IRZ). ARCADIS will create this IRZ by injecting organic carbon directly into the groundwater via geoprobe-type injectors. Figure 5.1 shows the approximate locations of injection points. Figure 5.2 shows the same for the Western Alluvial Area. Actual injection points will vary based on accessibility and the subsurface material into which the reagent is being injected. For example, injection points may be more closely spaced in areas where finer-grained materials are encountered in the saturated zone.

In addition, organic carbon will be incorporated into the shallow subsurface by filling shallow surficial trenches with gravel or other high permeability material, and pouring reagents into the trenches. This will introduce reducing agents into the vadose zone to minimize the potential impact of infiltration on the establishment and maintenance of the IRZ.

After strongly reducing conditions are created, additional injections will be performed as needed to introduce iron, sulfate, and/or additional organic carbon. These injections will create the "bank" of reduced iron compounds that geochemical modeling demonstrates will prevent the re-mobilization of uranium.

ARCADIS will monitor groundwater and collect soil core samples to verify that the desired geochemical conditions are being created. Additional injections of iron, sulfate, and/or organic carbon will be performed as needed until the specified geochemical conditions have been created. This fully developed forward IRZ will enable ARCADIS to plan injections for groundwater remediation within the plumes as well as prevent uranium from migrating downgradient as future injections within the plume create local groundwater gradients.

5.4 Groundwater Remediation

Following the creation of a strongly reduced reactive zone at the leading edges of the plumes in BA#1 and the Western Alluvial Area, ARCADIS will expand the IRZs by injecting treatment reagents into groundwater through existing wells and/or through new injection points. Figures 5.1 and 5.2 show the approximate locations of injection points. Actual injection points may vary based on accessibility and the material into which the reagent is being injected. For example, injection points may be more closely spaced where finer-grained materials are encountered in the saturated zone.

An infiltration trench will be constructed in Sandstone A in the Western Upland Area, and reagents will be introduced into the sandstone via this injection trench. Figure 5.3 shows the Western Upland Area, and portrays the approximate location of the infiltration trench.

Surface applications via shallow trenches may also be performed at selected locations in the Western Alluvial Area. ARCADIS will conduct groundwater and soil sampling and analysis in all three areas to enable them to modify the treatment of groundwater as needed to ensure immobilization and permanence of treatment.

5.5 Demonstration of Compliance

NRC can modify inputs to both the hydrogeologic and geochemical models to test the sensitivity of those models to various input parameters. Cimarron is confident that, provided those inputs remain realistic, these models will demonstrate that, once

specified geochemical conditions are created, uranium cannot re-mobilize at concentrations exceeding license criteria. Groundwater and soil samples demonstrating both the creation of the geochemical conditions ARCADIS commits to develop and uranium concentrations below license criteria will constitute demonstration of compliance with license criteria. A post-decommissioning monitoring plan is presented in Section 8.3 of this amendment to the SDP, Post-Decommissioning Monitoring.

5.6 Schedule

Upon NRC and DEQ approval of this amendment to the SDP, Cimarron will contract with ARCADIS to remediate the groundwater in these three areas. ARCADIS will mobilize within six months of NRC and DEQ approval, and will complete the remediation within 24 months of NRC and DEQ approval.

6.0 Project Management and Organization

6.1 Decommissioning Management Organization

The organization chart that would depict the personnel responsible for decommissioning activities would be the same as the organization chart for current activities on site. The Radiation Protection Plan and Quality Assurance Plan present this organization. The remediation contractor will function organizationally as any other contractor performing work on site. No changes are needed for decommissioning.

The Vice President, Cimarron Corporation, provides corporate oversight of the Cimarron facility.

The Project Manager is responsible to provide sufficient resources to perform site decommissioning activities, and oversees site staffing, executes contracts for discrete elements of the work, monitors site activities and compliance with regulatory requirements, and is responsible for schedule and budget maintenance.

The Radiation Safety Officer (RSO) is responsible for oversight of the Radiation Protection Program, chairs the As Low As Reasonably Achievable (ALARA) Committee, oversees training, personnel and area monitoring, is responsible for license compliance, and coordinates the activities of health physics personnel with others working on site.

The Quality Assurance Coordinator assesses compliance with license requirements and the Radiation Protection Program, and is responsible for document management.

Activity Supervisors oversee discrete tasks such as soil and/or groundwater sampling. Activity supervisors will be responsible to ensure that all personnel working on their activities have the required training and comply with the plans and procedures governing their work.

6.2 Decommissioning Task Management

6.2.1 Decommissioning Activities

Typical decommissioning activities include:

- Storage and injection of treatment reagents
- Collection and analysis of soil samples from select locations
- Collection of groundwater samples from select monitoring wells

Activity supervisors will oversee each of these tasks. Activity supervisors will have a dotted line relationship with either the Project Manager or the Site Manager.

6.2.2 Radiation Safety Activities

Activities related to radiation surveys or radiation safety include, but are not limited to:

- Scanning and sampling soils and sampling equipment
- Scanning and sampling injection equipment
- Sampling and analyzing groundwater produced in the recovery trench
- Personnel monitoring as needed

Individuals performing these activities will report to the Radiation Safety Officer. It is not anticipated that area or effluent monitoring will be performed, since licensed material should not be generated or released except in the form of soil or groundwater samples.

6.3 Training

The Cimarron training program is described in the SDP. The RSO is responsible to ensure that all workers have the applicable training prior to performing their work.

7.0 Health and Safety Program during Decommissioning

7.1 Radiation Safety Controls and Monitoring for Workers

The Cimarron Radiation Protection Program (RPP) ensures that radiological decommissioning is performed in accordance with all applicable regulatory requirements to protect the health and safety of workers, visitors, members of the public, and the environment. The RPP is implemented in accordance with written policies, procedures and instructions, and applies to all decommissioning activities conducted under License SNM-928. Policies and procedures are developed to maintain radiation exposures at levels As Low As is Reasonably Achievable (ALARA). The Cimarron ALARA Committee reviews decommissioning activities to ensure that the ALARA policy, philosophy, and commitments are integrated into applicable activities.

Groundwater remediation activities proposed in Section 5 will be performed in Burial Area #1, the Western Alluvial Area, and the Western Upland Area. The proposed remediation is an *in-situ* process where treatment reagents are injected directly into the subsurface. Neither the remediation process nor soil or groundwater sampling presents an increase in risk of exposure to workers, the public or environment.

Health Physics support and direction as well as radiation awareness training, special work permits, work plans and necessary procedures and policies will be the foundation of radiation health and safety for these activities. Cimarron does not anticipate that routine air sampling, respiratory protection, or internal or external exposure determination will be required. If in-process monitoring of exposed soils and equipment used for decommissioning activities indicates the need for these controls, such controls will be reinstated under the existing radiation protection program.

7.2 Contamination Control Program

Contamination control shall consist of indirect (smears) and direct (fixed) in-process alpha, beta or gamma surveys of personnel and equipment, as well as soil and groundwater analyses. Surveys shall be performed, to the extent practical, in

accordance with the 1987 U.S. NRC Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for Byproduct, Source, or Special Nuclear Material. Documentation of the results shall be maintained in accordance with Cimarron Quality Assurance Program requirements.

7.3 Instrumentation Program

Instruments used to support radiation protection program and decommissioning activities shall be calibrated and maintained in accordance with the Cimarron Radiation Protection Plan and subordinate procedures, and with ANSI-N323-1978.

7.4 Nuclear Criticality Safety

Criticality is not an issue for the Cimarron site, and will not be an issue for groundwater decommissioning.

7.5 Health Physics Audits, Inspections, and Recordkeeping Program

Audits and inspections of both decommissioning and health physics activities will be conducted in accordance with the Cimarron Quality Assurance Program. In addition, all quality critical records, including decommissioning records, will be maintained and controlled in accordance with the Cimarron Quality Assurance Program.

8.0 Environmental Monitoring and Control Program

8.1 Environmental ALARA Program

Cimarron currently implements an environmental monitoring program in accordance with Section 15 of its Radiation Protection Program. The environmental monitoring program evolved through the facility's operating years, and was designed to evaluate the impact of licensed material to the Cimarron River and site reservoirs, and to identify releases from facility impoundments and operations. Since decommissioning of facilities and soils is now complete, the environmental monitoring program is no longer appropriate for the Cimarron site. Cimarron will discontinue the environmental monitoring program upon NRC approval of this amendment to the SDP.

8.2 Effluent Monitoring and Control

The groundwater remediation project will not generate effluents. Cimarron does not plan to implement an effluent monitoring or control program for this effort.

Groundwater will be recovered from a groundwater recovery trench in the 1206 seep drainage way. Groundwater will be recovered for reinjection (after addition of treatment reagents as appropriate) in the Western Upland injection trench. An Oklahoma underground injection permit will be required prior to reinjection. ARCADIS will obtain this permit prior to initiating groundwater recovery and reinjection.

8.3 Post-Decommissioning Monitoring

Post-decommissioning monitoring will be performed when ARCADIS determines via performance monitoring that the desired endpoint has been attained. Post-decommissioning monitoring will be conducted one time prior to the preparation of a completion report.

Figure 8.1 shows the locations of post-decommissioning monitoring locations in Burial Area #1. Figure 8.2 shows the locations of post-decommissioning monitoring locations

in the Western Alluvial Area. Figure 8.3 shows the locations of post-decommissioning monitoring locations in the Western Upland Area. A total of eleven monitoring wells will be sampled for post-decommissioning monitoring. Groundwater from these eleven monitoring wells will be analyzed for total uranium by alpha spectroscopy and major anions and cations.

Soil samples will be collected at locations mid-way between injection points within 25 feet of the post-decommissioning monitoring wells specified above. Soil samples will be collected from the saturated zone, and will be analyzed for reduced sulfide and uranium.

To demonstrate compliance with license criteria, groundwater samples must yield < 180 pCi/l total uranium. Averaging will not be allowed for uranium – every groundwater sample must meet this criterion. Soil sample analytical results must demonstrate a molar concentration of iron sulfide at least 1,000 times the molar concentration of uranium for all soil samples. Averaging of soil results may be used to determine total iron sulfide available, accounting for soil heterogeneities.

ARCADIS will prepare a completion report presenting the analytical results of the post-decommissioning monitoring, and showing that the conditions achieved in groundwater (< 180 pCi/l total uranium) will remain in compliance with this criterion indefinitely.

8.4 Environmental Monitoring for Groundwater

As stated in Section 4.2, groundwater in three areas formerly exceeded release criteria, and groundwater assessment data collected prior to the submission of Site-Wide Groundwater Assessment Review (Cimarron, 2005) was not sufficient to demonstrate compliance with release criteria. Those areas are:

- Well 1319 Area
- Uranium Pond #1 Area
- Uranium Pond #2 Area

This section presents groundwater data collected to demonstrate compliance with release criteria for each of these three areas, and identifies monitoring wells which will be abandoned, as they are no longer needed. It also addresses the abandonment of other wells in areas not associated with areas requiring remediation or continued monitoring.

8.4.1 Well 1319 Area

Groundwater exceeded release criteria for uranium in Sandstone B and Sandstone C in a small area surrounding former Well 1319. Groundwater exceeding release criteria was removed by pumping. After the pumps were shut down, Cimarron initiated quarterly sampling of monitor wells 1319B-1 and 1319C-1, the only two wells that yielded groundwater exceeding release criteria. Table 8.1 presents data obtained from these wells. Figures 8.4 and 8.5 provide graphs of the data for each well, indicating when data was collected for assessment, remediation, and post-remediation monitoring.

Decommissioning of buildings and soil in Subarea K, the subarea impacted by licensed material in groundwater around Well 1319, has been completed. Cimarron believes this data demonstrates that the only media for which decommissioning was still required, groundwater, is complete. In addition, as stated in Site-Wide Groundwater Assessment Review (Cimarron, 2005), there is no need for further groundwater assessment in any of the Subareas formerly occupied by licensed operations, which include Subareas I, K, L, and the southern portion of Subarea N.

Upon DEQ and NRC approval, Cimarron will plug and abandon groundwater monitoring wells located in the Well 1319 Area, as well as other wells located in the above-mentioned Subareas. Cimarron proposes to abandon the following monitor wells:

1319A-1	1319B-1	1319C-1	1322	1323
1319A-2	1319B-2	1319C-2	1326	1327B
1319A-3	1319B-3	1319C-3	1328	1329
	1319B-4	1319B-5	1330	

In addition, several monitor wells were installed in areas in close proximity to former lagoons during site wide groundwater assessment activities, from which no further data is needed. Upon DEQ and NRC approval, Cimarron will plug and abandon the following monitor wells in these areas:

1331	1332	1333	1334	1348
1349	1353			

8.4.2 Uranium Pond #1 Area

Groundwater exceeded release criteria for Tc-99 in one well located downgradient from Uranium Pond #1 – Well 1312. This is the only well in this area that has ever yielded Tc-99 above the release criterion. Table 8.2 presents Tc-99 data for Well 1312. Figure 8.6 provides a graph of these data.

Active remediation was never required for this area; natural attenuation reduced the Tc-99 concentration in this area to less than the release criterion. Upon DEQ and NRC approval, Cimarron will discontinue monitoring in this area and will plug and abandon the following groundwater monitoring wells located in the Uranium Pond #1 area:

1311	1312	1313	1340	1341
1345	1354	1355		

8.4.3 Uranium Pond #2 Area

Groundwater has exceeded release criteria for Tc-99 at one location downgradient from Uranium Pond #2 – labeled Seep 1208. This is the only location in this area that has recently yielded Tc-99 above the release criterion. The highest concentrations of Tc-99 in groundwater in this area were obtained from Well 1336A. Table 8.2 presents Tc-99 data for these two locations. Figures 8.7 and 8.8 provide graphs of these data.

Active remediation was never required for this area; natural attenuation reduced the Tc-99 concentration in this area to less than the release criterion. Upon DEQ and NRC

approval, Cimarron will discontinue monitoring in this area and will plug and abandon the following groundwater monitoring wells located in the Uranium Pond #2 area:

1336A	1337	1338	1346	1347
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8.4.4 *Monitoring Wells in Other Areas*

Numerous monitoring wells were installed in the Cimarron River floodplain to evaluate potential releases from Uranium Ponds #1 and #2. These wells are no longer needed. Upon DEQ and NRC approval, Cimarron will plug and abandon the following monitor wells:

1320	1321	1324	1325	1335A
1339	1342	1343	1344	
T-51	T-52	T-53	T-54	T-55
T-56	T-57	T-58	T-59	T-60
T-61	T-63	T-69	T-80	

8.4.5 *Surface Water Sampling Locations*

Surface water samples were collected from the following locations as part of the environmental monitoring program. Upon DEQ and NRC approval, Cimarron will eliminate the environmental monitoring program and discontinue sampling of the following locations:

1201	1202	1204	1205	1206
1208	1209			

9.0 Radioactive Waste Management Program

Cimarron does not anticipate the generation of any radioactive waste during any of the above-described groundwater decommissioning activities. The existing radioactive waste management program, which has been utilized during previous decommissioning activities, will be utilized should any radioactive waste be generated during decommissioning.

10.0 Quality Assurance Program

The Cimarron Quality Assurance Program satisfies the applicable requirements of 10 CFR 50, Appendix B, and NQA-1. The Cimarron Quality Assurance Program is implemented and maintained in accordance with written policies, procedures and instructions.

A principal component of the program is to affirm the quality of project work performed during decommissioning by assuring that tasks are performed in accordance with approved plans by qualified personnel. This program ensures that all samples are collected, controlled and analyzed in accordance with all applicable quality controls such that data accuracy and validity are verifiable. The methods employed by Cimarron ensure the quality control of measuring and test equipment, and include project surveillances and inspections, corrective actions, and control of documents and records. Periodic audits and reviews are conducted to ensure that all aspects of the Cimarron Quality Assurance Program are being addressed.

11.0 Facility Radiation Surveys

11.1 Release Criteria

License condition 27(c) stipulates the use of the August 1987 U.S. NRC Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for Byproduct, Source, or Special Nuclear Material for the release of materials. Condition 27(c) also stipulates the use of the October 1981 Disposal or Onsite Storage of Thorium or Uranium Wastes from Past Operations for soils or soil-like material. Condition 27(b) stipulates 6.7 Bq/l (180 pCi/l) total uranium as the release criterion for groundwater.

11.2 Characterization Surveys

No characterization surveys are planned for decommissioning of groundwater; characterization was completed during groundwater assessment.

11.3 In-Process Surveys

During the construction of trenches for surface injections, shallow soil will be excavated and laid along side the trenches as spoils. These soils will be spread out over and around the trenches after they are backfilled with gravel. Health physics personnel will scan exposed soil in Subarea F to ensure that no material contains an elevated concentration of licensed material. Should scan results indicate that some of the excavated soil in Subarea F may contain elevated concentrations of licensed material, samples will be collected for analysis.

11.4 Final Status Survey Design

Final status surveys for structures and soils have been performed for the entire site. NRC has concurred that structures and soil comply with decommissioning criteria for all subareas except Subarea F. No further Final Status Survey Designs are needed.

11.5 Final Status Survey Report

No final status survey report is required for this decommissioning plan. Final status survey reports have been submitted for soils and buildings for all Subareas of the site. Cimarron will respond to NRC's comments regarding subsurface soil in Subarea F in a separate submittal, and the last final status survey will be complete.

Once the Final Status Survey for Subarea F is complete, the only information that will still be needed to obtain license termination relates to post-decommissioning monitoring after groundwater remediation is complete. Section 8.3 of this document describes the post-decommissioning monitoring that will demonstrate compliance with the release criteria for groundwater. A completion report describing the geochemical conditions and demonstrating that these conditions will ensure that groundwater concentrations will remain permanently below release criteria will be submitted to NRC following the conclusion of post-decommissioning monitoring.

12.0 Financial Assurance

12.1 Cost Estimate

ARCADIS has proposed to perform groundwater remediation in all three areas for a fixed price of \$6,975,000. This is a fixed price offer, and ARCADIS has obtained insurance to ensure that the geochemical conditions stipulated as demonstration of compliance are met within the time frame provided by the schedule presented in Section 5.6. ARCADIS' offer is contingent upon NRC approval of this Site Decommissioning Plan – Groundwater Decommissioning Amendment.

Cimarron has estimated the cost of health physics and other technical support for the completion of decommissioning to be approximately \$1,700,000. Cimarron has also estimated the cost of NRC fees to be approximately \$600,000. Both of these estimates are based on decommissioning being completed in accordance with the schedule presented in Section 5.6.

Should NRC require modification of this Site Decommissioning Plan – Groundwater Decommissioning Amendment in ways that change the substance of the plan, both the cost and schedule may be impacted. A more detailed cost estimate and financial assurance can be prepared once NRC and DEQ have approved this license amendment.

12.2 Financial Mechanism

Cimarron will modify the existing standby trust agreement and surety bond in accordance with the detailed cost estimate prepared upon NRC and DEQ approval of this license amendment.

13.0 References

Chase Environmental Group, April 1995, Site Decommissioning Plan.

Chase Environmental Group, 1998, Site Decommissioning Plan – Groundwater Evaluation Report.

ENSR, 2006, Conceptual Site Model, rev. 1.

Cimarron Corporation, 2005, Site-Wide Groundwater Assessment Review.

Chase Environmental Group, 1994, Radiological Characterization Report for Cimarron Corporation's Former Nuclear Fuel Fabrication Facility.

Nextep Environmental, Inc, 2005, Final Status Survey Report, Subarea F.

TABLES

TABLE 1.1
CIMARRON CORPORATION
SITE DECOMMISSIONING PLAN - GROUNDWATER DECOMMISSIONING AMENDMENT
SUBAREA SUMMARY

Phase Designation	Subarea	Acreage	FSSP Approved	FSSR Submitted	NRC Confirmatory Sampling	Release
I	A - E	690	5/1/1995	May 1995	Completed	4/23/1996
II	F	20	3/14/1997	Rubble - March 1998 Soil - August 2005	Pending	Pending
	G	20	3/14/1997	October 1999	Completed	Pending
	H	40	3/14/1997	November 1998	Completed	4/9/2001
	I	20	3/14/1997	June 1999	Completed	4/9/2001
	J	7	3/14/1997	September 1997	Completed	4/17/2000
	K	5	9/11/1998	February 2000	Completed	5/28/2002
III	L	5	9/11/1998	Subsurface - February 1996 Surface - July 1998	Completed	4/9/2001
	M	3	9/11/1998	December 1998	Completed	4/9/2001
	N	12	9/11/1998	January 2002	Completed	Pending
	O	7	9/11/1998	Subsurface - March 1998	Completed	4/17/2000
				Surface - February 1999		

TABLE 8.1
CIMARRON CORPORATION
SITE DECOMMISSIONING PLAN - GROUNDWATER DECOMMISSIONING AMENDMENT
WELLS 1319B-1 AND 1319C-1 TOTAL URANIUM DATA

Sample Date	1319B-1 Total Uranium (pCi/l)	1319C-1 Total Uranium (pCi/l)
Jun-03	200.5	232.2
Sep-03	195.3	308.5
Dec-03	146.6	105.6
Dec-03	179.5	98.9
Mar-04	177.4	75.1
Mar-04	179.2	39.4
May-04	132.6	51.1
Jun-04	136.6	30.1
Aug-04	132.7	29.2
Feb-05	99.6	19.4
Jun-05	109.3	19.7
Sep-05	102.5	18.1
Dec-05	84.7	18.9
Feb-06	90.8	20.6
May-06	86.7	14.97
Sep-06	64.5	15.5

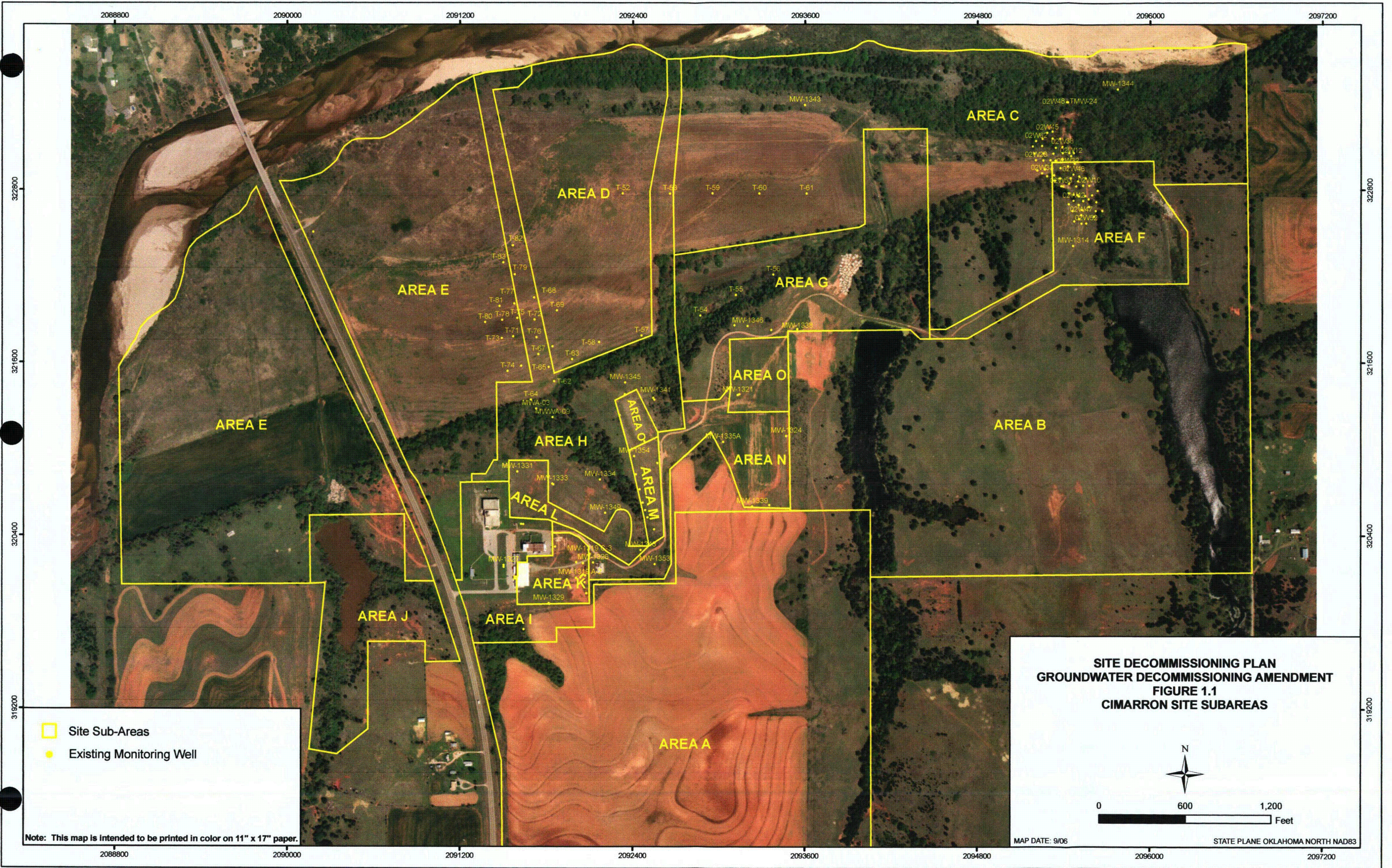
TABLE 8.2
CIMARRON CORPORATION
SITE DECOMMISSIONING PLAN - GROUNDWATER DECOMMISSIONING AMENDMENT
URANIUM POND #1 AND #2 AREA TECHNIUM-99 DATA

Sample Date	Well 1312 Tc-99 (pCi/l)	Seep 1208 Tc-99 (pCi/l)	Well 1336A Tc-99 (pCi/l)
May-96		4550	
Aug-96			1700
Oct-96	856		
Mar-97	3680	3960	2590
Jun-97	1470	2800	1930
Sep-97	2190	3040	1880
Dec-97	1570	2080	1200
Mar-98	1850	2300	1600
May-98	1820	1930	
Jun-98			1850
Sep-98	2110	2640	1510
Dec-98	1650	1820	1260
Mar-99	1450	2370	1160
Jun-99	569	1200	974
Sep-99	919	3140	713
Nov-99		3470	1160
Dec-99	1410		
Mar-00	1350	4350	1070
Jun-00	930	12.2	
Aug-00		547	
Sep-00	1100		
Sep-00		4030	939
Dec-00	1120		890
Mar-01	957	3560	946
Jun-01	747	3300	875
Dec-01	744		600
Dec-01		2490	
Jun-02	826	3230	
Jun-02			1060
Sep-02	1030		898
Sep-02		4050	
Dec-02	1030	3990	1020
Feb-03	1260	4280	
Jun-03	2060	5300	952
Sep-03	2320	2810	873

TABLE 8.2
CIMARRON CORPORATION
SITE DECOMMISSIONING PLAN - GROUNDWATER DECOMMISSIONING AMENDMENT
URANIUM POND #1 AND #2 AREA TECHNIUM-99 DATA

Sample Date	Well 1312 Tc-99 (pCi/l)	Seep 1208 Tc-99 (pCi/l)	Well 1336A Tc-99 (pCi/l)
Dec-03	4300	3220	
Mar-04	4590	3400	
May-04	910		
May-04		3140	
Aug-04	607	3320	949
Dec-04	943		
Feb-05	718		655
May-05	801	2810	839
May-05	755		
Sep-05	1050		857
Dec-05	1150		614
Feb-06	915		635
May-06	851	2980	577
Sep-06	1150	2910	594

FIGURES



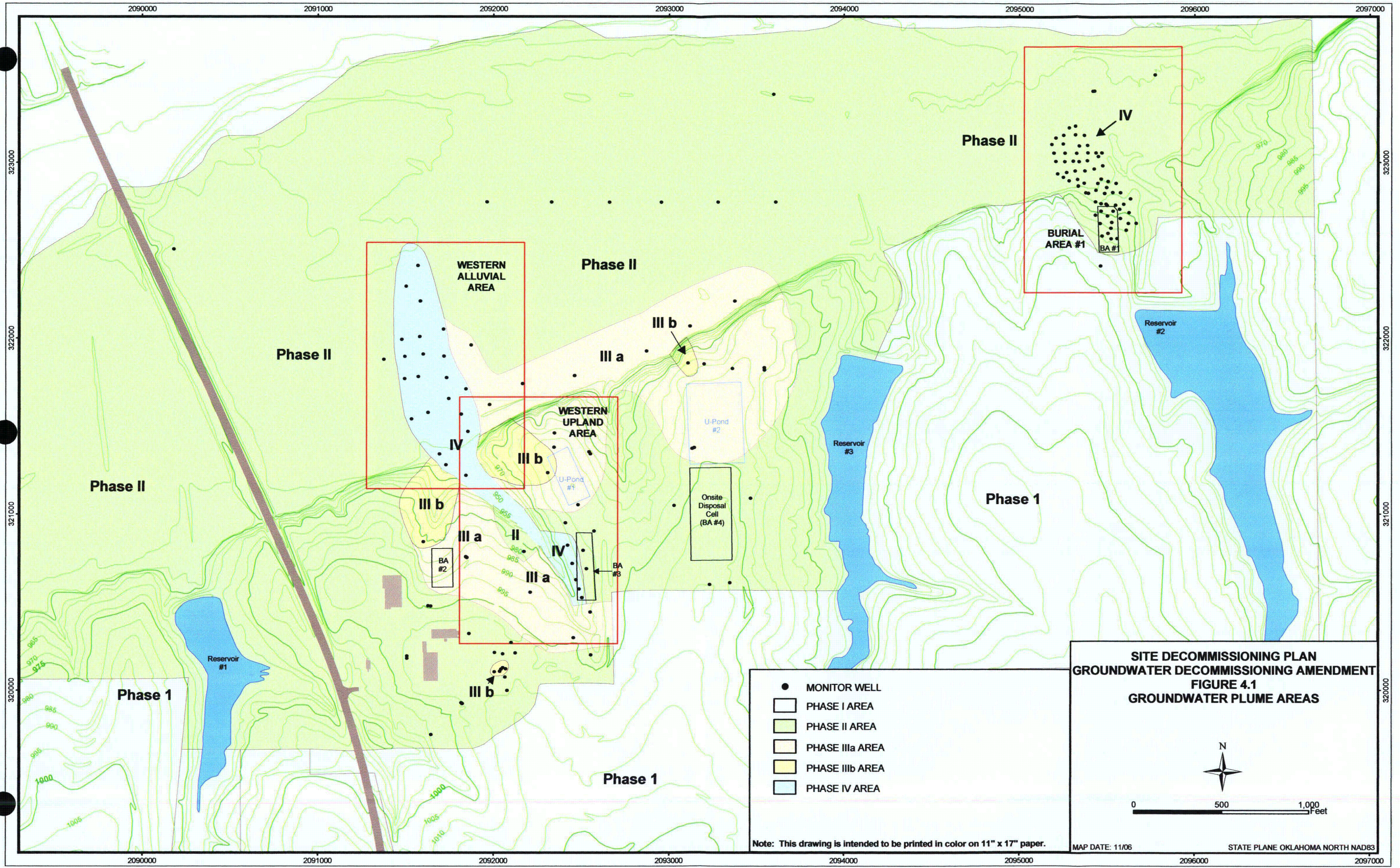
□ Site Sub-Areas
● Existing Monitoring Well

Note: This map is intended to be printed in color on 11" x 17" paper.

SITE DECOMMISSIONING PLAN GROUNDWATER DECOMMISSIONING AMENDMENT FIGURE 1.1 CIMARRON SITE SUBAREAS

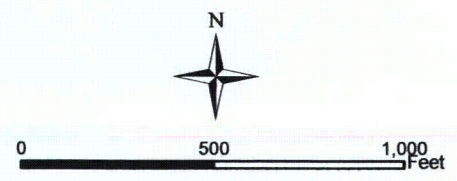
MAP DATE: 9/06 STATE PLANE OKLAHOMA NORTH NAD83

0 600 1,200 Feet



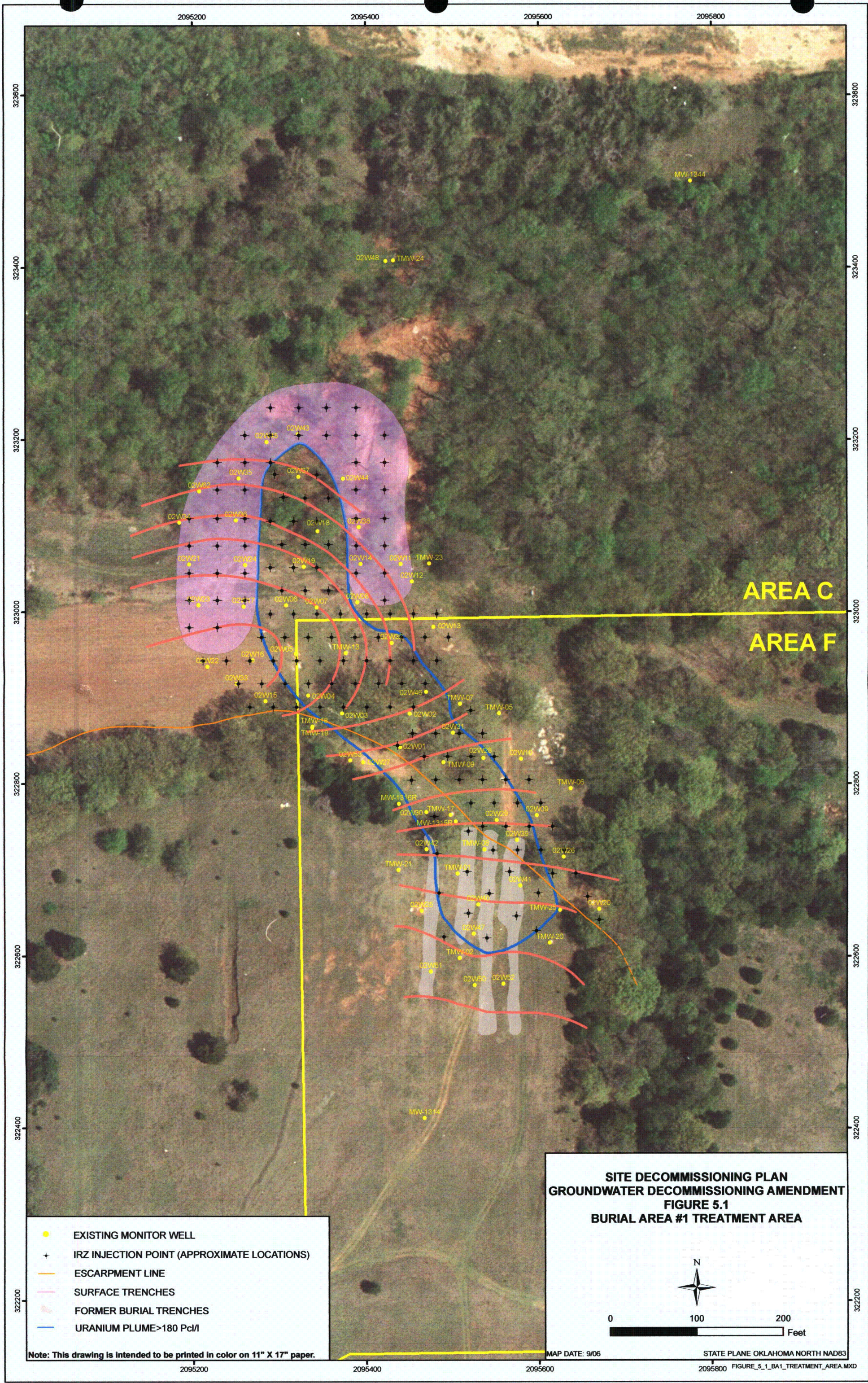
**SITE DECOMMISSIONING PLAN
GROUNDWATER DECOMMISSIONING AMENDMENT
FIGURE 4.1
GROUNDWATER PLUME AREAS**

- MONITOR WELL
- PHASE I AREA
- PHASE II AREA
- PHASE IIIa AREA
- PHASE IIIb AREA
- PHASE IV AREA

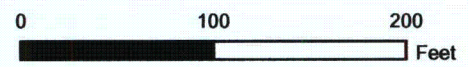


Note: This drawing is intended to be printed in color on 11" x 17" paper.

MAP DATE: 11/06 STATE PLANE OKLAHOMA NORTH NAD83



**SITE DECOMMISSIONING PLAN
GROUNDWATER DECOMMISSIONING AMENDMENT
FIGURE 5.1
BURIAL AREA #1 TREATMENT AREA**



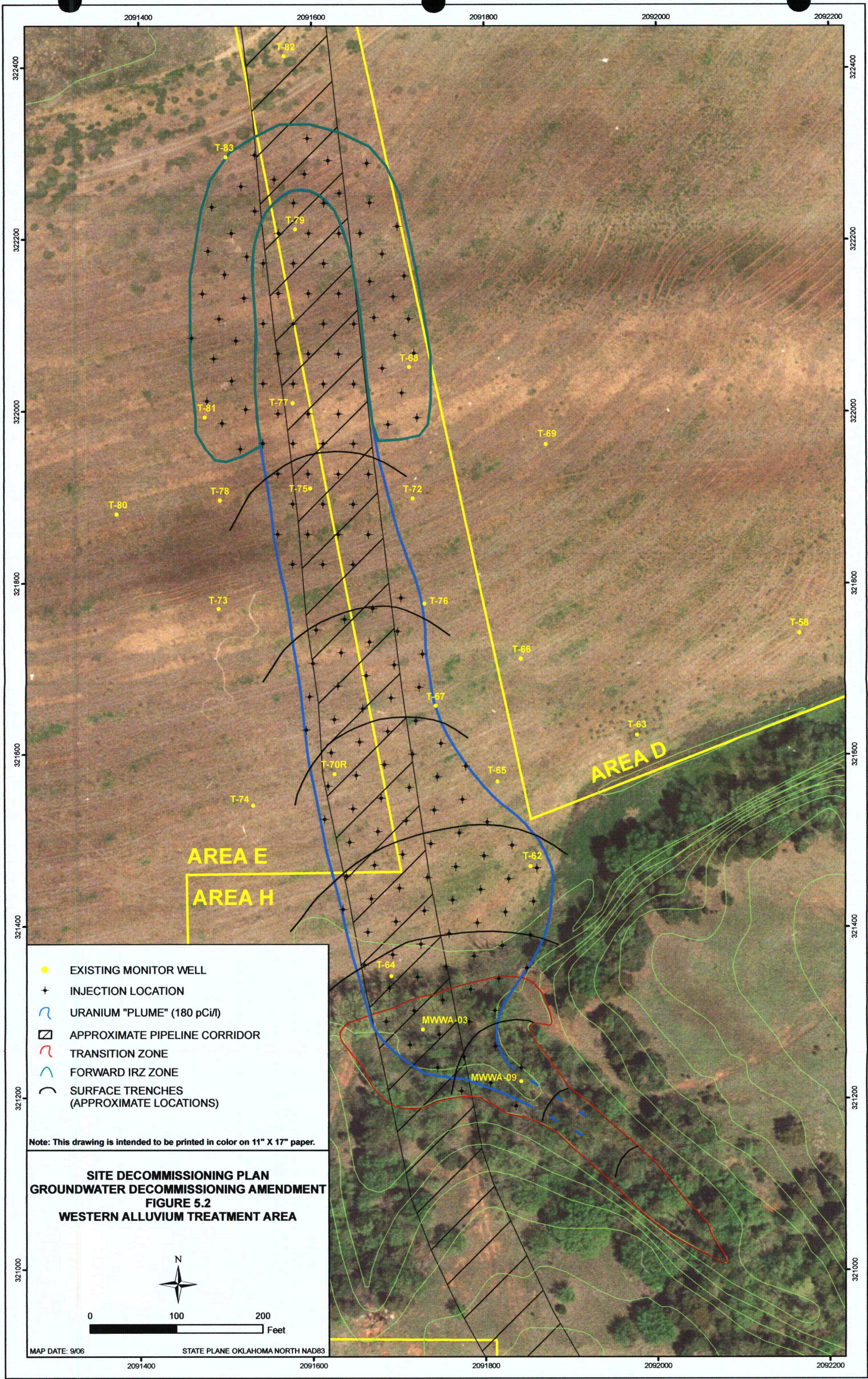
- EXISTING MONITOR WELL
- + IRZ INJECTION POINT (APPROXIMATE LOCATIONS)
- ESCARPMENT LINE
- SURFACE TRENCHES
- FORMER BURIAL TRENCHES
- URANIUM PLUME >180 Pci/l

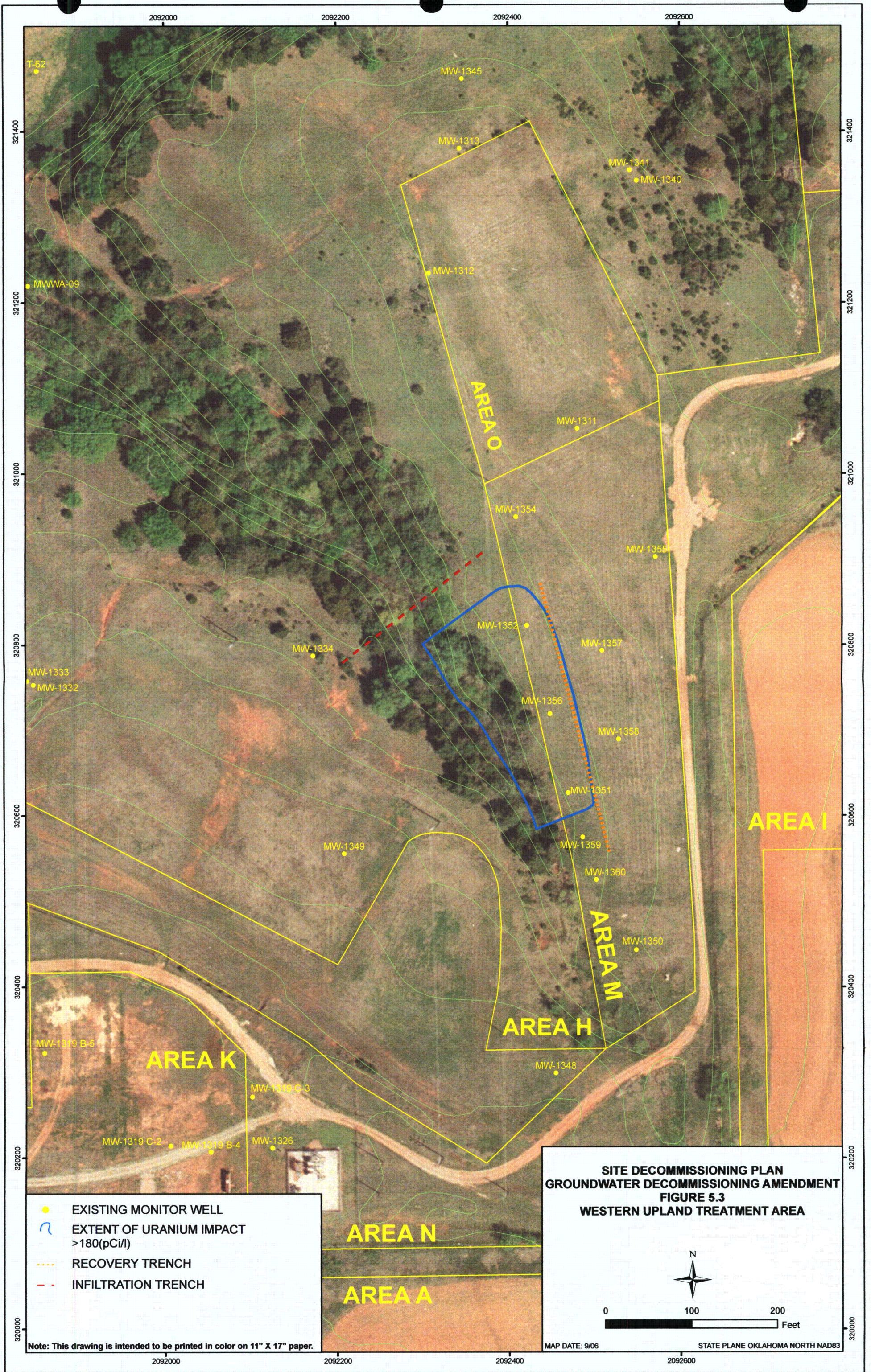
Note: This drawing is intended to be printed in color on 11" X 17" paper.

MAP DATE: 9/06

STATE PLANE OKLAHOMA NORTH NAD83

FIGURE_5.1_BA1_TREATMENT_AREA.MXD

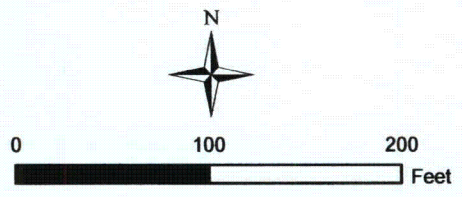




**SITE DECOMMISSIONING PLAN
GROUNDWATER DECOMMISSIONING AMENDMENT
FIGURE 5.3
WESTERN UPLAND TREATMENT AREA**

- EXISTING MONITOR WELL
- ⌈ EXTENT OF URANIUM IMPACT >180(pCi/l)
- - - RECOVERY TRENCH
- - - INFILTRATION TRENCH

Note: This drawing is intended to be printed in color on 11" X 17" paper.



MAP DATE: 9/06

STATE PLANE OKLAHOMA NORTH NAD83

2092000

2092200

2092400

2092600

321400

321200

321000

320800

320600

320400

320200

320000

321400

321200

321000

320800

320600

320400

320200

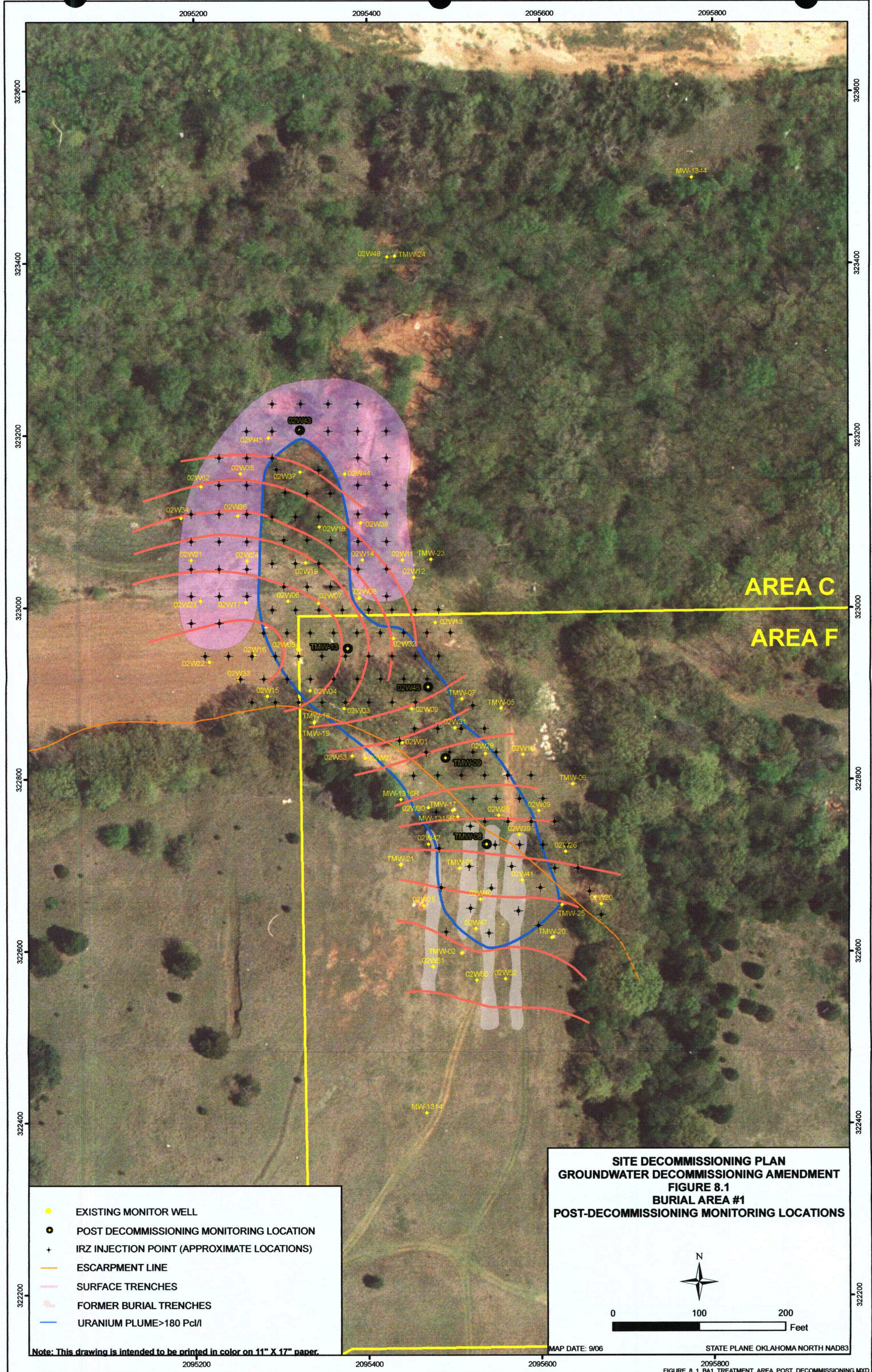
320000

2092000

2092200

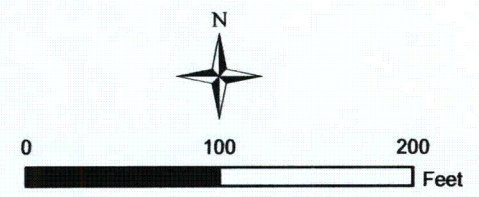
2092400

2092600



**SITE DECOMMISSIONING PLAN
GROUNDWATER DECOMMISSIONING AMENDMENT
FIGURE 8.1
BURIAL AREA #1
POST-DECOMMISSIONING MONITORING LOCATIONS**

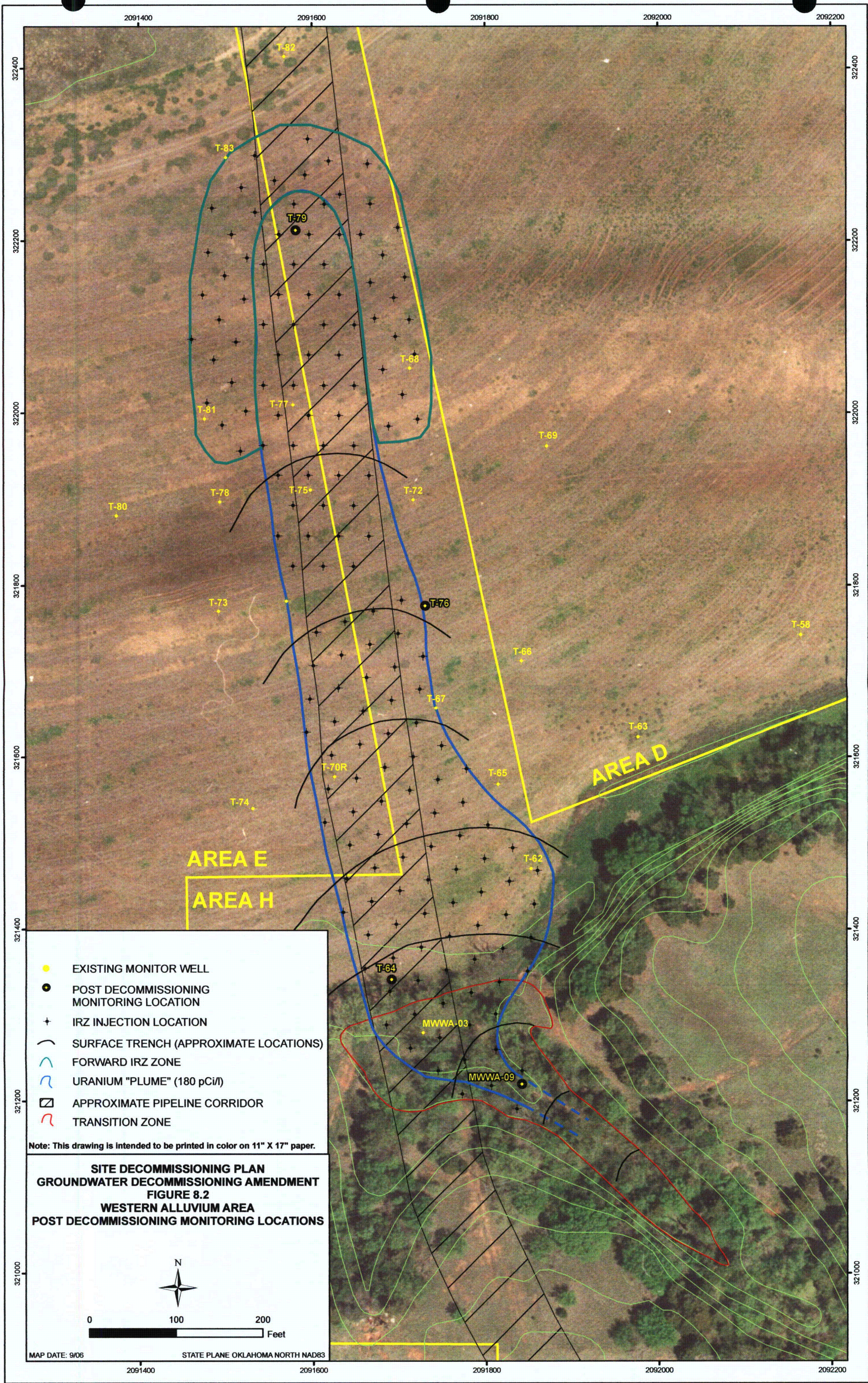
- EXISTING MONITOR WELL
- POST DECOMMISSIONING MONITORING LOCATION
- + IRZ INJECTION POINT (APPROXIMATE LOCATIONS)
- ESCARPMENT LINE
- SURFACE TRENCHES
- FORMER BURIAL TRENCHES
- URANIUM PLUME >180 Pci/l



Note: This drawing is intended to be printed in color on 11" X 17" paper.

MAP DATE: 9/06

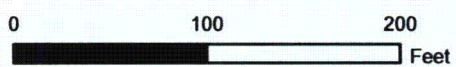
STATE PLANE OKLAHOMA NORTH NAD83



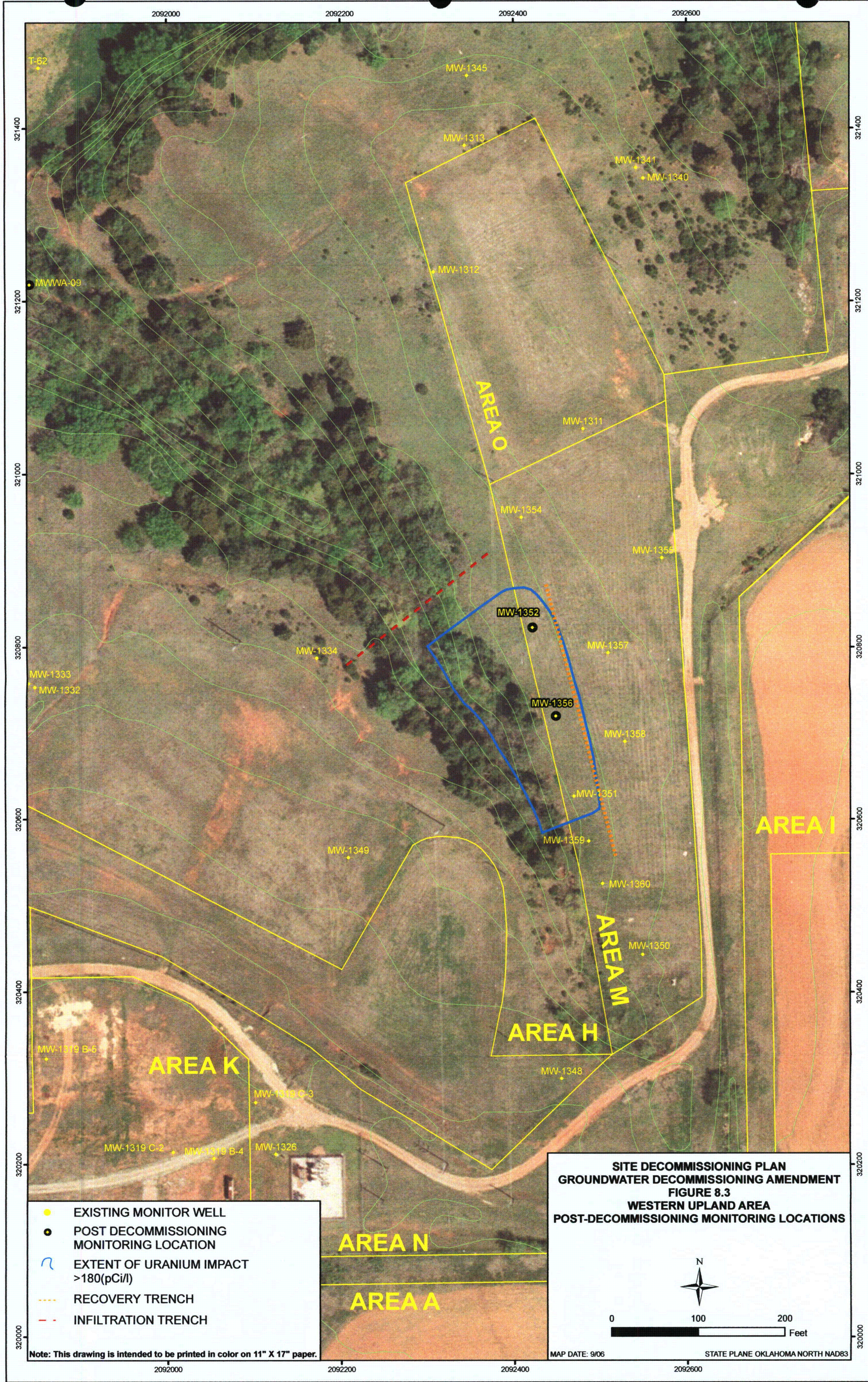
- EXISTING MONITOR WELL
- POST DECOMMISSIONING MONITORING LOCATION
- + IRZ INJECTION LOCATION
- SURFACE TRENCH (APPROXIMATE LOCATIONS)
- FORWARD IRZ ZONE
- URANIUM "PLUME" (180 pCi/l)
- APPROXIMATE PIPELINE CORRIDOR
- TRANSITION ZONE

Note: This drawing is intended to be printed in color on 11" X 17" paper.

SITE DECOMMISSIONING PLAN
GROUNDWATER DECOMMISSIONING AMENDMENT
FIGURE 8.2
WESTERN ALLUVIUM AREA
POST DECOMMISSIONING MONITORING LOCATIONS



MAP DATE: 9/06 STATE PLANE OKLAHOMA NORTH NAD83



- EXISTING MONITOR WELL
- POST DECOMMISSIONING MONITORING LOCATION
- ⤵ EXTENT OF URANIUM IMPACT >180(pCi/l)
- ⋯ RECOVERY TRENCH
- - INFILTRATION TRENCH

SITE DECOMMISSIONING PLAN
GROUNDWATER DECOMMISSIONING AMENDMENT
FIGURE 8.3
WESTERN UPLAND AREA
POST-DECOMMISSIONING MONITORING LOCATIONS

0 100 200
 Feet

MAP DATE: 9/06 STATE PLANE OKLAHOMA NORTH NAD83

Note: This drawing is intended to be printed in color on 11" X 17" paper.

2092000 2092200 2092400 2092600

321400
321200
321000
320800
320600
320400
320200
320000

321400
321200
321000
320800
320600
320400
320200
320000

2092000 2092200 2092400 2092600

Figure 8.4
Well 1319B-1 Uranium Data

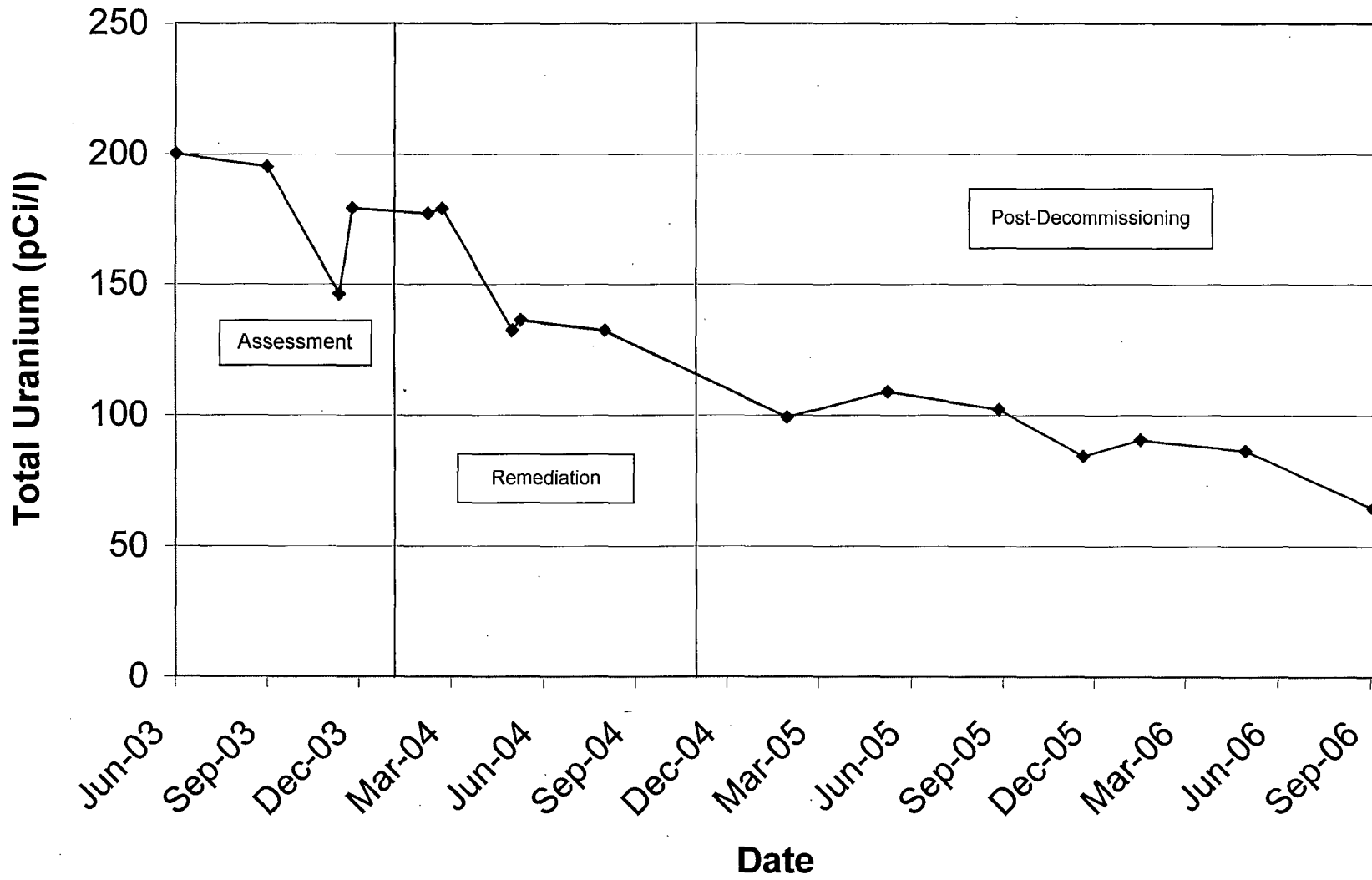


Figure 8.5
Well 1319C-1 Uranium Data

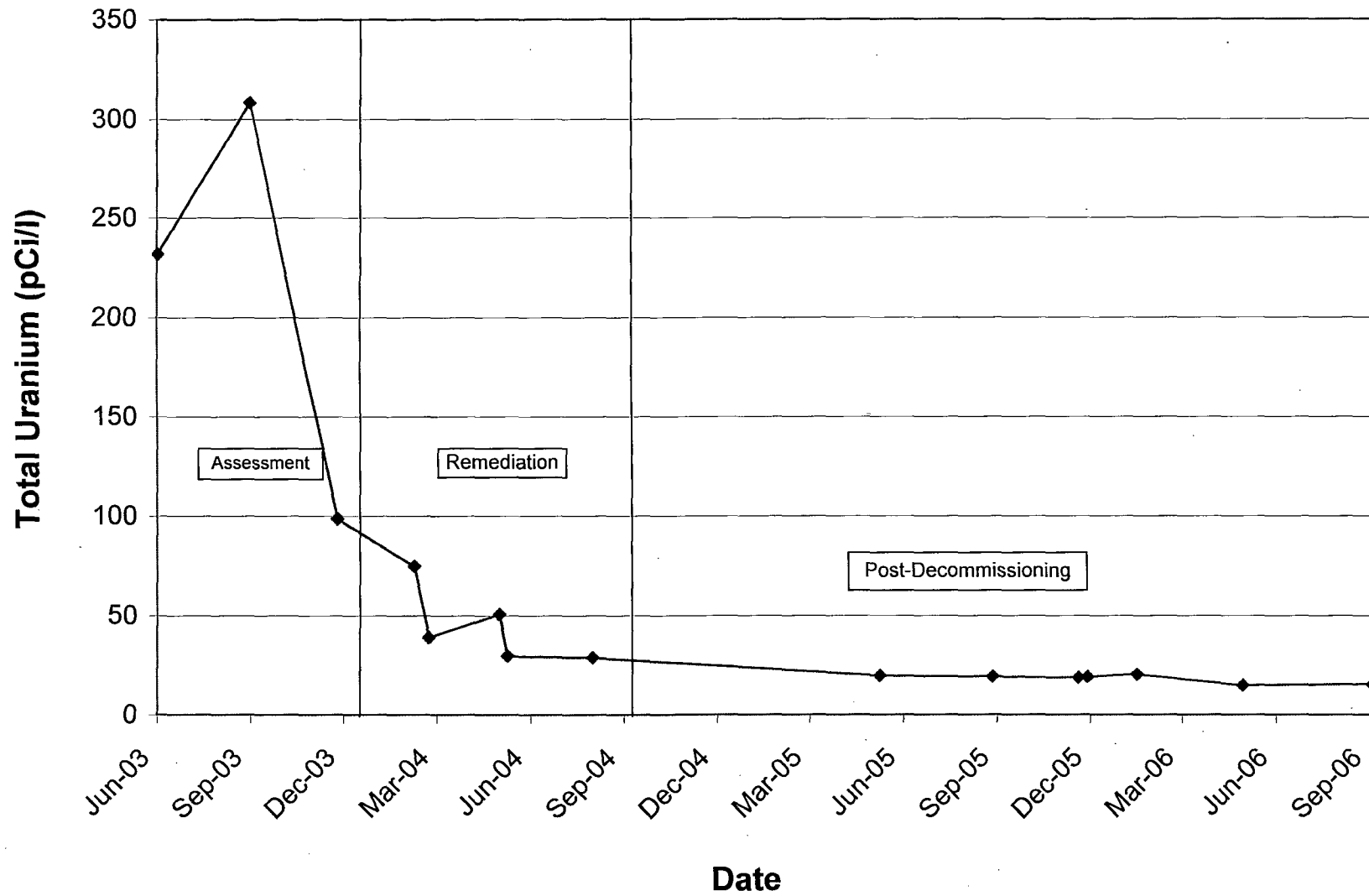


Figure 8.6
Well 1312 Tc-99 Data

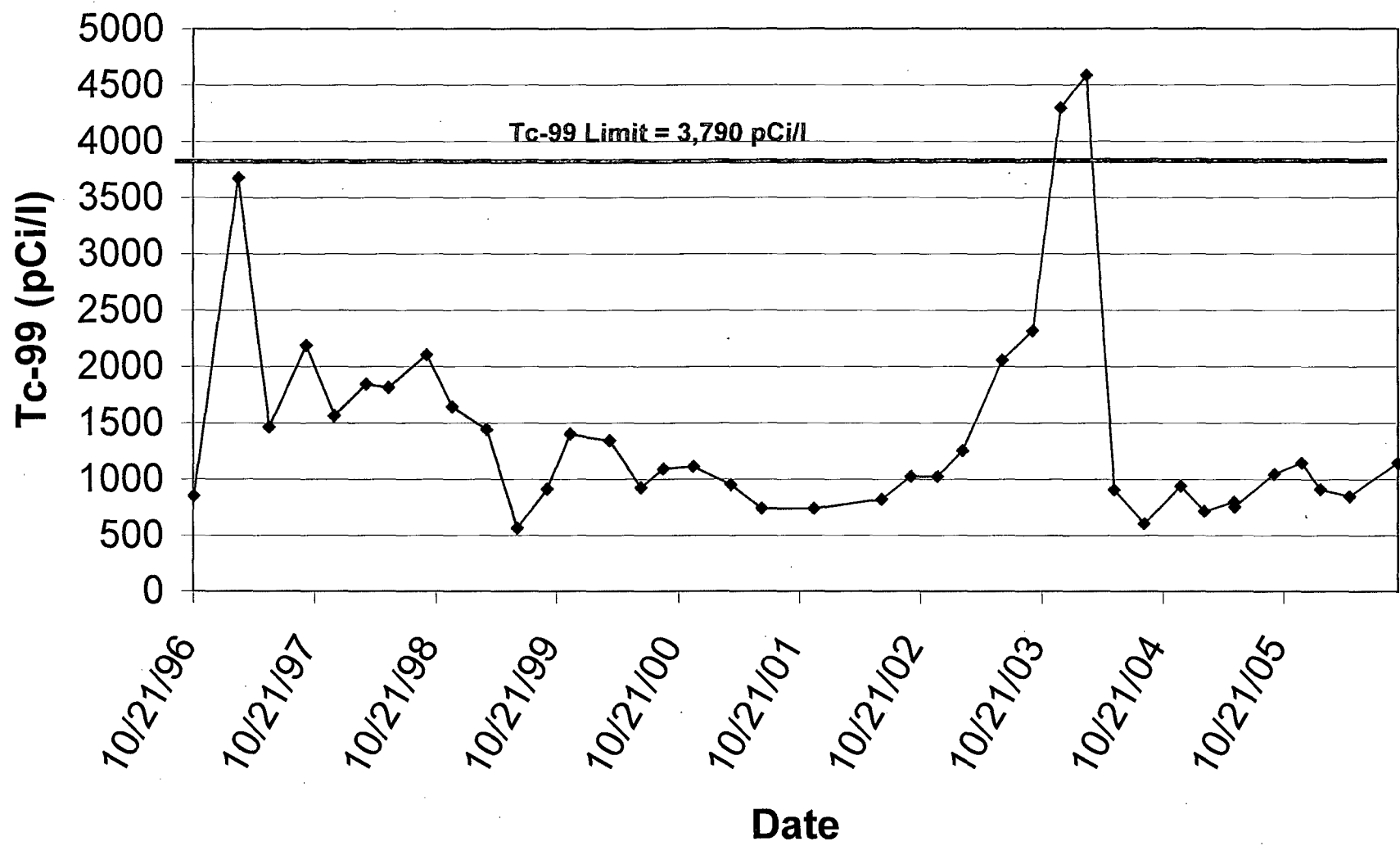
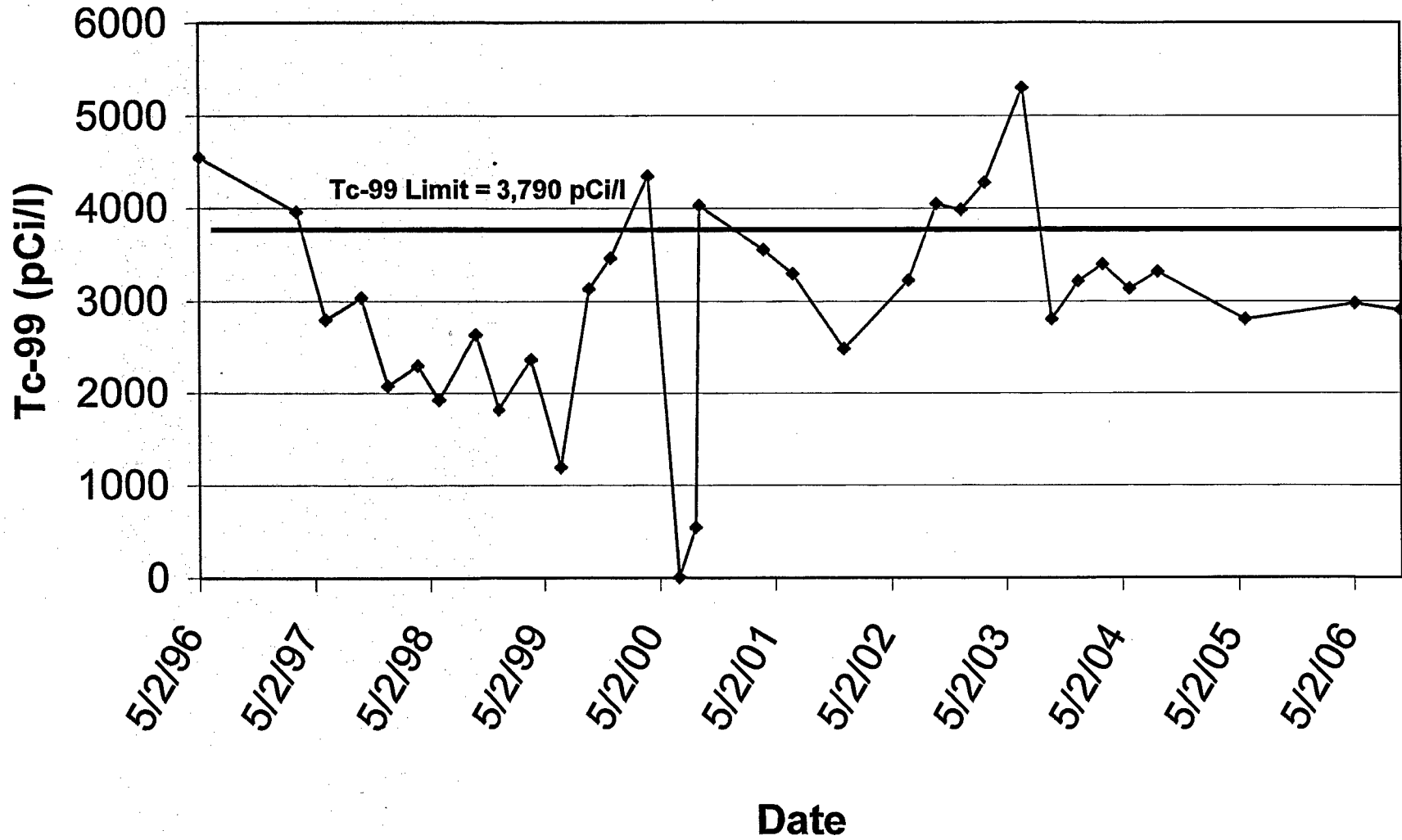
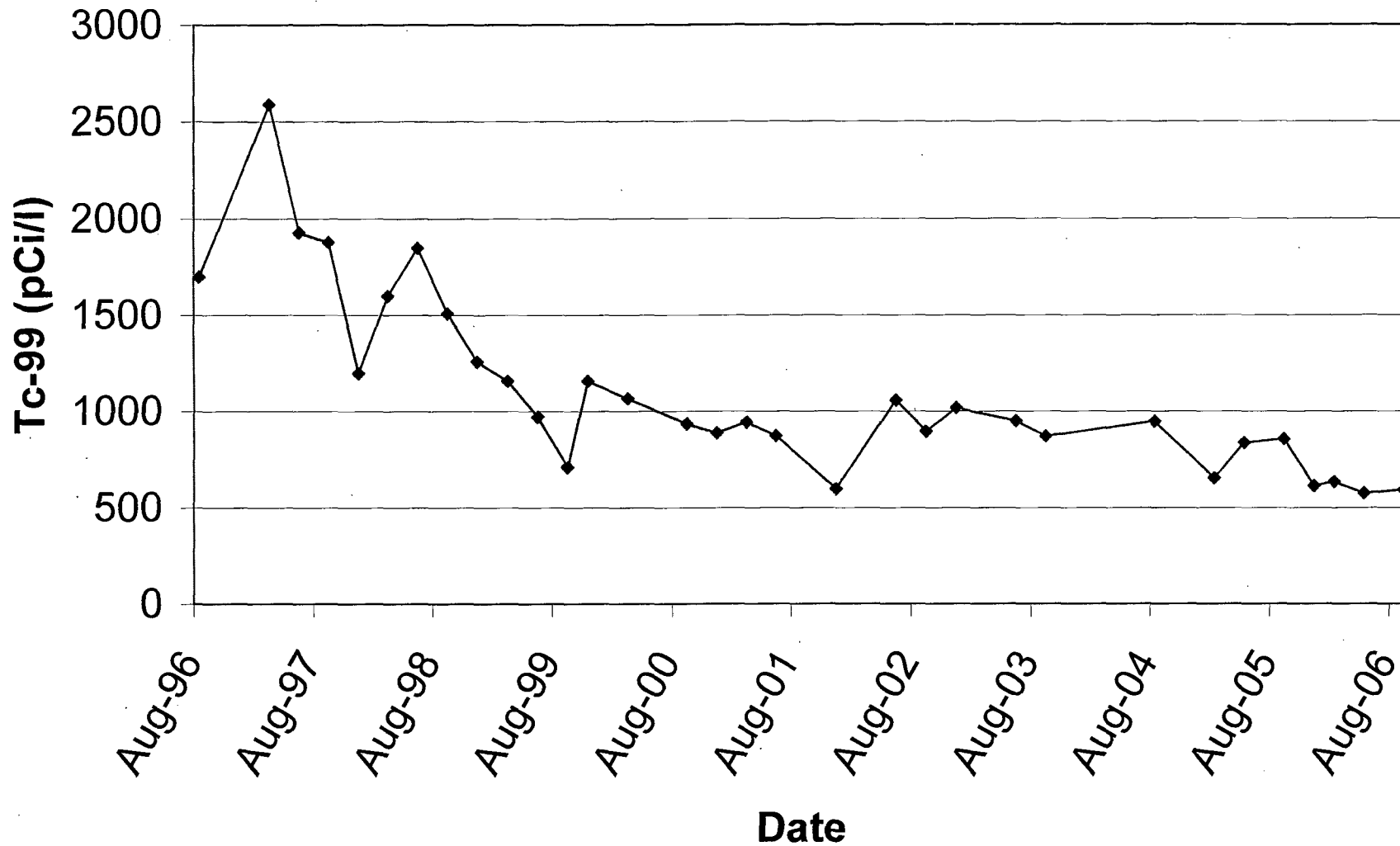


Figure 8.7
Seep 1208 Tc-99 Data



Tc-99 Limit = 3,790 pCi/l

Figure 8.8 Well 1336A Tc-99 Data



FIGURES

SDP ATTACHMENT 1

**WORK PLAN FOR IN-SITU BIOREMEDIATION
OF GROUNDWATER AT THE CIMARRON SITE**

TRONOX
INCORPORATED

**Work Plan for In-Situ
Bioremediation of
Groundwater at the
Cimarron Site**

Cimarron Facility
Crescent, Oklahoma

December 06, 2006

ARCADIS

Boyce Clark, Ph.D.
Senior Scientist

Paul Barnes
Senior Scientist

Jim Harrington
Vice President

**Work Plan for In-Situ
Bioremediation of Groundwater**

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Crescent, Oklahoma

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Our Ref.:
GPTRONOX.0002.00001

Date:
December 06, 2006

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Appendix

A	Geochemical Modeling Evaluation
---	---------------------------------

1. Introduction

This work plan describes the remedial action planned for the Cimarron Facility (Site) near Crescent, Oklahoma as shown on Figure 1. The following sections summarize the technical background for bioremediation of groundwater, the design and basis for the remedial activities, and the necessary steps ARCADIS will employ to ensure the permanence of the remediation.

1.1 Background

The historic fabrication of fuel elements from enriched uranium at the Cimarron Facility have resulted in uranium impacts to groundwater that exceed the site release criteria of 180 picocuries per liter (pCi/L) at each of the following locations:

- Burial Area #1 (BA#1);
- The Western Upland Area (WUA); and
- Western Alluvial Area (WAA).

The locations of these three areas are shown on Figure 2. The WUA is located in fractured bedrock and therefore does not have a defined “plume” but has wells completed in fractured sandstone that yield low levels of uranium adjacent to essentially “background” wells.

The Site operated from 1966 to 1975 under licenses from the Nuclear Regulatory Commission (NRC). Decommissioning activities began in 1976 and are being performed with oversight from the NRC and the Oklahoma Department of Environmental Quality (ODEQ). During the decommissioning process, the Cimarron Decommissioning Plan – Groundwater Evaluation Report (Cimarron Corporation 1998), which proposed a Site release criteria of 180 pCi/L total uranium, was approved. The NRC incorporated this standard into License SNM-928 as condition 27 (b) in License Amendment 15. Condition 27 (b) requires eight consecutive quarters of monitoring to demonstrate that uranium concentrations are maintained at or below 180 pCi/L.

1.2 Plume Status

As noted previously, there are groundwater plumes in three distinct areas which contain soluble uranium at concentrations in excess of the release criteria of 180 pCi/L total uranium. These plumes have been documented in prior correspondence with the NRC. Figure 3 shows the extent of the uranium plume (defined as groundwater exceeding 180 pCi/L) in BA#1, while Figure 4 displays the plume in the WAA, and Figure 5 displays the areas in which wells exceed 180 pCi/L in the WUA.

In addition to the previously documented plume delineation and field investigations, ARCADIS has performed limited sampling of aquifer conditions in the BA#1 plume area to help understand the solution and solid phase chemistry relevant to a bioremediation approach.

2. Overview of Approach and Objectives

The proposed remedial action for the Site incorporates biogeochemical reduction of dissolved uranium in groundwater detected above the release criteria of 180 pCi/L in the three identified areas. Specifically, the technology selected for this Site is an in-situ reactive zone (IRZ) to create an effective reduced environment conducive to precipitating uranium. The IRZ will be created through the subsurface injection of organic carbon (carbohydrates – often in the form of molasses) to create anoxic conditions in the areas of uranium-impacted groundwater. The timing, location, and concentration of reagent introduction is important to the proper implementation of this technology. In order to ensure that the injection of amendment does not in any way exacerbate existing conditions, an IRZ will be created at the down gradient edges of the plumes located in Burial Area #1 and in the Western Alluvium Area prior to amendment injection within the main body of the plumes. Creating a forward IRZ first prevents expansion of the groundwater plume by driving impacted groundwater through a pre-established treatment zone.

In addition to precipitating uranium, the approach entails depositing iron sulfide minerals within the existing plume area to stabilize and encapsulate the uranium, thereby preventing its remobilization above the approved Site release criteria (180 pCi/L or its equivalent for the uranium isotope ratios at the site of 110 micrograms per liter [$\mu\text{g/L}$]). These iron minerals, when reoxidized by ambient groundwater-containing oxygen, also sorb uranium, further preventing dissolved concentrations from exceeding the Site release criteria.

In order to validate the stabilization of dissolved uranium through mineral speciation and adsorption to the aquifer matrix material described above, ARCADIS has modeled the geochemical conditions created within the IRZ. A description of the modeling approach used by ARCADIS, along with the results of numerous modeling simulations depicting a variety of geochemical conditions, is provided in Appendix A of this work plan. Specifically, these results showed that, under sulfate-reducing conditions where iron sulfide (mackinawite) is formed, uranium is completely transformed to an insoluble uranium dioxide (uraninite) mineral phase. The model results also showed that mackinawite preferentially consumes oxygen, preventing uraninite oxidation and remobilization. When uraninite oxidation is complete (for a particular zone of the remediated aquifer) and uranium remobilization is allowed, the dissolved concentrations are kept low by sorption to iron oxide phases (such as hematite) which prevent exceedance of the Site release criteria. The model results show that, whether under reduced conditions with iron sulfide present or under re-oxidized conditions with

the iron sulfide converted to an iron oxide, uranium remains stable well below the Site release criteria. Consequently, although the geochemical model demonstrates that the reducing conditions that will be created during remediation should last greater than 1,000 years, this is not necessary to ensure that uranium will not mobilize at concentrations exceeding 180 pCi/l.

The Site groundwater model was also coupled with a geochemical sorption model to demonstrate that, even if uranium were instantaneously re-oxidized in localized zones or continuously reoxidized in small increments, it will not remain soluble in the plume area because it will rapidly sorb and precipitate on the aquifer matrix, where the iron sulfides and oxides have been created.

Experience with another similar in situ uranium treatment site, as well as published column studies (Abdelous and others, 1999) show that complete reduction to the concentrations indicated possible by these geochemical thermodynamic equilibrium models is not likely to occur. Several column studies and field experience shows uranium concentrations in the range of 10-30 pCi/L is typical in groundwater during and after bioremediation is performed for uranium. In these conditions, low levels of uranium, substantially below the release criteria of 180 pCi/L, will be dissolved in groundwater and mobilize at this protective concentration away from the plume area. This will have an effect to reduce the long-term risk associated with the treated plume, by decreasing the uranium available for remobilization. Preliminary calculations show that all of the existing plume mass could in this manner be allowed to remobilize at these very low, protective levels and that in a period of a few hundred years essentially no uranium would be left in the former plume area.

The following sections present a technical discussion which includes the approach to the biogeochemical processes, a summary of the geochemical modeling, and hydraulic conditions controlling IRZ treatment necessary to achieve the objectives. In order to optimize the performance of the remediation effort, the work will be staged with initial remediation efforts focused on the groundwater plume in Burial Area #1 where uranium concentrations in groundwater are the highest. Results from the full scale injection program at BA#1 will enable the optimization of treatment efforts in both the Western Alluvium and the Western Upland Areas. Pre-remediation sampling will occur at locations in both the Western Alluvium and the Western Upland Areas concurrent with the start-up of remediation at BA#1 to facilitate the rapid expansion of treatment from BA#1 to these other two sites.



ARCADIS

**Work Plan for In-Situ
Bioremediation of
Groundwater**

Cimarron Facility
Crescent, Oklahoma

The approach outlined in this work plan will be presented to the NRC for review and concurrence, along with the geochemical and groundwater model results. With NRC approval, ARCADIS will implement the remediation of the Site in each of the areas along the lines of the design laid out in this work plan. This will include additional detailed design of the IRZ remedial actions in each area to achieve the conditions demonstrated by the geochemical modeling to permanently stabilize the uranium plumes. The design for implementation in each area is presented below.

3. Conceptual Site Model

3.1 Geology

The localized geology of the Cimarron Site consists predominantly of the Garber Formation. The Garber Formation is exposed along the escarpment that borders the Cimarron River and consists primarily of sandstone units separated by relatively continuous siltstone and mudstone layers (J.L. Grant and Associates 1989). The sandstone units frequently have interbedded but discontinuous red-brown shale and mudstone lenses. The identifiable lithologic units at the Site are as follows:

- Sandstone A: Uppermost sandstone unit, generally red-brown to tan in color and up to 35 feet thick. Bottom of this sandstone unit occurs at an elevation of 970 feet above mean sea level (msl).
- Mudstone A: Red-brown to orange-brown, sometimes tan mudstone and claystone that separates Sandstones A and B. Ranges from 6 to 20 feet in thickness.
- Sandstone B: Second sandstone unit, similar in color and sedimentary features to Sandstone A. Found at elevations between 925 and 955 feet above msl and up to 30 feet thick. Found below Mudstone A.
- Mudstone B: Mudstone and claystone separating Sandstone B and Sandstone C. Similar in color to Mudstone A and ranges from 6 to 14 feet in thickness.
- Sandstone C: Lowermost sandstone in the Garber Formation. Similar in color and sedimentary features to overlying sandstones. This unit is at least 55 feet thick in the study area.

All three sandstone units found at the Cimarron Site are similar in lithology. They are fine to very fine-grained red-brown to tan sandstones with variable amounts of silt (J.L. Grant and Associates 1989). The silt content ranges from 10 to 50 percent where the sandstones with high silt content are difficult to distinguish from siltstone. The sandstones exhibit conglomeratic intervals approximately 2.5 feet thick with planar cross-stratification. Interbedded within these conglomeratic intervals are thin, silty laminae (J.L. Grant and Associates 1989). These features indicate that the sandstones were deposited in a fluvial environment, probably as deltaic channel sands.

The mudstone layers that separate the sandstones are mostly silty to shaley sedimentary units with a red-brown to orange-brown and tan color. These continuous mudstone layers probably represent overbank deposits formed during flooding of the delta. Correlation of the three sandstone units discussed above is based primarily on elevation and the presence of a thick mudstone unit at the bases of Sandstones A and B that can be correlated across most of the Site. Within each sandstone unit, there are frequent mudstone layers that are discontinuous and not correlative across the Cimarron Site.

3.2 Mineralogy

The sandstone units of the Garber Formation contain sand grains that are mostly quartz with minor amounts of feldspar and occasional magnetite and mica. The intergranular porosity varies with the silt content in each unit (J.L. Grant and Associates 1989). Cementing of the sandstone is weak and consists of calcite and hematite. Locally, thin intervals can be found that are well-cemented with gypsum and barite. Vugs found in the conglomerate zones discussed above are lined with calcite, gypsum, and barite (J.L. Grant and Associates 1989).

The mudstone layers occasionally exhibit desiccation cracks (J.L. Grant and Associates 1989) and are poorly consolidated. The mudstone layers are often encapsulated by thin, bluish-gray laminae that range in thickness from 0.1 to 4.0 inches. These "reduction zones" are common in red beds (J.L. Grant and Associates 1989) and, at the Site, the thickness of these reduction zones is approximately proportional to the thickness of the mudstone layer.

Auburn University conducted a mineralogical analysis of the sandstones and mudstones using X-ray diffraction, grain-size determinations, and cation exchange capacity measurements (J.L. Grant and Associates 1989). Quartz and feldspar were found to be the main clastic grains with kaolinite and montmorillonite as the clays in the fine-grained fractions. Calcite, iron oxides, and iron hydroxides were identified as the main cementing agents. The clay fraction ranged from 6 to about 20 percent in the clays and clay stones and from about 14 to 50 percent in the mudstones. The mudstones had a cation exchange capacity in the range of 6 to 22 milliequivalent (meq) per 100 grams (g). The sandstones had a cation exchange capacity generally below 6 meq/100g. Exchangeable cations were generally calcium and magnesium for both the sandstones and the mudstones.

Soil data were collected from borings TMW-9, TMW-13, and TMW-24 at two depth intervals in November 2002 and analyzed for total iron and total uranium. For the shallow interval (4.5 to 6.5 feet below land surface) total iron concentrations varied from 3,350 milligrams per kilogram (mg/kg) to 14,100 mg/kg, and total uranium concentrations varied from <1.0 mg/kg to 6.1 mg/kg. For the deeper interval (9.0 to 10.5 feet below land surface) total iron concentrations varied from 1,720 mg/kg to 6,900 mg/kg, and total uranium concentrations varied from <1.0 mg/kg to 4.5 mg/kg. Uranium was only detected in samples collected from boring TMW-9.

3.3 Hydrogeology

Groundwater in the area of the Cimarron Site is found in Permian-age sandstones of the Garber Formation and at depth in the underlying Wellington Formation. In addition, shallow groundwater is found in alluvial deposits associated with the Cimarron River and nearby streams. The Cimarron Site is within a major recharge area for the Garber Formation. Recharge to shallow groundwater has been estimated at 190 acre-feet per square mile, or about 10 percent of annual precipitation (Carr and Marcher 1977).

There is a regional groundwater high south of the Cimarron Site (Carr and Marcher 1977). In general, groundwater flows north toward the Cimarron River from this location. The regional northward gradient from the groundwater high to the Cimarron River in the shallow sandstone unit is approximately 0.0021 foot/foot (ft/ft). Locally, groundwater flow in outcropping sandstones in the area tends to follow topographic relief patterns, and a large percentage will discharge through seeps to bisecting drainage features.

At the Cimarron River and at Cottonwood Creek, regional groundwater flow in the freshwater zone of the Garber Formation is vertically upward to allow for discharge to these surface water features, which act as groundwater drains in this part of central Oklahoma (Carr and Marcher 1977).

Generally, groundwater flow at the Cimarron Site is northward from the groundwater high south of the Site toward the Cimarron River. However, groundwater flow will vary at the Site. Sandstones of the Garber Formation are interbedded with layers of mudstone, siltstone, or shale of varying thicknesses. Because of this interbedding, groundwater occurs in the individual sandstone layers and may or may not be hydraulically interconnected, at least locally, with adjacent sandstone layers. Within

the upper 200 feet at the Cimarron Site, four main water-bearing units have been previously designated as:

- Sandstone A;
- Sandstone B;
- Sandstone C; and
- Cimarron River Alluvium.

In those areas where Sandstone A is the uppermost water-bearing unit, flow in Sandstone A is controlled by local topography. Groundwater in Sandstone A flows from the topographically higher areas to adjacent drainages and reflects local recharge from precipitation events. Flow in Sandstones B and C is more regionally controlled. Generally, flow in Sandstones B and C is north to northwest toward the Cimarron River. In the vicinity of BA#1, local groundwater flow in Sandstone B is more to the north and east, because Sandstone B is the uppermost water-bearing unit and flow within it is influenced by local topography. Flow in the alluvium is toward the Cimarron River because the river is a gaining stream throughout its reach from Freedom (upstream of the site) to Guthrie (downstream of the site).

Each of the four water-bearing units at the Cimarron Site has its own specific flow patterns and hydraulic properties. For Sandstone A, slug tests completed by J.L. Grant and Associates (1989) gave a geometric mean hydraulic conductivity of 1.03×10^{-3} centimeters per second (cm/s) with a range from 2.41×10^{-4} cm/s to 5.7×10^{-3} cm/s. For Sandstone C, the geometric mean hydraulic conductivity was determined to be 7.85×10^{-4} cm/s. Aquifer tests in BA#1 (Cimarron Corporation 2003) included slug tests on many of the monitor wells and a pumping test using Well 02W56 with observation wells at distances from 16 to 107 feet from the pumping well. For Sandstone B, hydraulic conductivity estimates ranged from 9.97×10^{-4} cm/s to 2.39×10^{-5} cm/s.

For the alluvial sediments of the Cimarron River Floodplain, hydraulic conductivity estimates varied from values in the 10^{-2} cm/s to 10^{-3} cm/s range for the coarser sediments (sandy alluvium) to values in the range of 10^{-4} cm/s to 10^{-5} cm/s for sediments high in clays and silts (transitional zone). Because the alluvial sediments have higher clay and silt content near the escarpment where Sandstone B and

Mudstone B is exposed, the slug tests in the alluvial sediments reported lower hydraulic conductivities near the escarpment.

The surface drainages within the Cimarron Site receive flow from precipitation events and from groundwater base flow. Most of the drainages penetrate only Sandstone A and act as local drains for shallow groundwater during precipitation events. Sandstone B is penetrated by a drainage near BA#1. Sandstone C is not penetrated by the drainages and has no local interaction with stream flow. The groundwater in the Cimarron River alluvium drains to the river.

Floodplain alluvium receives water from five main sources in the Site's vicinity: 1) precipitation, 2) upward flow from Sandstone B or Sandstone C when either lies beneath the alluvium, 3) discharges from Sandstone A and Sandstone B at the escarpment, 4) surface water runoff from drainages, and 5) periodic flooding of the Cimarron River. Long-term water supply to the floodplain alluvium comes from upward flow in Sandstone B due to convergence of regional groundwater flow at the Cimarron River (Carr and Marcher 1977).

Precipitation recharges the alluvial floodplain at a rate of about 8 percent of annual precipitation (Adams and Bergman 1995). Periodic flooding by the Cimarron River temporarily affects bank storage in the alluvium adjacent to the river channel, but this effect is dampened by distance from the river to BA#1 and WAA.

Because groundwater flow varies locally across the Cimarron Site, a discussion of groundwater flow for specific areas of interest is presented in the following sections.

3.3.1 BA#1

Groundwater in the vicinity of BA#1 originates as precipitation that infiltrates into the shallow groundwater in the area of the former disposal trenches and flows into Sandstone B. This groundwater flows across a buried escarpment that acts as interface for the Sandstone B water-bearing unit and the Cimarron River alluvium and finally into and through the floodplain alluvium to the Cimarron River. Flow in Sandstone B is mostly northward in the area that is west of the transitional zone and northeastward along the interface with the transitional zone. Flow is driven by a relatively steep hydraulic gradient (0.10 ft/ft) at the interface between Sandstone B and the floodplain alluvium.

Once groundwater enters the floodplain alluvium, the hydraulic gradient decreases to around 0.023 ft/ft, and flow is refracted to a more northwesterly direction. The decrease in hydraulic gradient is due in part to the much higher overall hydraulic conductivity in the floodplain alluvium compared with Sandstone B. The refraction to the northwest may also be due to a paleochannel in the floodplain alluvial sediments. The direction of this paleochannel is to the northwest near the buried escarpment and then is redirected to the north as it extends farther out into the floodplain. Once groundwater passes through the transitional zone, it enters an area of sandy alluvium where the hydraulic gradient is very low. The flow direction in this area is controlled primarily by two flow components: the northwesterly flow from the paleochannel in the transitional zone and the northerly flow from Sandstones B and C, both of which discharge to the alluvium in the western portion of BA#1. In addition, in this area groundwater flow directions will shift in response to seasonal water level fluctuations and flood events.

3.3.2 Western Upland Area

In the WUA, the drainage between the former Uranium Pond #1 and the former Sanitary Lagoons acts as a local drain for groundwater in Sandstone A. Groundwater flows toward this drainage from both the east and west including Burial Area #3 (BA#3) and the former Sanitary Lagoons. The thick vegetation and groundwater seeps, such as those found at the WUA, attest to groundwater base flow entering this drainage (thus becoming surface water) from Sandstone A.

Groundwater gradients steepen along the cliff faces of the drainage. Along the cliff face bordering the Cimarron River Floodplain alluvium just north of the former Uranium Pond #1, groundwater flows north to northwest toward the floodplain in Sandstone A and discharges in myriad small seasonal seeps that are difficult to consistently locate. Groundwater gradients in Sandstone A near the former Uranium Pond #1 are approximately 0.01 ft/ft toward the drainages to the northeast and northwest and about 0.02 ft/ft toward the north. Groundwater levels in Sandstone A range from around 7 feet below ground surface (bgs) at the south end of the 1206 Seep Area near Well 1353 to around 26 feet bgs near the escarpment (Well 1312). Groundwater in Sandstone A surfaces and flows into the drainage to the west of BA#3 from small seeps that commingle in the drainage.

Groundwater in Sandstones B and C flows northwest toward the Cimarron River beneath the WUA. In Sandstone B, the groundwater gradient is toward the north-northwest at about 0.023 ft/ft. In Sandstone C, the gradient is also toward the north at about 0.013 ft/ft (J.L. Grant and Associates 1989). Groundwater flow in Sandstones B

and C is below the base of the escarpment in the WUA; thus, Sandstones B and C do not form seeps in the escarpment. These two water-bearing units are not intercepted by the drainages around BA#3.

3.3.3 Western Alluvial Area

Groundwater flow in the WAA is found in the alluvial floodplain of the Cimarron River. Groundwater flow in this area is generally northward toward the Cimarron River. With hydrogeologic characteristics similar to the sandy floodplain alluvium near BA#1, this area exhibits a very low hydraulic gradient, and groundwater flow patterns are affected by seasonal fluctuations in water levels and periodic flooding.

4. Remediation Approach

The approach proposed by ARCADIS is an in-situ bioremediation method in which the primary contaminant, soluble uranium in the form of uranyl dicarbonate, is converted through biogeochemical reactions to the immobile and stable mineral uraninite. . This biogeochemical reaction is generally accomplished by simply adding a biodegradable organic carbon substrate, which ultimately stimulates the growth of indigenous bacteria capable of creating the reductive conditions necessary to mineralize uranium. In addition to formation of uraninite, iron sulfide and other reduced iron oxides are formed that additionally stabilize the uraninite and act as a sorbent for any uranium that dissolves during the re-establishment of oxidized conditions. The attached Geochemical Modeling Evaluation (Appendix A) describes how these combined reactions permanently stabilize a treated aquifer under either continued reducing conditions or re-oxidized conditions.

In addition, ARCADIS will form other reduced mineral precipitates using other reductive biogeochemical reactions, such as iron and sulfate reduction, to enhance uraninite stability. These minerals are formed by transformation of native iron oxides to iron sulfides (mackinawite, greigite, pyrite, and others) and reduced mixed-valence iron oxides (magnetite and green rust). The reductive transformation of native ferric iron oxides is performed by microorganisms that naturally occur in the groundwater environment when an organic carbon source is added. If necessary, additional iron and/or sulfate can be added to optimize the ratio of reduced iron minerals to uraninite. The ratio of {reduced iron sulfide minerals}:uraninite has been shown in the geochemical modeling memo (Appendix A) and in natural systems to limit the potential for remobilization, with higher concentrations of FeS minerals showing stronger stabilization.

4.1 Biogeochemical processes

The bioremediation process that is proposed at the Cimarron Site has been used extensively to degrade chlorinated solvents and to stabilize metals within contaminated aquifers. As of 2006, more than 230 sites have been treated by the IRZ technology (Nyer *et al.* 2001; Suthersan 2002; Harrington 2002). The proposed process consists of the following steps:

- 1) Determination of the background biogeochemical conditions within the plume to be remediated, with special emphasis on the current rate of migration of oxygen into the plume, and the concentrations of dissolved and solid phase electron acceptors

present in the plume area. These electron acceptors typically include dissolved oxygen, nitrate, dissolved and structural mineral-associated iron (III) and manganese (III and IV), dissolved and adsorbed uranium (VI), and dissolved and structural mineral-associated sulfate.

- 2) Formation of reducing conditions through the removal of oxygen and nitrates within and around the contaminated plume area. This will be accomplished by the injection of organic carbon, which will be oxidized and degraded by microbial activities (fermentation and organic carbon oxidation).
- 3) Precipitation of the uranium as a reduced uranium (IV) oxide (UO_2 [solid]). This is a microbially induced reductive oxidation (redox) reaction, where organic carbon is oxidized and uranium is reduced (organic carbon is the electron donor, and uranium is the electron acceptor). With time, the freshly precipitated uranium will become increasingly crystalline and insoluble (Casas *et al.* 1998).
- 4) Precipitation of other reduced compounds adjacent to and around the uranium precipitated in Step (3). These other reduced compounds will primarily be iron sulfides, formed as a result of microbial sulfate reduction, where organic carbon is oxidized and sulfate is reduced to sulfide and reduced iron (II)-containing oxides. Typically, organic carbon injected into groundwater will sequentially deoxygenate the aquifer and then support the reduction of uranium, followed by the reduction of structural iron compounds and dissolved sulfate (Zehnder and Stumm 1989). All of these reactions are microbially performed redox reactions. The process is designed to precipitate iron sulfides so that the molar concentrations will be a large ratio (more than 1,000 times the molar concentration of precipitated uranium oxides). For example, in the BA#1 plume, the mass of iron sulfides and oxides that ARCADIS proposes to create in this work plan is more than 6,000 times the molar mass of uranium. The mass of uranium in the existing plume has been estimated by several investigators (including ARCADIS) to be between 100 and 200 pounds.
- 5) Determine that sufficient reduced minerals have been deposited in the plume to deoxygenate the plume area in order to maintain uranium stability. This will typically involve recovery of solid phase materials and determination of the mass of reduced compounds.
- 6) Determine that the rate of uraninite remobilization does not exceed the Site release criteria for uranium. In other words, that reoxidation of the plume does not result in the release of uranium from the precipitated mass in a manner that will cause

concentrations in groundwater to exceed the Site release criteria. This has been demonstrated numerically in the attached Geochemical Modeling Evaluation. Groundwater sampling and a post-treatment study will provide empirical data to support the stability of the uraninite.

4.1.1 Uranium Removal by Microbial Reduction in Groundwater

Over a decade ago, Lovley *et al.* (1991) and Lovley and Phillips (1992) proposed the remediation of uranium in groundwater using an in-situ bioremediation process. Since that proposal, an extensive bibliography has been published documenting the removal of uranium by microbial processes in groundwater or simulated groundwater conditions. This bibliography is summarized in Lloyd and Macaskie (2000). The following papers are particularly relevant to documenting that injection of an organic carbon source into a typical uranium plume will result in uranium precipitation as insoluble uranium oxides, and that sulfides can be co-precipitated with the uranium to provide long-term uranium stability:

Senko *et al.* (2002) show that uranium reduction can be rapidly achieved in an aquifer containing excess organic carbon into which soluble uranium is introduced and acetate, lactate, and formate (organic carbon sources) are supplied. They also demonstrate the importance of excluding nitrate and denitrification intermediates from the aquifer following uranium reduction to prevent remobilization of the uranium.

Chang *et al.* (2001) showed that Sulfate Reducing Bacteria (SRB) are abundant in groundwater in a zone containing high concentrations of uranium at the Shiprock, New Mexico site, and that these bacteria are capable of uranium reduction, sulfate reduction, and iron sulfide precipitation. Microbial reduction of uranium was shown to result in soluble uranium concentrations as low as 1 pCi/L.

Abdelouas *et al.* (2000) performed column studies that showed that excess iron sulfide is an optimal material to provide a redox buffer to prevent oxidative dissolution of uranium. They state “the more iron sulfide present, the higher the stability of uraninite,” the primary mineral form we propose to create in this work. They documented that a maximum concentration of 29 pCi/L dissolved uranium was formed during re-oxidation of freshly precipitated uranium where a 10^4 molar excess iron sulfide was precipitated along with the uranium. ARCADIS proposes to create a similar molar ratio at the Cimarron Site during remediation so that, even if the aquifer became oxidized, uranium concentrations would not approach the Site release criteria.

Spear *et al.* (2000) showed that uranium reduction proceeds rapidly in the presence of excess organic carbon, and that sulfate reduction will also occur along with uranium reduction if sufficient organic carbon is added and sulfate is available.

Abdelouas *et al.* (1999) also performed column studies where accelerated oxidation experiments documented uranium stabilization for simulated “hundreds of years” where iron sulfide had been co-deposited with the uranium.

Numerous other recent papers have documented that uranium removal and sulfate reduction follows the injection of sulfate and organic carbon into groundwater containing uranium, as well as the ability of these systems to prevent remobilization of uranium at concentrations of concern. A recent paper (Wan and others, 2005) suggests that high concentration of alkalinity can shift the equilibrium between the solid and aqueous forms of uranium. These conclusions were drawn from column studies with sustained concentrations of high alkalinity ranging from 1,200 to 1,500 mg/L. Baseline alkalinity concentrations at the Site range from 200 to 600 mg/L with potential transient increases of approximately 200 mg/L resulting from bacterial respiration. ARCADIS has performed numerical modeling of uranium stability under these ranges of alkalinity which indicate no increase in soluble uranium concentrations as a function of alkalinity. Additional simulations varying the concentration of calcium and magnesium were performed to evaluate the effect on carbonate equilibrium within the Site groundwater system. Preliminary results indicate no significant change in uraninite solubility as a function of concentration for these divalent cations.

4.2 Enhanced Sorption

4.2.1 Sulfate Reduction and the Role of Iron Sulfides

SRB have been utilized to perform in-situ bioremediation for a wide variety of contaminants, including hydrocarbons, chlorinated solvents, and heavy metals. To perform sulfate reduction, an electron donor, typically organic carbon, and sulfate (which acts as the electron acceptor) must be present. Many SRB have been shown to be capable of uranium reduction as well (Chang *et al.* 2001; Spear *et al.* 2000).

The ARCADIS process primarily relies on SRB to utilize the added carbon source to transform soluble sulfate and mineral or dissolved phase iron and reduce the sulfate to sulfide. Sulfide then chemically reacts with iron to form iron sulfides. The sulfate reduction/iron sulfide formation process naturally occurs in soils and sediments of lakes, rivers, swamps, and estuaries; it is a nearly universal process wherever oxygen

can be excluded or minimized. SRB are nearly ubiquitous bacteria. SRB are often active in clay lenses in otherwise aerobic aquifers and are also abundant in root zones where photosynthetic exudates are produced or plant biomass is degraded (Otero and Macias 2002).

To initially activate the sulfate reduction process at the Cimarron Site, ARCADIS will add only organic carbon. However, the existing soluble sources of sulfate are limited to a few hundred milligrams per liter (mg/L). To create iron sulfides in the range shown to create stable uraninite (between 5,000 and 20,000 mg/kg reduced iron mineral phase), ARCADIS will inject sulfate, once the microbial population has acclimatized, at concentrations that facilitate these mineral phases. Sulfate concentrations, both in the soluble and the solid phase, will be critical for determining the required sulfate addition rate and accordingly will be measured in samples collected from both the groundwater and aquifer matrix in the treatment areas.

In the absence of iron (and other oxidized minerals), sulfate reduction in aquifers will lead to accumulation of aqueous sulfide (HS⁻). In the Cimarron soils, however, where oxidized iron minerals (such as hematite) are abundant (grab samples range – 1 to 3 percent), sulfide will react with the iron, reducing the ferric iron to ferrous iron. Ferrous iron formed in this way is relatively soluble; however, additional sulfide formed will quickly react with the ferrous iron and, at pH greater than 6.0, iron sulfide minerals will rapidly precipitate. The temporary increase in dissolved iron concentrations will last for a few months. ARCADIS will therefore monitor the pH to ensure that the iron sulfide precipitates from solution. It is also possible, in localized areas, that the iron content of the aquifer mineral phases will not be sufficient to create the solid phase reduced iron sulfide and oxide minerals desired. Where this is the case, supplemental iron in the form of iron sulfate will be added until an optimal ratio is achieved. The presence of the IRZ at the forward edge of the plume will prevent iron migration beyond the treatment area, and additional iron sulfides and oxides will be formed in this zone.

Iron sulfide has been recognized as being critical to maintaining uranium stability in groundwater during bioremediation (Abdelouas *et al.* 2000 and 1999) as well as in natural uranium ore deposits. Leventhal and Santos (1981) studied the relative importance of organic carbon and sulfide sulfur for stabilizing and precipitating uranium in a Wyoming roll-type deposit. A very strong correlation was found between uranium and sulfide sulfur, indicating both a role for sulfur in depositing the uranium as well as in maintaining its stability. It is important to note that the sulfide continues to perform a stabilizing function in such deposits, which have been measured as millions of years

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old. Guilbert and Park (1986) call these deposits “kinetically stable” where the sulfide sulfur acts to control uranium stability. In uranium ore geology terms, ARCADIS will be creating a “regionally reduced” host aquifer at the Cimarron Site. In these geologic conditions, a very small fraction (typically less than 10^{-8} of the uranium in the ore deposit) is made soluble per year (Waste Isolation Systems Panel 1983). The formation of natural deposits of uranium that are stabilized by sulfide is the basis for role front and sedimentary deposits that have been stable for the long time scales that the NRC requires for remediation sites such as Cimarron. Formation of iron sulfide to stabilize and precipitate dissolved uranium is an approach with strong verification of permanent stability by comparison with these natural systems.

Iron sulfide has also been recognized as an important redox buffer for several situations that are instructive for Cimarron. Pauwels *et al.* (1998) studied the reactivity of naturally occurring pyrite where nitrate was injected. Their data showed that this iron sulfide source, even though aged over geologic time scales, was still reactive toward maintaining in-situ reducing conditions. Nitrate reduction was rapid (half-life of reduction of 2 days in a sandy aquifer matrix), leading to the oxidation of pyrite to ferric iron and sulfate minerals, which deposited as jarosite and natroalunite. Tesoriero *et al.* (2000) showed that, in aquifers receiving agricultural runoff, oxygen and nitrate in the runoff were reduced by iron sulfide when infiltrated runoff reached the deeper aquifer. Hartog *et al.* (2001) showed that iron sulfide, reduced iron compounds (including siderite) in addition to iron sulfides, and bulk organic matter can all provide redox buffering in aquifers receiving agricultural runoff. ARCADIS cites these examples as relevant for the “resident farmer” scenario, indicating that, even under agricultural runoff scenarios, the uranium can be maintained insoluble by iron sulfide.

An additional factor to maintain uranium stability, even in conditions where iron sulfide has been exhausted in the aquifer, is the residual iron oxides that form after iron sulfides oxidize. These freshly formed oxides have a higher surface area and are more reactive than those iron oxides that were formed and have been present for thousands of years. Lack *et al.* (2002) showed that ferric iron oxides sorb uranium with strong binding energy (bidentate and tridentate inner-sphere complexes). Ferris *et al.* (2000) showed that these iron oxides could maintain very low dissolved uranium concentrations (less than 30 pCi/L). Martin and Kempton (2000) have shown continued reactivity of hydrous ferric oxides formed in this way for more than 30 pore volumes. This means that, for the Cimarron plume, the iron oxides that will form as oxygen enters the plume area (transported by diffusion in rainwater and in groundwater) will prevent uranium from ever remobilizing at concentrations even approaching 180 pCi/L.

4.2.2 Uranium Stability Summary

The papers referenced above provide the information needed to identify the necessary characteristics of a stable, fully reduced zone. To remain stable over long periods of time, a reduced zone must contain a variety of reduced compounds after treatment, including some combination of the following:

- Iron sulfides (ranging from amorphous FeS to pyrite). To ensure very low soluble uranium concentrations over long periods of time, the concentration of iron sulfides must be several orders of magnitude higher than the concentration of uranium in the reducing zone;
- Elemental sulfur;
- Residual reduced organic carbon, either incorporated in cellular biomass or stored by microorganisms;
- Reduced uranium compounds (UO_2 and potentially US_2); and
- Potentially a variety of other reduced sulfur, manganese, iron, and trace mineral compounds.

In the in-situ reactive zone, the re-oxidation and remobilization of uranium will be limited by the oxygen that is available to react with the precipitated uranium. The available oxygen will be controlled by the presence of stored, reduced compounds emplaced in the aquifer by the treatment process.

In relative terms, expressed in molar ratios of uranium to all of the other reduced compounds stored in the aquifer, the potential oxidation of uranium will be very low compared with the potential oxidation of iron, sulfur, and other reduced species. Utilizing FeS compounds alone, more than 10^3 moles of FeS will be present to every mole of UO_2 . The proposed remediation plan anticipated the introduction of oxygen via natural pathways and provides for sufficient reduced compounds to exhaust these sources of oxygen. As the aquifer materials are exposed to oxygen, FeS would oxidize at least as rapidly as the precipitated UO_2 and consume the oxygen. Because the ratio of iron sulfide to uranium is so large, a very limited amount of oxygen will be available to react with uranium. Because UO_2 will be precipitated first during treatment, the FeS precipitate would be laid down over the UO_2 as a FeS coating. FeS will therefore be exposed to the oxygen in the groundwater before uranium-containing precipitates

would be exposed. A small amount of the uranium in the aquifer will mobilize very slowly as the FeS is depleted and, because there is so much more FeS in the aquifer material, the uranium will only mobilize at concentrations substantially lower than 180 pCi/L. As noted above, this mobilization of very low levels of uranium will in time reduce the total mass of uranium in the former plume area, leading to a time where no significant uranium mass is left in the former plume areas.

The basic premise of this approach is confirmed by the geochemical modeling performed and documented in the attached geochemistry memo (Appendix A). Even under conditions of saturated dissolved oxygen and molar ratios as low as 700:1 iron to uranium, the Site release criteria was consistently achieved.

4.2.3 Remobilization Calculations

NRC requires assurance that uranium will not remobilize at concentrations exceeding 180 pCi/L over a period of 1,000 years. To ensure that uranium will not remobilize, it is necessary to project the potential delivery of oxygen to the aquifer over that time period. There are three significant sources of dissolved oxygen: groundwater entering the aquifer from upgradient, precipitation infiltrating from the surface, and diffusion of atmospheric oxygen through the vadose zone. ARCADIS has purposely overestimated the quantity of oxygen delivered by these three pathways to ensure that more than enough iron sulfides remain in the aquifer to consume this quantity of oxygen. BA#1 will be discussed for purposes of evaluation, but the processes are consistent for the other areas as well.

ARCADIS measured the dissolved oxygen concentration in groundwater in BA#1 at several locations and determined an average concentration of approximately 0.62 mg/L, with a maximum measured value of 0.84 mg/L. Specifically, groundwater was sampled in Wells TMW-9, TMW-13, and TMW-24 where dissolved oxygen (DO) was found to range from 0.31 to 0.84 mg/L, with an average of 0.62 ± 0.25 mg/L. Iron was measured in aquifer materials and determined to be between 0.6 and 3.1 percent by weight in six samples obtained within 10 feet of those wells. Monitoring results obtained by Cimarron show nitrate concentrations of 2.88 and 0.12 mg/L in Wells 1315 and TMW-13, respectively, in June 2002. Sulfate concentrations have been measured between 70 and 300 mg/L in the plume area.

Based on the width of the plume (maximum 300 feet), the depth of the plume (maximum 20 feet), the hydraulic gradient (0.006 ft/ft) (ENSR Conceptual Site Model, October 2006), and the permeability of Sandstone A (5×10^{-3} cm/sec; J.L. Grant and

Associates, 1989), a total of 5.1 million liters of groundwater will enter the plume area per year. At a DO concentration of 0.8 mg/L, no more than 9 pounds of oxygen will be delivered to the plume via this pathway.

Assuming that rainfall is saturated with oxygen (8.0 mg/L), that annual precipitation averages 36 inches per year, that 100 percent of that water enters the aquifer without reduction in oxygen content, and that the plume and additional treatment area covers 4 acres, a total of approximately 260 pounds of oxygen will be delivered to the plume by this pathway.

Complete removal of oxygen in the groundwater will cause some increase in the oxygen transfer into the groundwater because the diffusional gradient will be increased. Based on a maximum measured oxygen concentration of 0.8 mg/L in the groundwater, calculations based on Henry's Law indicate that the oxygen content in the soil above the groundwater is now 0.0189 atmospheres, or 9 percent of the oxygen content in the atmosphere. Depletion of the groundwater oxygen will increase the gradient by that same percentage. The existing flux that is maintaining groundwater at the 0.8 mg/L concentration is 1,060 pounds per year over 4 acres. (This is based on Fick's Law, assuming a depth to groundwater of 10 feet, initial oxygen in the atmosphere is 0.2352 kilogram per cubic meter [kg/m^3], an oxygen gradient of 0.21 to 0.02 atmospheres, a D_{eff} of 4×10^{-9} centimeters squared per second [cm^2/sec] limited by the nearly saturated conditions at the soil-groundwater interface, and an area of 4 acres). The increase of oxygen transmission when the gradient is increased by 9 percent is about 96 pounds per year over 4 acres.

Combining the three pathways above, a total of 365 pounds of oxygen would be delivered to the plume area in 1 year. Assuming this remains constant for 1,000 years, a total of 365,000 pounds of oxygen will be delivered to the plume area over 1,000 years. Based on the equation: $\text{FeS}_2 + 3.5\text{H}_2\text{O} + 3.75\text{O}_2 \rightarrow \text{Fe}(\text{OH})_3 + 2\text{SO}_4^{2-} + 4\text{H}^+$, 357,550 pounds of iron sulfide would be needed to deplete this mass of oxygen from the water. ARCADIS proposes to form approximately 1,000,000 pounds of iron sulfide (an excess factor of nearly three times that required) so that less than half of the iron sulfide is reacted by the end of 1,000 years.

The presence of other reduced compounds besides iron sulfide makes this calculation conservative. In groundwater saturated with dissolved oxygen, approximately 8 mg/L of O_2 would be available to react with the precipitated uranium and the iron sulfide that coats it. Because the molar ratio of iron sulfide to uranium will be at least 103, only 0.008 mg/L dissolved oxygen would be available to react with the uranium. The rest

would react with the overwhelming available iron sulfide. This concentration is equivalent to 2.5×10^{-8} mole per liter O_2 . This is all the oxygen that would be available for uranium oxidation, yielding a maximum dissolved uranium activity of 40 pCi/L that would be in the groundwater at any given point in the plume. This concentration is similar to that calculated by the geochemical modeling.

4.3 Geochemical Modeling

A geochemical modeling evaluation was performed to evaluate the fate and transport of soluble uranium in groundwater under various geochemical conditions representative of the Site. These simulations model the reductive precipitation of uranium to the mineral uraninite (UO_2) and evaluate the stability of this insoluble mineral phase over time as geochemical conditions return to baseline.

Model simulations were run using Geochemists' Workbench (GWB; Rockworks, Golden, Colorado), a geochemical model capable of describing the precipitation, dissolution, and sorption of uranium under Site conditions in both batch and transport scenarios. Additionally, MODFLOW with MT3DMS was used with a Site flow model and output from GWB to model sorption of uranium as a function of transport through the system. The attached Geochemical Modeling Evaluation (Appendix A) describes this work in detail.

4.4 Hydraulic Feasibility

Several methodologies are available for IRZ development and injection of reagents. These include direct-push injection points for one-time or multiple injections, installed injection wells, and trenches or infiltration galleries. For the Cimarron Site, it is expected that IRZ development will be accomplished using a combination of injection wells, direct-push injection points, and shallow trenches to apply the treatment reagent to the affected groundwater and capillary fringe. Information from the conceptual site model (CSM) prepared by ENSR (October 2006) has been used to develop a preliminary (60 percent) design for the application of reagents in each of the three areas. The final design of the reagent delivery systems will occur after information is collected in the field during preliminary operation of the initially installed portions of the planned systems. This proposed approach also has the flexibility for adjustments and system additions depending on the results of treatment performance monitoring.

Target zones for IRZ development include the sandy, more prolific zone of the alluvial aquifer within BA#1 and the WAA; the transitional alluvial zone at BA#1 and the

transitional zone at the Western Alluvial Area – both containing a higher percentage of silts and clays; and the bedrock zones associated with BA#1 and the WUA. The approach for the delivery system to establish the IRZ in each of these areas is discussed in the following sections.

4.4.1 BA#1

Based on the distribution of the impacted groundwater within BA#1, IRZ development will be implemented within three zones of varying hydrogeologic conditions. These include the upland bedrock zone in the former source area, which consists predominantly of sandstone; the transitional alluvial zone located adjacent to the bedrock escarpment consisting of sand with silts and clays; and the sandy alluvial zone consisting primarily of sands with high hydraulic conductivities.

In general, the delivery of treatment reagents and IRZ development within the affected groundwater will be accomplished with a series of closely spaced injection points located throughout the plume area. The object is to create treatment zones around each injection point that will overlap with the treatment zones created by adjacent injection points. This will ensure treatment coverage throughout the plume area. In addition, treatment reagent will be applied to the ground in shallow trenches on the surface above the plume. The trenches will be placed on contour, and the treatment reagent will be designed to slowly wash into the vadose zone by surface recharge. The reagent added in this manner will stabilize any uranium that could be present in the unsaturated and phreatic zones and will provide reduced materials to consume oxygen that diffuses into the plume from the atmosphere.

Because injection of reagent will locally displace water within the uranium plume, several safeguards are planned to prevent the occurrence or perceived appearance of plume spreading during the treatment phase. These will include the installation of a “Forward” IRZ located on the downgradient boundary of the uranium plume (see Section 5.4.1), the implementation of plume treatment by injecting from outside the plume first and then toward the center, and by monitoring performance during plume treatment to control hydraulic response on a real-time basis.

IRZ development within impacted groundwater in both alluvial zones will be accomplished with injection wells and the use of direct-push injections. Injection well construction is expected to be accomplished using 3-inch diameter polyvinyl chloride (PVC) wells with wrapped screens appropriately gravel-packed and developed to increase injection efficiency. The installation of these wells will provide for a permanent

infrastructure to conduct additional treatments as required throughout the plume treatment phase. It is expected that direct-push injection points will also be utilized for plume injections. Direct-push injection points will consist of either one-time injection points, where reagent is injected through a delivery string after it is pushed into the target injection zone with a direct-push rig, or through the installation of a direct-push point (i.e., sand point) that can be utilized for multiple injections. Drilled and completed injection wells are expected to provide for a more efficient delivery system. However, due to its convenience, direct-push technology will be used on a larger scale if proven effective. The degree to which direct-push point installations will be utilized will be determined during the design testing phase described in Section 5.

Within the alluvial zones, the appropriate spacing of individual injection points to ensure complete treatment coverage will depend on the variability of hydrogeologic characteristics such as hydraulic conductivities, hydraulic gradients, saturated thicknesses, and effective porosities. Based on the understanding of hydrogeologic conditions presented in the CSM, the preliminary design contemplates injection point spacings of 50 feet or less within the treatment grid. Injection point spacing will be further evaluated during initial system construction and testing with any necessary adjustments continuing through systems operation (treatment) performance monitoring.

Treatment of the vadose zone immediately adjacent to the water table will be accomplished by utilizing shallow (approximately 2.5 feet deep) infiltration trenches. These trenches will be constructed along surface topographic features to mimic natural recharge. It is expected that more than 2,000 feet of shallow trenching will be utilized. The trenches will be filled with gravel or similar porous media to affect the infiltration of treatment reagent. The trenches will then be filled with reagent, which will slowly infiltrate the vadose zone by surface recharge facilitated by precipitation or irrigation during extended dry periods.

IRZ development within impacted groundwater in the upland bedrock will be accomplished with injection wells and the use of shallow infiltration trenches. Whereas three inch diameter wells are proposed for use in the alluvium, injection wells installed in the upland bedrock will consist of 6-inch diameter PVC wells with wrapped screens appropriately gravel-packed and developed to increase injection efficiency. The installation of these wells will provide for a permanent infrastructure to conduct additional treatments as required throughout the plume treatment phase. Based on the CSM, 15 injection wells will be required to provide adequate coverage. Injection point spacing for the plume injections will be further evaluated during the design testing

phase. The injection scheme will also be adjusted as required based on performance monitoring that will be conducted during the plume treatment phase.

The development of these injection wells will result in the removal of some groundwater. However, because many of these wells will be in areas with uranium concentrations in groundwater below the release criteria of 180 pCi/L, we propose to capture and either mix the water containing elevated concentrations of uranium with low concentration water, or segregate and hold the higher uranium concentration groundwater depending on regulatory outcomes. Ideally, an effort will be made to permit the use of blended development water (from all of the wells) as recirculation water that will be mixed with reagents for re-injection. If this water cannot be permitted for this use, it will be treated and disposed as necessary.

Shallow (approximately 2.5 feet deep) infiltration trenches will also be utilized to affect treatment in the upland bedrock area. These trenches will be installed perpendicular to the former burial trenches to facilitate infiltration of treatment reagent into the former, back-filled trenches and induce reagent flow to mimic natural flow patterns. It is expected that four infiltration trenches will be utilized to bisect and fully span the length of all four of the former burial trenches.

4.4.2 Western Upland Area

The extent of groundwater impacts within the WUA appears to be more limited in size, and uranium impacts have occurred sporadically. It is currently assumed that former BA#3 was the potential source for uranium impacts in this area. The impacts migrated westerly through bedrock fractures or other secondary porosity features from BA#3 to the drainage and as a result do not exist in the same form as the alluvial plumes at BA#1 and the WAA.

The approach for treatment within the WUA is to utilize a high permeability infiltration trench to essentially flush the fractures in the impacted area with treatment reagent and fresh water. The trench will be approximately 10 to 15 feet deep and 5 feet wide and will be installed extending approximately 325 feet in length in an orientation that is generally parallel to the western face of the former BA#3. During the treatment phase, reagent and/or fresh water will be continuously applied to the infiltration trench and allowed to mimic natural flow pathways that were originally utilized by the uranium discharging from BA#3.

A recovery trench will be installed within the drainage feature downstream of the impacted groundwater seepage area to collect seep water containing uranium and residual treatment amendment. Water collected from the recovery trench will be recirculated to the infiltration trench located in the BA#3 area once it has been dosed with additional treatment reagents. The recovery trench will be operated as necessary depending on the flow of water and residual uranium concentrations. Circulation of freshwater or reagent-amended, interceptor-trench water will continue for up to 18 months.

4.4.3 Western Alluvial Area

The delivery of treatment reagent and IRZ development within the affected groundwater of the WAA will be accomplished in a manner similar to that of the sandy alluvial zone of BA#1. A series of closely spaced injection points will be located throughout the plume area. The object is to create treatment zones within the hydraulic influence area of each injection point that will overlap with the treatment zones created by adjacent injection points. The alluvial transition zone will be treated in a manner similar to that of the BA#1 transition zone. This will ensure treatment coverage throughout the plume area.

IRZ development within impacted groundwater will be accomplished with injection wells and the use of direct-push injections. Injection well construction is expected to be accomplished using 3-inch diameter PVC wells with wrapped screens appropriately gravel-packed and developed to increase injection efficiency. The installation of these wells will provide for a permanent infrastructure, allowing for additional treatments as required throughout the plume treatment phase. It is expected that direct-push injection points will also be utilized for plume injections. Direct-push injection points will consist of either one-time injection points, where reagent is injected through a delivery string after it is pushed into the target injection zone with a direct-push rig, or through the installation of a direct-push point (i.e., sand point) that can be utilized for multiple injections. Drilled and completed injection wells are expected to provide for a more efficient delivery system. However, due to its convenience, direct-push technology will be used on a larger scale if proven effective. The degree to which direct-push point installations will be utilized will be determined during the design testing phase described in Section 5.

The appropriate spacing of individual injection points to ensure complete treatment coverage will depend on the hydraulic conductivity, hydraulic gradient, saturated thickness, and effective porosity of this alluvial area. Based on the hydrogeologic



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Cimarron Facility
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conditions identified in the CSM, injection points will be installed on spacings of 50 feet or less within the treatment grid. Injection point spacing for the initial plume injections will be further evaluated during the pre-design testing phase. The injection scheme will also be adjusted as required based on performance monitoring that will be conducted during the plume treatment phase.

5. Proposed Sequence of Activities

5.1 Baseline Geochemical Data collection

In addition to uranium concentration data obtained by Cimarron in previous groundwater characterization studies, ARCADIS will perform baseline groundwater and aquifer solids monitoring in all three Site areas (WUA, WAA, and BA#1) to establish geochemical conditions prior to field injection. These geochemical conditions will be used to determine the requirement for additional injection of iron, sulfate, and total organic carbon (TOC). Baseline monitoring will include the following:

1. Determine the concentration of iron, sulfate, nitrogen species (nitrate, ammonia, Total Kjeldahl Nitrogen [TKN]), and TOC in groundwater in the plume area, in the IRZ area, and in the sandstone. Representative wells in the plume area will be sampled to obtain this information.
2. Determine the concentration of iron, sulfur species (total and sulfate minerals), nitrogen species (nitrate, ammonia, TKN), and TOC in aquifer matrix material in the plume area, in the IRZ area, and in the sandstone. These data will be obtained from cores or other samples obtained near the wells used to establish groundwater baseline data.
3. Determine the existing uranium dissolved phase vs. sorbed and mineralized phase to determine total uranium phase that will require reduction.

Solid and aqueous phase material must be fully analyzed in order to adequately describe the biogeochemical system. The detailed monitoring data collected for each of these media types is described in the following sections.

5.1.1 Solid Phase

Samples of aquifer solids from BA#1 and WAA will be collected from five spatial locations with two depth intervals per location (vadose and phreatic). Samples will be collected via direct-push or split-spoon collection method. The collection of sample specimens, their preservation, packaging, shipment and analysis will be performed in accordance with the Sampling and Analysis Plan that has been approved for the Cimarron site and is incorporated in this Work Plan by reference. The following solid phase analyses will be performed.

5.1.2 Mineralogy

Mineralogical analysis will be performed and will include the use of X-ray Diffractometry to identify crystalline mineral phases such as uraninite, calcite, hematite, etc.

Additionally, a scanning electron microscopic analysis with energy dispersive X-ray probing (XDS) will be performed to identify various iron oxides that are coating the aquifer grains. This analysis will allow the identification of currently co-precipitated and/or sorbed uranium and other ions.

5.1.3 Soils Analysis

Wet chemistry methods will be performed on aquifer material to determine the mass and reactivity of secondary minerals as well as general geochemical characteristics. Understanding the acid and base neutralizing capacity of the soil will allow a more complete understanding of how the IRZ will propagate, how the precipitation of uraninite and iron sulfide will proceed, and the long-term stability of the uraninite and iron sulfide. Because iron is an important mineral in the remediation design, it is important to measure the reactivity of iron on the aquifer solids. This is done by measuring available iron using extractants of various strengths to establish a range of iron concentrations that may be observed. Many metals exhibit different behaviors under reducing conditions with regard to mobility and sorption. Therefore, the following tests will be performed which will allow ARCADIS to predict the extent to which many of these changes will occur:

- Soil slurries will be analyzed for acidity and alkalinity to determine the acid and base neutralizing capacity of the material;
- Total metals will be analyzed using a nitric digestion and inductively coupled plasma-atomic emission spectrometry (ICP-AES);
- Sequentially Extractable Metals (SEM) will be examined with analysis for Fe, Mn, U, Pb, Cd, Cr, As, Hg, Ag, Ba, Se;
- Fe, Mn, U, and As associated with amorphous Fe oxides will be determined by hydroxylamine extraction; and
- Fe, Mn, U, and As associated with crystalline FE oxides will be determined by Citrate-Dithionite-Bicarbonate-extraction.

Additionally, a small batch test using aquifer solids in the presence of Site groundwater will be inoculated with various concentrations of organic carbon and allowed to incubate. Aliquots will be removed and analyzed via ICP-AES over time to measure the change in aqueous metals concentration during a biologically induced reduction. Upon completion of these batch reduction tests, samples from the aquifer material will be analyzed for mineralogy as described above to determine what additional mineral phases have formed from the reducing environment and the increase in alkalinity.

5.1.4 Aqueous phase

Groundwater samples from the boring locations will be collected and containerized with zero-headspace for analysis. Both unfiltered and field-filtered (0.45-micron groundwater filter) groundwater samples will be collected. Samples will be stored in darkness and chilled to 4 degrees Centigrade for shipment to an ARCADIS designated laboratory. Refer to Table 1 for a list of parameters, methods, and handling information. Monitor wells proposed for performance monitoring in BA#1 include TMW-2, TMW-1, TMW-8, TMW-21, TMW-9, TMW-13, and O2W43 (Figure#3). Monitor wells proposed for performance monitoring in WAA include T-79, T-68, T-69, T-58, and T-72 (Figure#4). These wells will be monitored from prior to the start of remediation through completion of both the remediation efforts and the submission of a completion report to the NRC. Information from the wells during active remediation will be used to optimize remedy performance. Upon achieving the remediation objectives, all of the data collected from the wells will be considered in the preparation of the completion report. The report will illustrate that the necessary reduction in uranium concentrations has been achieved and that the precipitated uranium meets the necessary conditions of stability in the aquifer as predicted by the geochemical model in order to achieve final closure for the site.

5.1.5 Data Evaluation

The solid and aqueous phase information will be evaluated for the potential iron and sulfate sources available to participate in the formation of iron sulfide. The inclusion of iron and/or sulfate will be adjusted in the injection mixture based on the relative availability of dissolved and/or solid phase iron and sulfate sources.

The addition of TOC will be adjusted based on the presence of dissolved oxygen, nitrate, sulfate, and solid phase iron and manganese oxides that can participate in redox reactions as electron acceptors. The final concentration of TOC (molasses and methanol) will be adjusted based on the stoichiometry of the reaction with each of

these phases, and to produce the solid phase iron sulfide that will be used to stabilize the uranium.

5.2 Hydrogeology

Design enhancement injection testing will be conducted prior to installing a complete delivery system for IRZ development within the impacted plumes. The testing will focus on the construction methodology and radius of influence of individual injection points and the design parameters for injection well and system operation.

5.2.1 Injection Design Testing

Injection design testing will be conducted in three areas: the sandy alluvium, the transitional alluvium, and the sandstone bedrock. Specifically, the areas at the Cimarron Site where testing is being planned will include the sandy alluvium in BA#1 downgradient of the uranium plume in the area currently targeted for placement of the Forward IRZ (see Section 5.4.1), the transitional alluvium in BA#1 in the middle of the uranium plume near the bedrock escarpment, and in the upland sandstone bedrock of BA#1 near the former burial trenches.

Two injection techniques will be tested in both of the alluvial environments. These include direct-push technology by injecting reagent through a delivery string driven into the target injection zone with the direct-push rig and the installation of a 3-inch diameter PVC injection well with wrapped screen that is gravel-packed and developed. For the upland bedrock, injection testing will be conducted utilizing a 6-inch installed well with wrapped screen that is gravel-packed and developed.

Each injection test will be conducted by injecting approximately 10,000 gallons of organic carbon test reagent into each test point. The test reagent will be made up of water from the on-site reservoirs and an organic carbon solution of dissolved molasses. The reagent will include a conservative tracer such as potassium bromide which, along with total organic carbon measurements and water level data, can provide radius of influence information. The reagent will be injected at pressures that will not exceed 1 pound per square inch (psi) per foot of distance from ground surface to the top of the screened interval.

5.2.2 Design Data Collection

The existing monitoring wells located within the area of each injection test will be monitored closely throughout the active injection period and throughout a follow-up period of stabilization.

During test injections and post-injection monitoring, the nearby monitoring wells within the area of each test will be monitored for response. Data to be collected from each selected monitoring well will include:

- Depth to water measurements (to evaluate flow directions and mounding during injection);
- TOC (to evaluate degradation rates from which a TOC half life will be calculated),
- Dissolved sulfate and ferrous iron (to measure any iron or sulfate reduction within the period of the tracer test);
- Field measurements of dissolved oxygen and oxidation-reduction potential (to determine oxygen consumption and extent of formation of reduced conditions); and
- Tracer such as bromide (to determine groundwater flow directions and velocity).

Data collection frequency will be daily until field conditions stabilize or until conditions dictate a less frequent interval.

5.2.3 Design Data Results

The full-scale system will be constructed and operated based on the enhanced-design data derived during testing of initially installed injection components. This data will provide very clear understandings for the optimization of the following:

- Injection methodology utilization;
- Geochemical response;
- Finalized injection point spacing and grid size;

- Injection volumes, pressures, and expected rates of delivery; and
- Required reagent concentrations.

5.3 Full-Scale Groundwater Treatment

5.3.1 Forward IRZ (WAA and BA#1)

IRZs will be established downgradient (forward) of the BA#1 and WAA plumes prior to plume remediation. The location of the forward IRZ is within the projected path of plume movement, and this location is illustrated for both the BA#1 and WAA plumes in Figures 3 and 4. Monitoring groundwater chemistry in the forward IRZ area will enable ARCADIS to refine its calculations of the mass of TOC, iron, sulfate, etc., needed to ensure both plume remediation and long-term stability. Additionally, the forward IRZ will serve as a zone that will rapidly precipitate uranium should the migration of uranium be accelerated by subsequent upgradient remedial action.

The forward IRZs will be established by injection of an organic carbon substrate to support reductive microbial processes. The organic carbon substrate will consist of a dilute molasses solution to achieve optimum reducing conditions and establish multiple groups of reductive microorganisms (iron reducers, fermenters and sulfate reducers). Once established, a low-molecular weight carbon source (dilute methanol) will be added to achieve further sulfate reduction. It should be noted that all of these compounds are agricultural products or microbiological nutrients commonly used in groundwater remediation. The IRZ will be established by injecting water containing the organic substrate that is sufficient to encourage microbial growth into the formation using injection wells or well points or a Geoprobe[®] or similar apparatus. The total number of locations will be determined after hydraulic tests are performed and the hydraulic data are evaluated as described in Section 5.2. These data will provide the basis for the well spacing in each area IRZ.

The forward IRZs will be monitored for several months following the initial organic carbon substrate solution injections by measuring redox potential in wells within the IRZ area. After strongly reducing conditions are established in this area, a second injection series will be performed. This second injection series will introduce additional organic carbon solution, potentially iron, and potentially sulfate. The addition of iron and sulfate will depend on the data collected during baseline monitoring and will be balanced to provide the stoichiometric requirement for iron sulfide formation.

Additional monitoring will be performed to show that sufficient iron sulfide is being formed. This will be accomplished by sampling groundwater and aquifer matrix material removed from within the IRZ area where total reduced iron and sulfur are measured (USEPA Methods 6010/6020 and 9030B/9034). Additional injections may be performed in the IRZ area until the appropriate iron sulfide concentrations are achieved.

5.3.2 Surface Application of Organic Carbon Solution (BA#1 Plume only)

An organic carbon solution will be applied to the ground in shallow trenches (less than 3 feet deep) on the surface above the plume and the additional stabilization area. These trenches will be located in the areas identified on Figure 3. The trenches will be placed on contour, and the organic carbon substrate solution will be applied in and around these trenches. Trenches will be created via excavation and backfilling with granular material through which liquids can be infiltrated into the soil. The TOC may be in a liquid or solid form and will be designed to slowly infiltrate into the vadose zone by surface recharge. Ideally, meteoric precipitation will provide sufficient water for infiltration of the organic carbon solution. However, if surface application occurs during the dry season, ARCADIS may irrigate the field to enhance the downward migration of these compounds. The organic carbon added in this manner will stabilize any uranium that might be present in the unsaturated zone and will generate reduced material that will consume oxygen diffusing into the plume from the atmosphere.

5.3.3 Remediation of the WAA and BA#1 Plumes

This is the first step of the process that actually reduces the concentration of uranium in groundwater within the plume area; hence, this constitutes the beginning of groundwater remediation. The entire plume will be remediated in place by the in-situ reduction of uranium and placement of iron sulfide to maintain uranium in an insoluble form. The process will be identical to that performed for the establishment of the IRZ, but the location of the treatment will be throughout the plume area. The approximate locations of the proposed plume injections are shown in Figures 3 and 4. The purpose of the plume treatment is to create conditions in the plume that stabilize uranium in place for more than 1,000 years. This will be accomplished by first reducing uranium concentrations via in-situ microbial precipitation, and second by injecting the reagents that naturally occurring microbes transform to create an iron sulfide phase. As previously discussed, this will lead to the consumption of oxygen and maintenance of reduced conditions in-situ for more than 1,000 years.

The IRZ will be established by injection of an organic carbon substrate to support reductive microbial processes. The organic carbon substrate will consist of dilute molasses solution to achieve optimum reducing conditions and establish multiple groups of reductive microorganisms (iron reducers, fermenters and sulfate reducers). Once established, a low-molecular weight carbon source (dilute methanol) will be added to achieve further sulfate reduction. The dose of organic carbon for this area will be calculated after the additional geochemical and hydraulic data are collected and the final design has been established. However, the design includes injections that begin in the downgradient area near the IRZ and at the edges of the plume, and work their way toward the center of the plume and into the upgradient area. This will minimize the movement of uranium, keeping as much as practical immobilized at its current location. Because the injections will occur within a period of only a few weeks, groundwater will not travel a significant distance. Groundwater movement will flow toward the forward IRZ which will serve to prevent the forward spread of the plume.

The IRZ will be monitored for several months following the initial organic substrate solution injections by measuring total organic carbon (TOC) in wells within the plume area. A series of injections will be performed after strongly reducing conditions are established in the IRZ. This injection series will consist of additional TOC and may include iron and/or sulfate. The addition of iron and sulfate will depend on the data collected during baseline monitoring and will be balanced to provide the stoichiometric requirement for iron sulfide formation. As injections occur and the monitoring information is received, the injection mixtures will be refined to adjust the total organic carbon (TOC) concentrations, and the iron/sulfate ratios (to adjust to the potential iron and sulfate sources in the aquifer matrix) and frequency of the injections will be timed to limit movement of injected materials out of the additional treatment area.

Additional monitoring will be performed to demonstrate that the uranium is being converted to the solid phase and that an iron sulfide phase is being formed. This will include groundwater sampling for uranium, iron, and sulfate as well as aquifer matrix sampling within the plume area for total reduced iron and sulfur.

5.3.4 Upgradient Sandstone Reagent Application (BA#1 and BA#3)

Similar to the forward IRZ and main-plume IRZ remedial activities, the sandstone aquifer upgradient from the BA#1 plume will be treated to create reducing conditions, and an iron sulfide phase will be deposited in the aquifer. The purpose of this upgradient treatment is to treat any dissolved uranium in this area, and to deplete dissolved oxygen so that upgradient groundwater will be de-oxygenated prior to

migration into the plume area. The injections in this area will use existing wells supplemented with newly constructed injection wells screened in Sandstone B.

The organic carbon solution will first be injected into the BA#1 area Sandstone B wells (the only sandstone impacted by uranium from the former burial trenches), followed by a small volume of fresh water injected to push the organic carbon solution away from the well. After reducing conditions have been formed, additional organic carbon solution with iron and sulfate will be injected to create iron sulfide-forming conditions. Multiple injections may be used to obtain sufficient iron sulfide deposition to achieve more than 1,000 years of uranium stabilization.

The application of reagent to the sandstone in the BA #3 area will be performed through an infiltration trench installed within the footprint of the former BA #3 trench. Water collected from a trench installed downgradient of the BA #3 (see Figure 5) will be amended with reagents (dilute molasses, methanol, and iron sulfate) and injected into the injection trench. Operation of the collection and injection trench will continue for up to 18 months.

It is expected that low concentrations of reagents will be measured in the seeps within the draw downgradient of the injection trench, and that reagent strength will be adjusted to minimize the breakthrough of reagents to the seepage area. Treatment will continue until the all of the wells in the BA#3 area show uranium concentrations below 180 pCi/L, and the combined flow in the collection trench in four consecutive quarters is below 180 pCi/L.

5.3.5 Performance Monitoring of IRZs

The performance monitoring for all IRZ systems will include demonstration of TOC consumption (by monitoring TOC in groundwater), demonstration that sulfate and iron are being converted to iron sulfide (by monitoring iron and sulfate depletion in the dissolved phase and measuring iron sulfide formation in the solid phase), and demonstrating that low uranium concentrations are being formed by the IRZ across the entire plume area. The TOC monitoring will be performed at least quarterly during the injection process in all treatment areas. Dissolved uranium will be monitored quarterly during the injection time period and for two years after injections have ceased.

Dissolved iron and sulfate will be monitored quarterly during the injection process in all treatment areas. Solid phase measurements of iron sulfide will be performed in five areas each from BA#1 and WAA plume areas after the injections have been

completed. The solid phase results will be used to document that the treatment is complete, that iron sulfide has been formed at a rate sufficient to stabilize the uranium.

5.3.6 Surface Restoration

After remedial activities are complete, all monitoring wells in the plume areas will be plugged and abandoned. Any surface disturbance in the areas will be reclaimed, and the area above the plume will be graded to provide positive drainage, and native vegetation will be planted. These steps will decrease infiltration of precipitation into the plume area. This will further reduce the potential delivery of oxygen to the plume area.

6. Demonstrating Longevity

An extensive numerical modeling analysis was performed to evaluate the stability and longevity of solid phase uranium in groundwater under various geochemical conditions representative of the Cimarron Site. The model approach simulated the reductive precipitation of soluble uranium to the mineral uraninite and then evaluated the stability of this insoluble mineral phase over time as geochemical conditions return to baseline oxidizing conditions. The fate and transport of the oxidatively dissolved uranium was evaluated in the context of sorption and other attenuation mechanisms.

Model simulations were run using Geochemists' Workbench (GWB; Rockworks, Golden, Colorado), a geochemical model capable of describing the precipitation, dissolution, and sorption of uranium under Site conditions in both batch and transport scenarios. Additionally, MODFLOW with MT3DMS was used with a currently existing flow model created for the Site (ENSR Corporation) and output from GWB to model sorption of uranium as a function of transport through the system.

The study first modeled the electrochemical reduction of soluble uranium currently existing at the Site by the addition of organic carbon to the groundwater system. This results in the precipitation of the uranium mineral uraninite and the precipitation of the iron mineral mackinawite, which are stable under reducing conditions. Upon the cessation of the organic carbon addition, the Site groundwater will return to background oxidizing conditions. Therefore, the stability of the uraninite and mackinawite were evaluated using GWB to determine the period during which the uraninite was stable and then the concentration of soluble uranium expected to leach into groundwater over time. Finally, modeling simulations were run using the same tools to evaluate the effect of sorption to attenuate the newly dissolved uranium. Geochemical data used in the model were from actual Site analysis of groundwater from monitor well TMW-9 and soil boring TMW-9 (10 feet bgs). Because the amount of iron in the system available to react is important to the permanence of the uraninite, several model runs were performed in which a percentage (10, 25, 50, 75, 100) of the total iron in the TMW-9 soil boring sample was used. This is termed reactive iron. A complete model report is presented as Appendix A to this work plan.

The following scenarios were simulated and results discussed.

Scenario 1 was performed using GWB and simulated the reductive precipitation of uranium in the system from soluble uranium and any uranium sorbed to aquifer solids to the mineral uraninite. The production of the reduced amorphous iron sulfide mineral

mackinawite, as conditions were driven to electrochemically reducing, was also included in the simulation.

In the model output, all of the uranium in the system (dissolved and sorbed phase) was converted to uraninite (32.34 mg/L of solution). The mass of mackinawite varied from 7.15 g for the 10 percent reactive iron mass to 71.56 g for the 100 percent reactive iron mass. This yielded uranium-to-iron sulfide ratios of 1:679 (10 percent reactive iron), 1:1,699 (25 percent reactive iron), 1:3,345 (50 percent reactive iron), 1:5,096 (75 percent reactive iron), and 1:6,783 (100 percent reactive iron).

Scenario 2 was performed using GWB and simulated the dissolution behavior of the uraninite and mackinawite once groundwater conditions revert to pre-treatment oxidizing conditions. Model runs were performed using the highest reported dissolved oxygen concentration of 1.2 mg/L for groundwater at the Site and a worst case of 8 mg/L. Simulations were performed using batch reaction and one-dimensional transport.

In all dissolution simulations, the mackinawite acted as a sacrificial reductant and was oxidized before any of the uraninite underwent oxidation. The pore volume estimates before uraninite begins to dissolve are clearly a function of the mass of reactive iron available to form mackinawite. The pore volumes required to exhaust the mackinawite ranged from 500 (using 8.0 mg/L dissolved oxygen) to 1,900 (using 1.2 mg/L dissolved oxygen) for 10 percent reactive iron to 5,000 (using 8.0 mg/L dissolved oxygen) to 19,000 (using 1.2 mg/L dissolved oxygen) for 100 percent reactive iron. The concentration of uranium liberated once the mackinawite is exhausted was evaluated as a function of pH and dissolved oxygen.

- Under the 100 percent reactive iron permutations, the uranium concentration ranged from 1.47 µg/L (1.2 mg/L dissolved oxygen, pH 5) to 8.96 µg/L (8.0 mg/L dissolved oxygen, pH 6.8).
- Under the 75 percent reactive iron permutations, the uranium concentration ranged from 3.48 µg/L (1.2 mg/L dissolved oxygen, pH 6.8) to 11.91 µg/L (8.0 mg/L dissolved oxygen, pH 6.8).
- Under the 50 percent reactive iron permutations, the uranium concentrations ranged from 5.21 µg/L (1.2 mg/L dissolved oxygen, pH 6.8) to 17.86 µg/L (8.0 mg/L dissolved oxygen, pH 6.8).

- Under the 25 percent reactive iron permutations, the uranium concentrations ranged from 10.02 µg/L (1.2 mg/L dissolved oxygen, pH 6.8) to 32.60 µg/L (8.0 mg/L dissolved oxygen, pH 6.8).
- Under the 10 percent reactive iron permutations, the uranium concentrations ranged from 25.01 µg/L (1.2 mg/L dissolved oxygen, pH 6.8) to 84.00 µg/L (8.0 mg/L dissolved oxygen, pH 6.8).

When transport was included in the dissolution simulations, it was possible to estimate the time frame of uraninite dissolution. Two groundwater velocities were used based on output from the currently existing ENSR Conceptual Site Model.

- Using a 0.5-foot-per-day groundwater velocity (conservative estimate of alluvial lithology – ENSR CSM Report (Revision-01), October 2006), the model predicted that mackinawite will be exhausted and uraninite dissolution will occur in approximately 25,925 years (14,065.7 pore volumes).
- Using a 5-foot-per-day groundwater velocity (sandstone lithology– ENSR CSM Report (Revision-01), October 2006), the model predicted that mackinawite will be exhausted and uraninite dissolution will occur in approximately 154.8 years (14,065.6 pore volumes).

Scenario 3 was performed using GWB and MODFLOW/MT3DMS and examined the fate and transport of the oxidatively dissolved uranium from Scenario 2 with an emphasis on sorption to iron oxide minerals as the dominant attenuation mechanism.

Sorption simulations with 100 percent reactive iron available in the system converted to ferric oxides through the oxidation of mackinawite and a uranium concentration of 500 µg/L leached into the system (output from Scenario 3 batch calculations) indicate that uranium sorption will happen almost instantaneously and that uranium concentrations will drop below the regulatory limit of 110 µg/L within less than 1 foot of the source. Considering that this is a conservative scenario, and that 500 µg/L of uranium will not instantaneously enter the system ubiquitously, it is unlikely that the regulatory limit of 110 µg/L uranium will be exceeded for any significant distance within the treatment area. In order to evaluate an extreme worst case scenario, Simulations were performed using 5000 ug/L uranium (consistent with current Site concentrations). These simulations indicate that uranium will not approach the regulatory limit.

Simulations using 10 percent reactive iron available in the system show a uranium concentration of 10 µg/L within 0.5 foot of the source, indicating that uranium is instantaneously sorbed onto iron hydroxide surfaces even at this low estimate of iron.

Simulations conducted to model uranium sorption under lower alkalinity concentration conditions did not yield significantly different results.

Scenario 4 was performed using MODFLOW/MT3DMS in the context of the site-specific flow model developed by ENSR and evaluated the fate and transport of uranium if an instantaneous release of 500 µg/L occurs (derived from the output of Scenario 2 above) as a function of sorption. Scenario 5 evaluated the fate and transport of uranium using an assumed mass loading rate of 0.1 pound per year of uranium leaching into solution. Both simulations were performed with a reactive iron estimate of 50 percent and a correlative partitioning coefficient (Kd) of 59 liters per kilogram.

Model results indicate that the mass released is almost entirely sorbed onto the reactive iron sites, leaving behind very low concentrations of uranium in solution (less than 0.1 µg/L). The concentrations do not exceed 0.1 µg/L until 100 years after the start of remediation, when enough mass is released to reach concentrations in the aqueous phase higher than 0.1 µg/L. The simulations show that even after 1,000 years, the concentrations never exceed 1.1 µg/L of uranium. An additional simulation was conducted in Scenario 4 to evaluate the effect of higher concentrations of uranium into solution (as a worst case scenario). An instantaneous release of uranium of 5000 µg/L was simulated and results indicate that the strong sorption capacity of the iron oxides attenuate the uranium concentration to 11 µg/L (highest simulated value for the 1000 years).

The model assumes that the sorption reaction is fast enough, relative to groundwater velocity, to be treated as instantaneous; no kinetic limitations were considered between the solid and aqueous phases.

When the effects of iron hydroxide adsorption and groundwater dilution are considered, the highest calculated uranium value in the plume area is 3.09 µg/L for an initial release of 500 µg/L into the system and 44.6 µg/L for an initial release of 5000 µg/L, using GWB. Using MODFLOW/MT3DMS, the highest simulated uranium concentration using an initial value of 500 µg/L is 1.1 µg/L. When using 5000 µg/L uranium as an initial release, the maximum uranium concentration in solution is 11 µg/L after sorption. These values are one to two orders of magnitude lower than the release criteria.

Results from GWB and MODFLOW/MT3DMS were generally in good agreement. Therefore, using a very conservative approach, the dissolved uranium concentration resulting from the oxidative dissolution of reductively precipitated uraninite being protected by mackinawite will not approach the regulatory limit.

6.1.1 Treatment Completion Report

A completion report will be issued at the end of the injection period after all of the monitoring results have stabilized for these key reactants and products. This report will provide the basis to demonstrate that the former plume areas are now stabilized, that the mass of iron sulfide is sufficient to stabilize the WAA and BA#1 plume areas, and that the iron in the aquifer systems will provide a sufficient sorptive capacity for uranium should the plume areas reoxidize. This completion report will update the geochemical modeling with actual results from each plume area, and demonstrate that each area is permanently stabilized. This document will provide the basis for cessation of groundwater monitoring at the Cimarron site.

The geochemical and groundwater modeling demonstrate that the key parameters to evaluate the potential for uranium to become re-dissolved in groundwater above the site release criteria are solid phase iron, either in its sulfide form, or its oxide form. The performance monitoring results (Section 5.3.5) will be used to provide actual site inputs to initialize the geochemical model described in the attached Geochemical Modeling memo. Measured iron oxide and iron sulfide content from these areas will be used to define the solid phase matrix; other solid phase parameters measured as described in Sections 5.1.2 and 5.1.3 will also be used to produce an accurate solid phase matrix for the modeling evaluation. At least 7 g/kg iron as iron sulfide will be created prior to cessation of the injection program such that sufficient iron sulfide will have been created. When this concentration is created, the geochemical model shows that uranium will not remobilize even under saturated oxygen conditions.

The geochemical model does not show any sensitivity of the model to even saturated dissolved oxygen; hence, dissolved oxygen will not be measured other than to confirm that under the iron sulfide-rich aquifer conditions created that it is completely depleted. Similarly, uranium concentrations will be measured just to show that the geochemical model is accurate in its predictions.

The treatment completion report will demonstrate that the actual field conditions when geochemically and hydraulically modeled show no potential for uranium remobilization, and that the solid phases necessary for this demonstration have been collected from

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the aquifer. Based on this demonstration, no long-term groundwater monitoring program will be necessary for license termination.

7. References

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TABLES

Table 1. Aqueous Analytical Program Parameter List, Laboratory Methods, and Sample Collection and Preservation Requirements.

Parameter	Method ⁽¹⁾	Container Type ⁽²⁾	Preservative ⁽³⁾	Holding Time
<u>Metals</u>				
Total Metals (U, Fe, Mn, As)	6010	250 mL plastic	HNO ₃ pH<2	6 months
Dissolved Metals ⁽⁴⁾ (U, Fe, Mn, As)	6010	250 mL plastic	HNO ₃ pH<2	6 months
<u>Geochemistry Parameters</u>				
Alkalinity	310.1	120 mL plastic	4°C	7 days
Major Anions (PO ₄ ³⁻ , Cl ⁻ , NO ₃ ⁻ , SO ₄ ²⁻)	300.0	500 mL plastic	4°C	48 hours
Major Cations (Ca ⁺ , Mg ⁺ , Na ⁺ , K ⁺)	6010B	500 mL plastic	HNO ₃	6 months
Total Organic Carbon	9060	125 mL amber glass	H ₂ SO ₄	28 days

- (1) Method - The analytical protocol(s) recommended for the parameter of interest. This number represents U.S. Environmental Protection Agency approved analytical protocols.
- (2) Container - Specifies the type, size, and material of construction of the sample containers for a given analysis.
- (3) Preservative - Describes the appropriate sample preservative to be placed in a given sample container for a given analysis.
- (4) Sample will be filtered in field.

°C Degrees Celsius.
 PO₄³⁻, Cl⁻, NO₃⁻, SO₄²⁻ Phosphate, Chloride, Nitrate, Sulfate.
 H₂SO₄ Sulfuric Acid.
 HNO₃ Nitric Acid.
 Ca⁺, Mg⁺, Na⁺, K⁺ Calcium, Magnesium, Sodium, Potassium.
 mL Milliliter.