EXECUTIVE SUMMARY FOR ANASTASI&WILLIAMS_1984

PAPER: Anastasi, F. S. and Williams, R. E., 1984, AQUIFER RESTORATION AT URANIUM IN SITU LEACH SITES: INTERNATIONAL JOURNAL OF MINE WATER, V. 3, P. 29-37

OVERVIEW:

- This paper discusses the remobilization of metals during the ISL process.
- Aquifer restoration after ISL is more problematic. Many of the elements go back to background, but not all.

SIGNIFICANCE:

- Background on ISL process:
  - Type of rocks- permeable sandstones
  - Lixiviant/solution- sodium bicarbonate, hydrogen perioxide and/or oxygen
  - Provides well field configurations
- Aquifer restoration is costly and time consuming.
- Provides a look at two R&D sites in Wyoming with different well field setups and different ISL solutions.
- Did only 6 month restoration attempts.
- Problems: heterogeneity of the sandstones
- Needs:
  - Thorough characterization of the hydrogeology
  - Baseline geochemical studies
  - Detailed borehole geophysical data should be collected for all wells

EXECUTIVE SUMMARY FOR IAEA_1239

PAPER: IAEA, 2001, MANUAL OF ACID IN SITU LEACH URANIUM MINING TECHNOLOGY: VIENNA, NUCLEAR FUEL CYCLE AND MATERIALS SECTION, INTERNATIONAL ATOMIC ENERGY AGENCY, TECDOC 1239, 294 P.

OVERVIEW:

- A manual produced by the IAEA concerning ISL.
- First manual to describe, in English, both acid and alkaline leach systems. Sidebar: U.S. uses exclusively alkaline systems since they are considered to be less harmful to the environment.
- Covers the history of ISL, geology and geochemistry of ISL sites, the hydrology, modeling ISL, laboratory experiments, wellfield experiments, wellfield design, treatment of produced solutions, wellfield operations best practices, how to best protect the environment, and ISL facilities.

SIGNIFICANCE:

- Approximately 15% of the world's uranium is produced by ISL.
- ISL is young and still evolving based on science, economic and regulatory demands.
- Advantages – Low capital costs, high cash flow within a year, rapid payback, reduced startup and development time, lower power consumption, less equipment needed, lower labor requirements, reduced radiation exposure, lower environmental impacts, greatly reduced solid wastes, higher recovery rates of ore, and ability to recover ore from otherwise inaccessible deposits by other mining methods.
- Acid vs. Alkaline ISL Advantages – more uranium recovery, fewer pore volumes of solution needed (3-4 for acid, 10-12 for alkaline), shorter period of leaching, recovery of by-products, limited seepage off site due to plugging of pores by mineral precipitates, no oxidants needed due iron oxide in recycled solutions, and possibility of "self-restoration" of groundwaters
- Acid vs. Alkaline ISL Disadvantages – acid consumption goes up in carbonate-bearing rocks, pore plugging before extraction is complete, higher concentrations of dissolved solids in recycled fluids, and costs of corrosion-resistent materials and equipment.
- Wellfield design should take into consideration the geology and hydrology of the rocks, the types of ore contained within them, the composition and concentration of leaching solutions, and what useful by-products can co-produced.
- Uranium precipitation at the surface depends on the original solutions used to release the uranium from the ore to design what chemicals and resins to use at the surface.
- Acid leaching creates more potential for log term environmental problems, therefore it requires more stringent controls and longer term monitoring.
- Strict controls to prevent spills or leaks.

EXECUTIVE SUMMARY FOR CRANE_CURTIS2007.PDF

PAPER: DAVIS, J.A. AND CURTIS, G.P., 2007, Consideration of Geochemical Issues in Groundwater Restoration at Uranium In-Situ Leach Mining Facilities: Washington, DC, U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, *NUREG/CR-6870*, 150 P.

OVERVIEW:

- This detailed report covers what types of uranium deposits are amenable to ISL (In-situ Leach), how ISL works, modeling of ores and facilities, geochemical reactions going on between oxidant and ore, groundwater restoration, and groundwater modeling.
- How does ISL work: 1) pumping of an oxidizing solution into the sandstone horizon with uranium ore, 2) resulting in the dissolution of the ore, 3) pumping out the now U-enriched fluid, and 4) filtering out the uranium. Sidebar: See Bland_Scholle2007 for brief description.
- Currently Wyoming and the Gulf Coast of Texas are the only operating facilities in the U.S.

SIGNIFICANCE:

- ISL works best on roll-front uranium deposits in sandstones. Sidebar: The type of deposits we have in Grants mineral belt.
- Forty percent of decommissioning costs involve groundwater sweep (pumping water, creating a cone of depression, and letting groundwater replace it) and reverse osmosis (RO, filtering through membranes).
- There is little scientific literature on ISL groundwater restoration.
- A Wellfield Highland Uranium Project in Wyoming – Original plans required 4 mil gallons of water to be pumped from the field, in the end 9 mil gallons were used from 1991-1998. Combination of techniques was used: groundwater sweep, RO and reductant recirculation. Waters were tested until 2004. U concentrations prior to ISL was 0.05 ppm, after ISL was 3.53 ppm (approximately 100 fold increase). Other elements and compounds that didn't return to baseline were ammonium, arsenic, calcium, chloride, iron, magnesium, manganese, nitrate, nitrites, radium, selenium and sulfate.
- Crow Butte Mine Unit No. 1 – A pilot project using groundwater sweep. Uranium went from 0.092 ppm to 1.73 ppm.
- Ruth ISL Facility in Wyoming - Uranium went from 0.01 ppm to 0.41 ppm. Other elements that went up were arsenic, iron, manganese and vanadium. Used groundwater sweep and RO followed by the injection of hydrogen sulfide to return the aquifer to reducing conditions.
- To date, restored groundwaters have not returned to baseline. Groundwaters can show significant increases in uranium, arsenic, selenium, molybdenum, radium and vanadium.

- Long-term pumping and monitoring is needed to see if restoration is successful. Concentrations increase with time after pumping stops.
- Computer models to develop better understand ISL wellfield dynamics including groundwater models.
- Hydrogen sulfide decreases uranium, selenium, arsenic and vanadium concentrations in restored groundwaters.

EXECUTIVE SUMMARY FOR SER_URANIUM_FORUM_FINAL_REPORT.PDF

PAPER: HALL, S. 2009, Groundwater Restoration at Uranium In-Situ Recovery Mines, South Texas Coastal Plain: Washington, DC, United States Geological Survey, *Open-File Report 2009–1143,* 36 P.

OVERVIEW:

- To determine the effectiveness of groundwater restoration at ISR mines, the following topics will be addressed:
- Effectiveness of groundwater restoration.
    - o "Has any ISR mine in the United States returned post-mining groundwater to baseline?" Answer: Not based upon analysis of the Texas database because "final value" records were found for only 22 of 77 PAAs (13 of 36 mines).
    - o We can conclude that in Texas, ISR mines are characterized by high baseline arsenic, cadmium lead selenium radium and uranium After mining and restoration for those cadmium, lead, selenium, radium, uranium. restoration, well fields that reported "final values" in TCEQ records, more than half of the PAAs had lowered levels of many elements, including some that dropped below MCL.
    - o Of those elements for which MCL is established, the majority of PAAs showed increases in uranium and selenium after mining and restoration and decreases in arsenic, cadmium, fluoride, lead, mercury, nitrate, and radium to below baseline for the majority of well fields.
    - o Analytes for which secondary standards have been established show that sulfate is the only constituent that increased in the majority of well fields after mining and remediation, whereas chloride, TDS, iron, and manganese decreased. Chemical constituents for which no MCL or secondary standards were set are higher than baseline for calcium, magnesium, bicarbonate, conductivity, alkalinity, and ammonia. Sodium, potassium, silica, and molybdenum were lower than baseline in the majority of well fields after mining and remediation.
- Long-term stability of well fields.
- An evaluation of best restoration technologies, including:
    - o Pump and treat techniques (Texas),
    - o The addition of reductants (Wyoming and New Mexico), and
    - o Bioremediation (Nebraska and Wyoming).

SIGNIFICANCE:

- Current ISR installations: Smith Ranch/Highland (WY), Crow Butte (NE), Kingsville Dome (TX) and Alta Mesa (TX)

- Texas ISR units:
  - Goliad Formation (Tp); a series of Miocene mudstone, conglomerates, and limestones, which is host to seven ISR mines
  - Oakville Sandstone and Catahoula Formation (Tm); Miocene and Oligocene sandstone, clays, mudstones and Catahoula tuffs hosting 27 mines; 15 mines in the Oakville Sandstone and 13 mines in the Catahoula Formation
  - Whitsett Formation (Te, Jackson Group); Oligocene mudstones, sandstones and tuffs which host two mines.
- Remediation methods:
  - Reverse osmosis and ion exchange are methods of removing contaminants from groundwater in well fields. The cleaned water is then reinjected into the well fields (Mays, 1994).
  - Reducing agents (H, NaS and H_2S) have been added to well-field groundwater in an attempt to return groundwater and host rocks to reducing conditions, thereby reversing the effects of oxidizing mining solutions (lixiviants) within the aquifer.
  - Bioremediation, the stimulation of native bacteria within the aquifer whose life processes fix metals from solution, is another remediation technique currently receiving much attention (Long and others, 2008).

EXECUTIVE SUMMARY FOR IAEA_1174

PAPER: IAEA, 2000, METHODS OF EXPLOITATION OF DIFFERENT TYPES OF URANIUM DEPOSITS: VIENNA, NUCLEAR FUEL CYCLE AND MATERIALS SECTION, INTERNATIONAL ATOMIC ENERGY AGENCY, TECDOC 1174, 84 P.

OVERVIEW:

- The choice of mining method is dependent on the type of uranium ore deposit present at a locality. Many deposits are not amendable to ISL and can only be mined by more traditional underground or surface technologies.
- Mining methods: open pit, underground and ISL.
- This paper provides an overview of the history of uranium mining, the type and geology of uranium deposits, project planning, environmental impact studies and their development, current mining methods, environmental controls, uranium production (sorting and processing), decommissioning and site reclaimation of mines, mills, processing plants, and waste rock and tailings (gives an example from a mine with costs), ore handling and operating costs.

SIGNIFICANCE:

- Decisions on mining method are based on part on geology, hydrology, economic considerations, environmental regulations, and decommissioning costs. Choosing the wrong mining method can greatly increase costs and time for decommissioning while decreasing profits. Companies want safe and economic operations.
- Uranium mining is not that different from other metals, but because of the radioactive nature of the ore, health and social issues play an important role in the entire process from designing the mine to finally decommissioning it.
- Scientific parameters that affect mining: location, depth, size, shape, orientation, geotectonics, mineralogy, hydrology and boundary conditions.
- The social and economic benefits need to outweigh the liabilities from mining. The ALARA principle is followed by most companies, because you cannot eliminate the risks associate with uranium mining, companies try to keep doses and risks to "as low as reasonably achievable."
- Surface mining is more efficient and cost effective than underground mining.
- Open-pit mining – high-grade ores require special shielding for workers and increased monitoring (air, water and workers), control water runoff from the site, control water runoff into the pit, and large surface areas to store overburden and wastes.
- Underground mining – while many of the practices are similar to other mining, the radioactivity of the ore limits human exposure (most countries limit exposure to 20 microsieverts/year), design layout allows remote

control of mining and hauling equipment, complex ventilation designs to remove radon, and minimize water flow (another radon pathway).

- In-Situ Leach - combines mining and extraction technologies, can be used only on bedded sandstone deposits, greatly decreases worker exposure, and best method to exploit low-grade ores in sandstones.
- Decommissioning plans are site specific as well mine type specific.
    - Open pit – remove waste rock, regrade steep walls, and pits that have had their ore removed are used as tailings storage with caps over the tailings.
    - Underground mines – production of detailed maps, regional stability to make certain no surface collapse occurs, modeling the hydrogeology to make certain mine drainage does not impact local aquifers or surface waters, underground workings can be used to store waste rock if isolated from hydrologic cycle, and surface openings must be closed off.
    - ISL – restoration of the aquifer is the major problem and may take several years.

EXECUTIVE SUMMARY FOR IAEA_1428

PAPER: IAEA, 2005, GUIDEBOOK ON ENVIRONMENTAL IMPACT ASSESSMENT FOR IN SITU LEACH MINING PROJECTS: VIENNA, NUCLEAR FUEL CYCLE AND MATERIALS SECTION, INTERNATIONAL ATOMIC ENERGY AGENCY, TECDOC 1428, 170 P.

OVERVIEW:

- Environmental Impact Statements (EIS) are required prior to opening or expanding mines.
- An attempt to address all issues that might effect environment prior to any damage in an ISL operation.
- EIS should provide information to all interested individuals/groups, provide a forum for public opinion and comments on proposed project, provide a framework for the decision-maker to interact with economic, environmental and technical factors, and final decommissioning and reclaimation plans.
- This paper provides information and guidance on the development of an EIS as well as case histories from around the world. Also gives a brief history of ISL.

SIGNIFICANCE:

- A major part of project planning, and it assesses potential impacts on the biological, physical and socio-economic environment.
- Steps in EIS –
  - Feasibility study to determine if the deposit can be developed economically should include an environmental baseline study,
  - Participants in the Environmental Impact Assessment (EIA) include proponent (the company that wants to develop a site), regulatory authorities (both state and federal) and the public,
  - Scoping describes the environment and project in enough detail to be able to identify and assign priority to all issues of potential impact,
  - Baseline environmental data includes site selection, meterology, geology, surface hydrology, subsurface hydrology, abandoned drill holes, flora and fauna, soil and subsoil chemistry, background radiological and non-radiological characteristics of soil, flora, fauna and water, noise, previous and current industrial and agricultural activities, populations, employment and other environmental features,
  - Project description including exploration history, pilot testing, commercial operations, groundwater remediation, decommissioning activities, waste management, post decommissioning monitoring and associated socio-economic activities,
  - Identification of potential environmental impacts (short-term and long-term) and the "value" of those impacts,
  - Preventing, mitigating and monitoring impacts,
  - Remediation and decommissioning impacts, and
  - Socio-economic impacts.

EXECUTIVE SUMMARY FOR MUDD1998

PAPER: MUDD, G., 1998, AN ENVIRONMENTAL CRITIQUE OF IN SITU LEACH MINING: THE CASE AGAINST URANIUM SOLUTION MINING: VICTORIA, FRIENDS OF THE EARTH (FITZROY) WITH THE AUSTRALIAN CONSERVATION FOUNDATION, 154 P.

OVERVIEW:

- An environmentalist view of in-situ leach (ISL).
- International examples of ISL.
- An overview of uranium geology, groundwater hydrology, ISL,

SIGNIFICANCE:

- Advantages of ISL – lower production costs, and less waste.
- Disadvantages – pumping oxidizing (acid or alkaline fluids) fluids into an aquifer can mobilize harmful elements, contamination of surrounding aquifers, restoration of the aquifer is costly and hard to achieve.
- Problems with ISL – equipment failure, pond failure, chemical and biological interactions between the aquifer and the oxidizing fluids, poor engineering, human error, and not understanding the science (geology or hydrology).
- ISL and Australia –
  - Alkaline solutions are more environmentally benign,
  - Acidic solutions generate more heavy metals,
  - Uranium mining companies need to be good neighbors.

NM Bureau of Geology & Mineral Resources Open File Reports

OFR #	Mining Districts
19	The Terry Uranium Prospect near Monticello, NM: a breccia U deposit
25	The history of the United Nuclear – Homestake Partners U Milling Operations, Grants, NM: Milling operations and procedures
28	Mineral Resource Evaluation on State Lands: A brief discussion of U
99	Uranium and Thorium deposits in the Zuni Mountains
103	Uranium potential in the Riley-Puertecito area, Socorro Co., NM
138	Uranium potential of the Datil Mountains-Pietown area, Catron Co. NM Sidebar: One of the current exploration permits is near to this area.
148	Abandoned or Inactive Uranium Mines in New Mexico
155	Vein deposits with Uranium in New Mexico
176	Uranium potential of the Tejana Mesa-Hubbell Draw area, Catron Co., NM
183	Uranium and Thorium deposits of New Mexico: A database
192	Uranium potential in Torrance Co.
193	Uranium-Vanadium production in the eastern Carrizo Mtns., San Juan Co., NM and Apache Co., AZ
211	Resource potential, including uranium, in parts of Sandoval and Bernalillo Cos, NM
228	Mineral resource potential in northwestern New Mexico
230	Resource potential of Cibola Co., NM
353	Uranium resources and mines of the Grants district
407	Geology, exploration and production history of the Begay No. 1 and Carrizo No. 1 Uranium-Vanadium mines, San Juan Co., NM
420	Geology and production history of Plot 7 Uranium-Vanadium mines, San Juan Co., NM
432	Geology, exploration and production history of the Alongo and Red Wash Uranium-Vanadium mines, on H.S. Begay's Mining Permits, San Juan Co., NM
451	Geology, exploration and production history of the Cottonwood Butte (Plot 8) Uranium-Vanadium mine, San Juan Co., NM
465	Geology, exploration and production history of the Begay No. 2 Uranium-Vanadium mines, San Juan Co., NM
466	Geology, exploration and production history of the Tent No. 1 and Carrizo No. 1 Uranium-Vanadium mines, San Juan Co., NM
486	Mineral resources Wild Horse Mesa, Burro Mountains, Grant Co., NM

EXECUTIVE SUMMARY FOR OF11-1140.PDF

PAPER: OTTON, J.K., 2011, Annotated Bibliography of Environmentally Relevant Investigations of Uranium Mining and Milling in the Grants Mineral Belt, Northwestern New Mexico: Washington, DC, United States Geological Survey, 88 P.

OVERVIEW:

- Studies of the natural environment in the Grants Mineral Belt in northwestern New Mexico have been conducted since the 1930s; however, few such investigations predate uranium mining and milling operations, which began in the early 1950s.
- This report provides an annotated bibliography of reports that describe the hydrology and geochemistry of groundwaters and surface waters and the geochemistry of soils and sediments in the Grants Mineral Belt and contiguous areas.
- The reports references and discusses a large volume of information about the environmental conditions in the area after mining started.
- Data in the papers may provide much basic information about the baseline conditions that existed over large parts of the Grants Mineral Belt prior to mining. Other data may provide information that can direct new work in efforts to discriminate between baseline conditions and the effects of the mining and milling on the natural environment.

SIGNIFICANCE:

- Collects a huge amount of data and provides summaries for most of the area
- Invaluable resource for regional geology and geochemistry of water and soil/rock of the area.

EXECUTIVE SUMMARY FOR OFR_251

PAPER: HOLEN, H. AND HATCHELL, W.O., 1986, GEOLOGICAL CHARACTERIZATION OF NEW MEXICO URANIUM DEPOSITS FOR EXTRACTION BY IN SITU LEACH RECOVERY: SOCORRO, NEW MEXICO BUREAU OF GEOLOGY AND MINERAL RESOURCES OPEN FILE REPORT 251, 95 P.

OVERVIEW:

- Report provides information on the location, size and type of uranium deposits that could be exploited by ISL.
- Requirements: 1) ore must be in saturated zone, 2) ore must be horizontal, 3) ore body has to be permeable, and 4) ores must be leachable.

SIGNIFICANCE:

- Provides site specific data on ISL pilot plants and planned projects.
- Redistributed ores are better for ISL than primary ore.
- New Mexico has large resource that is amenable to ISL.
- 83% of the reserves are deeper than 1000 ft.
- Many of the New Mexican deposits have high carbon values which inversely impacts the ores ability to be extracted by ISL.

EXECUTIVE SUMMARY FOR SARANGI&BERI_2000

PAPER: SARANGI, A. K. AND BEIR, K. K., 2000, URANIUM MINING BY IN-SITU LEACHING: KHARAGPUR, TECHNOLOGY MANAGEMENT FOR MINING, PROCESSING AND ENVIRONMENT, IIT.

OVERVIEW:

- This paper covers types of uranium deposits and which deposits are amenable to ISL (In-situ Leach)
- Provides the basics of a commercial ISL operation including wellfield design, environmental issues, and recovery of metals from the solution
- Provides a pro-ISL viewpoint to mining

SIGNIFICANCE:

- Discusses how common uranium is in the environment
- Provides information on what geologic/hydrologic conditions are optimal for ISL
- Gives the advantages of ISL, but none of the disadvantages to ISL
    - Mine deposits that would be otherwise difficult to impossible to reach
    - You can mine poorer grades of ore
    - Less surface damage
    - No tailings
    - Less risk to personnel
    - Lower costs & quicker returns on investment

EXECUTIVE SUMMARY FOR SER_URANIUM_FORUM_FINAL_REPORT.PDF

PAPER: The Future of Uranium Production in Wyoming: A Public Forum on In-Situ Recovery, 2010: Laramie, *University Of Wyoming, School Of Energy Resources*, 18 P.

OVERVIEW:

- Wyoming has the largest uranium ore deposits in the United States. Only one mining site in Wyoming is active, the Smith Ranch-Highland in-situ recovery (ISR) facility operated by Cameco. ISR, a process developed in the 1960s, reverses the historic process through which uranium is deposited in sandstone. Oxygenated water pumped into the ore body dissolves the uranium. It is then pumped back to the surface and uranium is precipitated out of the water, collected, and shipped as yellowcake to conversion and enrichment facilities. ISR does not involve the unearthing, blasting, tailings, grinding, or crushing, associated with conventional mining. ISR accounts for 86% of total US uranium production, and the increasing number of federal mining claims indicate renewed interest in uranium production.
- Future production in Wyoming includes one ISR facility on standby to be restarted in 2011, three licensed but not yet built facilities, five at the permitting stage, and three at the pre-permitting stage; two conventional mines are also at the pre-permitting stage. The primary factors affecting future production are the quality of the deposits, state and federal regulatory requirements, and the price of yellowcake. Based on historic high and low prices, Wyoming can expect in the future between 5 and 12 mines operating, producing between 5 and 12 million pounds, annually.
- It is estimated that every five 900-pound drums of yellow cake produced in Wyoming supports approximately one job, provides $59,000 in labor income, and generates almost $9,000 in Wyoming states taxes and royalties.

SIGNIFICANCE:

- The state has issued an RFP for ISR-related research to address gaps in our knowledge. This included groundwater issues, an area of strength at UW. It will also address how to reduce the disruption and costs of exploration for ore deposits including adapting techniques from other fields.
- A technical forum in two years to review the results of this state funded research and also invite other, international research in uranium recovery.
- There was disagreement between industry and environmental group representatives regarding the extent of excursions at ISR facilities to date, and the nature of the risk if/when excursions occur. It was noted that uranium is ubiquitous in the environment and that some municipalities that

are not near any uranium recovery operations have to treat their drinking water for uranium. No evidence of an ISR facility contaminating a municipal drinking water supply was provided.

- Cameco has recognized that bonding for the Smith-Ranch Highlands site has been insufficient and is in the process of submitting a new bonding calculation that will significantly increase the bond.

Basin-Scale Aquifer and Contaminant Characterization in the Grants Mineral Belt

A joint scope of work by the New Mexico Bureau of Geology and Mineral Resources and the USGS New Mexico Water Science Center.

Background

The Grants Mineral Belt (GMB) was an important source of uranium ore from the 1950's to the 1980's. The GMB extends along the southern margin of the San Juan Basin in Cibola, McKinley, Sandoval, and Bernalillo Counties and includes the Shiprock and the Grants Mining Districts. Land ownership within the GMB consists of public, tribal, and private property.

Water generated by uranium mining and milling activities, including mine dewatering, aquifer depressurizing, ore leaching, and storage of process waters in evaporation and tailing ponds, generally was discharged directly to land surface or to the subsurface by impoundment infiltration (United States Environmental Protection Agency, 2010). From mining operations alone, the United States Environmental Protection Agency (2010) estimates that 80 billion gallons of mine water were extracted from the subsurface over a 30-year period, with the majority discharged to the surface.

Site-specific studies of the effects of uranium activities on groundwater and surface water have been conducted or are underway at major mining and milling sites within the Grants Mineral Belt. These site-specific studies have raised additional issues that need to be addressed in a regional context. Such issues include the effect of the hundreds of small legacy mining operations on groundwater and surface water quality, the effect of naturally-occurring uranium deposits on groundwater quality, the source, flow paths, the effects of mining on the geochemical evolution of water within the GMB. These issues, however, cannot be fully addressed without a detailed regional hydrologic and geochemical framework.

The New Mexico Bureau of Geology and Mineral Resouces and the U.S. Geological Survey propose to provide a regional hydrogeologic and geochemical framework to answer the issues that have arisen from the site-specific studies.

Objective

The objective of this study is to provide a regional hydrogeologic and geochemical framework for the Grants Mineral Belt (See Figure 1). The objective will be accomplished through completion of tasks described in the APPROACH section of this scope of work.

Approach

Task 1: Organization of preexisting data in comprehensive database: Distribution of Uranium, including Mines, Mills, and Deposits

Objective: Update existing compilations of existing data from all state, federal and private agencies that currently have information on known mines, mills, and other potential sources. Geologic, hydrologic and geochemical characteristics of the area will also be compiled and entered into a searchable, relational GIS-based database. The NMBGMR has been collecting geologic and production data on mining districts, mines and mills, since it was created in 1927. One of its founding missions was to act as a repository for cores, well cuttings, and a wide variety of geological data. The NMBGMR is in the process of converting years of archival uranium mining data (information on location, production, reserves, geology, geochemistry, resource potential, mining history, development and ownership) into relational databases that will be integrated with ArcGIS and available to the public on the internet. Existing data and databases at the NMBGMR include a GIS database of uranium mines, prospects, deposits, and mills in New Mexico; a bibliography of the geology, hydrology and mineralogy of the state and a specialized library collection of uranium publications; a map database of geological, hydrological, gravity, and mine maps; and collections of geophysical well logs and historic photographs.

Work plan:

Compilation of Existing Data

1. Obtain and catalogue additional data from other government agencies and industry on uranium deposits in New Mexico.
2. Update the uranium portion of the New Mexico Mines Database, including an update of production data tables and literature. File data at the NMBGMR will be keyed to appropriate mines and districts in the database.
3. Identify uranium mine maps cataloged in the NM Map database to scan and georeference. Over 2,000 mine maps are in this database.
4. Identify mine maps from the 885 folders of the Homestake Mining Company collection database that need to be scanned, georeferenced and cataloged into the NM Map database.
5. The cataloging, scanning and georeferencing of mine maps has focused to date on coal mine maps with funding support from the Office of Surface Mining (OSM) and Mine Safety Health Administration (MSHA). We have utilized the scanning facilities of the OSM office in Pittsburg Office to scan

coal mine maps and aperture cards of mine plats. We can utilize their facility to scan uranium maps.

6. These data will be tied to other databases such as the RAMS (Remediation of Abandoned Mines Survey) database, New Mexico Department of Health Environmental Public Health Tracking Program, New Mexico Mining and Minerals Division databases, New Mexico State Land Office, U.S. Bureau of Land Management AMLIS (Abandoned Mine Lands Inventory System) and other programs.

Data Analysis

1. Update the existing ARCGIS integration of the New Mexico Mines Database and uranium resource and deposit maps to show spatially the uranium deposits, both mined and unmined.
2. Update ARCGIS maps showing the spatial and temporal distribution of the Grants uranium deposits within the different geologic units (Todilto, Salt Wash, Westwater Canyon, Brushy Basin, Poison Canyon sandstone, Jackpile sandstone, redistributed deposits in the Morrison and Dakota formations). Differentiate mined and unmined deposits.
3. Update ARCGIS maps with locations of former and present mines and mills, waste rock and tailings piles, and associated water impoundments.
4. Continue the interpretation of NURE data using ARCGIS, including the airbourne geophysical data and the geochemical data.
5. Continue to perform field verification of selected deposits, mines and prospects.

Task 2: Geology and Geophysics – Build high-resolution 3-D Geologic Model
Objective: Geologic maps and subsurface geologic models provide the necessary framework for all subsequent tasks, including source and aquifer characterization, contaminant-transport modeling, and effective remediation. Some geologic data exist, but do not provide the necessary detail.

Work Plan:

Acquisition of New Data and Synthesis

1. Currently, the New Mexico Bureau of Geology and Mineral Resources (NMBGMR) is working on several 7.5-minute quadrangles in the area. The STATEMAP Program and NMBGMR have completed an initial round of mapping on the Mount Taylor, Lobo Springs, Cerro Pelon, San Mateo, San Lucas Dam, and Ambrosia Lake quadrangles (Figure 2). Future work

will build on this mapping footprint to provide high resolution mapping of the entire study area (to be determined).

2. Individual quadrangle maps will need to be compiled and edgematched to generate a seamless 1:24,000 scale digital map for the area. Regional and local scale cross sections will be generated during this synthesis phase to highlight bedrock stratigraphy and structure, and basin fill (alluvium and colluvium) deposits. All maps will be generated in ArcGIS and provide a foundational GIS framework for all spatially related data.
3. Regional scale cross sections will highlight major bedrock stratigraphic units and their thickness and structure. The wealth of subsurface data in the area will constrain regional cross sections to accurately display subsurface geology. The key here is to better understand the distribution of potential aquifer-bearing units, their hydraulic properties, and how connected the bedrock units are to the overlying volcanic and basin fill material.
4. Local scale cross sections will help refine the local stratigraphy, thickness of basin fill and bedrock units, and identify areas where hydraulic connections between basin-fill deposits and deeper bedrock aquifers or volcanic units could facilitate movement of potential contaminants to or from the deeper bedrock aquifers.
5. Geophysical tools may be useful to better refine the thickness of basin fill deposits and perhaps identify subsurface bedrock topography that may influence groundwater flow and contaminant transport. Down hole instruments will help resolve details in bedrock stratigraphy to better control regional cross sections and the fine resolution interpolation of important bedrock facies in the region.

Task 3: Hydrogeologic Characterization and Conceptual Hydrogeologic Model Development

Objective: Identify and characterize hydrostratigraphic units and aquifer properties that influence regional and local groundwater flow, quantity, quality, and the interactions of groundwater and surface water. An understanding of aquifer geometry and properties is fundamental to development of an accurate conceptual model of regional and local groundwater recharge, flow, and discharge and the transport of and possible exposure to potential contaminants.

Work plan:

Compilation of Existing Data

1. Compile available surface hydrologic data including locations of streams and springs, streamflow, basin characteristics, results of seepage studies,

and climate data (precipitation, temperature, snow pack, tree-ring studies).

2. Compile available subsurface hydrogeologic data including locations of wells, well logs (drillers, lithologic, electric, temperature), water levels, and aquifer properties (hydraulic conductivity, transmissivity, storativity) of bedrock and unconsolidated sediment (Figure 1).
3. Compile available water-quality data including data from wells, springs, and surface-water bodies.
4. Data will be entered into an appropriate database and will be integrated as needed in ARCGIS to help identify informational and geospatial data gaps.

Data Analysis

1. Well and water-level data will be interpreted as to formation of completion.
2. Water-level data will be analyzed in the context of regional geologic information to define regional groundwater flow directions and gradients within identified aquifers and hydrostratigraphic units.
3. Water-level data will be analyzed to identify areas of recharge to and discharge from identified aquifers and hydrostratigraphic units.
4. Where sufficient density of water-level data permits, the data will be analyzed to determine horizontal and vertical flow paths on local scales. Of particular interest is the identification of hydraulic connections between bedrock and overlying alluvial aquifers and development of a conceptual model of flow between these hydrostratigraphic units.
5. Historical water-level data will be evaluated to determine if flow in GMB aquifers changed in response to the initiation and/or cessation of former uranium activities. Stratigraphic, structural, and hydrologic head data will also be evaluated relative to uranium deposits, mines, and prospects to help identify possible flow and transport pathways, and better understand potential hydrologic interconnection between point sources and contaminated and uncontaminated water-bearing strata.
6. Water-chemistry data will be used to identify the general and unique qualities of water from aquifers and hydrostratigraphic units. Water chemistry data may also help in the identification of areas where exchange of groundwater and surface water occurs.
7. Water age-date data will be used to help constrain groundwater flow paths from recharge areas, through uranium-bearing areas, to discharge areas and will help in the development of the conceptual model.

8. Results of geologic, hydrologic and geochemical data will be integrated in ARCGIS and other mapping and analysis software to develop a hydrogeologic and hydrogeochemical conceptual hydrogeologic model of potential contaminant flow and transport.

Acquisition of New Data

1. Existing water wells will be organized into a network of monitoring wells for acquisition of water-level data. Water-level data may be collected at frequencies varying from hourly to annually. The monitoring well network design will incorporate wells already being measured as part of the USGS-OSE state-side groundwater monitoring network.
2. Wells selected for hourly water-level measurements will be instrumented with transducers and data recorders for acquisition of the data. Water levels in wells will be monitored for a minimum of two years.
3. Geographic areas with substantial data gaps may require the installation of surface-water gages, monitoring wells, and/or precipitation monitoring stations and the collection and analysis of water samples. Monitoring wells would be designed to monitor water levels at discreet depths within selected aquifers (nested wells).
4. Local areas where hydrologic conditions change rapidly may also require additional data collection.
5. Newly-acquired data will be analyzed and used to refine the conceptual hydrogeologic model.

Task 4: Geochemical Characterization

Objective: Identify and characterize the nature and extent of natural and anthropogenic uranium contamination. Assessment of current and future risks to public health is a primary concern, and thus understanding the current nature and extent of contamination is critical to this goal. Comprehensive sampling and chemical analyses of groundwater and surface water will provide baseline data to assess the nature and extent of contamination, evaluate risk to public health, provide data to initiate and facilitate contaminant-transport modeling, and support decisions regarding remediation. An assessment of Grants Mineral Belt's (GMB) soil, surface water, and groundwater will be needed to evaluate both the natural and anthropogenic uranium contamination currently present. This will require compiling data collected from prior characterization and remediation projects performed by the United States Environmental Protection Agency (USEPA data), Nuclear Regulatory Commission (NRC), and other regional records and studies. These data and new data from surface waters and groundwater wells will be used by geohydrologists to model and evaluate the environmental effects on the aquifers and surface sediments to aid in the identification of areas needing remediation.

Work Plan:

Compilation of Existing Data

1. Identify known mining-impacted sites in the GMB. This will involve identifying and accurately locating abandoned mine and mill sites and other areas of contamination such as small mining operations and test pits, transportation routes, building materials that used mine wastes, and areas contaminated by wind and water-borne material.
2. Using information derived from the databases compiled in previous tasks, develop a sampling plan for the soils, rocks and water to determine the nature and extent of contamination in the GMB. This includes determining baseline uranium distribution and attempting to determine natural and anthropogenic sources of contamination in the study area.
3. Identify a subset of sites from the well-monitoring network established in *Task 3* that are up gradient and down gradient from natural ore bodies and mine sites to better resolve natural and anthropogenic sources of contaminants and the extent and transport direction of contaminant plume(s).

Acquisition of New Data

1. Collect and analyze surface water, groundwater and soil samples for radionuclides, heavy metals and other chemicals that are harmful to humans. All samples not associated with a well location will be assigned latitude-longitude coordinates using global-positioning (GPS) or conventional surveying equipment. Other basic chemical analyses of water and soil samples will be conducted to provide information on solute concentrations, anion and cation compositions, age of water, source of water, and water-rock interactions. All analyses will be conducted using stringent quality assurance and quality control standards to ensure high data quality and comparability. See Table 1 for recommended parameters.
2. Conduct detailed sampling of mine, mill and other contaminated sites (including natural sites) for geochemical analyses to determine point sources of contaminant entry into soils and groundwater.
3. Determine baseline concentrations of uranium in groundwater and surface water in areas where uranium is naturally occurring. Areas identified during geochemical characterization that potentially pose a threat to nearby citizens and communities can be sampled in more detail. Water samples will be collected from existing water wells and from surface waters from the region. If possible, samples from discreet zones

within water wells will be sampled and analyzed to provide as much information as possible for the geohydrologic models.

4. Store all newly collected data in the ArcGIS accessible relational database developed during previous tasks. This data will be utilized in decisions regarding remediation.
5. Use resulting geochemical data to help develop and refine hydrologic conceptual models and develop a contaminant-transport model that identifies the shape and location of contamination plumes and the controls on plume migration.
6. Develop regional contaminant maps for the GMB based on the water and soil data. These maps will differentiate between baseline and elevated contaminant concentrations in the region. These concentration maps, in conjunction with the mining site impact maps, will provide valuable insights into the source of contamination, whether by natural or anthropogenic means.

The scope of work outlined here is designed to be multidisciplinary and ready to be partitioned into discrete task objectives. All elements are required for a comprehensive study; however, the tasks can phase in and out or run concurrently depending on funding availability and the interests of the funding agencies.

Figure captions:

Figure 1: Shaded relief map showing the extent of a regional scale aquifer and chemical characterization study. The two black outlines represent two possible scenarios, one focused exclusively on the high impact areas and the larger encompassing much of the drainage basin of interest. The regional scale study captures the important watersheds of the Zuni Mountains and Mount Taylor and contains the bulk of past mining localities (shown as mine symbols). The blue dots represent wells that are currently in the USGS water database and the size of the circle indicates the relative number of measurements recorded.

Figure 2: Geologic map of the Grants area showing the status of 1:24,000 scale geologic mapping. The geology of the region is characterized by gently northeast-dipping sedimentary bedrock units (blue to green colors). Overlying bedrock layers are volcanic rocks of Mount Taylor (pink) and El Malpais (red). Filling the valley bottoms are alluvial deposits shed from adjacent highlands (yellow). This index map also shows the status of geologic mapping; green and purple boxes indicate recent and current mapping by the Bureau of Geology, yellow boxes indicate quadrangles that are currently proposed to the USGS for new mapping, and the blue and pink boxes indicate legacy mapping by the USGS and the Bureau of Geology respectively. The older mapping requires significant revision to modernize these products.

Reference

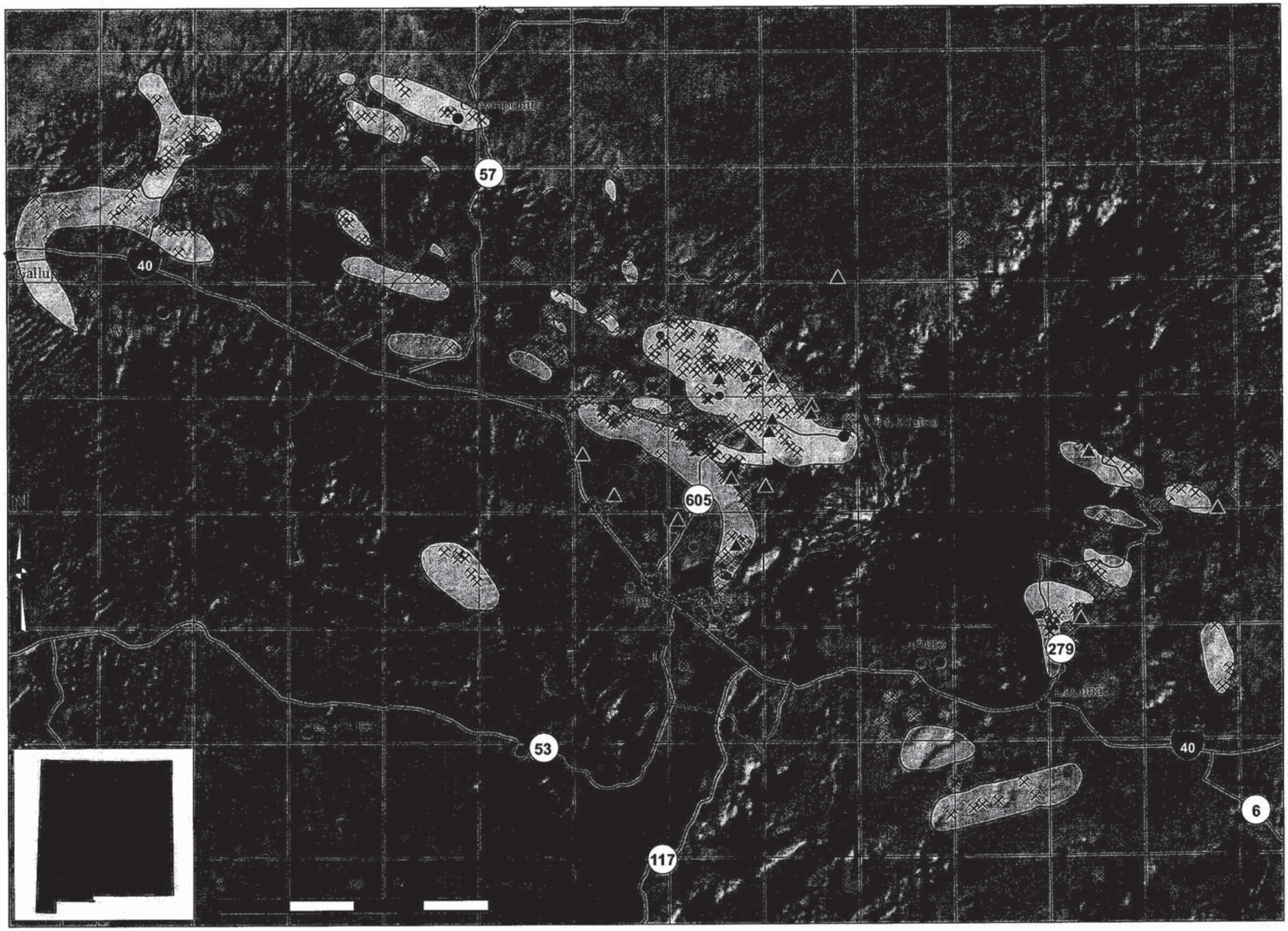
U.S. Environmental Protection Agency, 2010, Assessment of health and environmental impacts of uranium mining and milling, five-year plan, Grants Mining District, New Mexico: U.S. Environmental Protection Agency, Region 6, 52 p.

Table 1: Recommended analyses for aquifer and contaminant characterization in Grants Mineral Belt

Basic chemical parameters	Contaminant determinations
pH	Aluminum
Eh	Antimony
Temperature	Arsenic
Conductivity	Barium
Dissolved oxygen	Cadmium
Alkalinity	Cerium
Chloride	Chromium
Sulfate	Copper
Sulfides	Iron
Fluoride	Lead
Bromide	Manganese
Nitrate	Mercury
Nitrite	Molybdenum
Ammonia	Nickel
Phosphate	Radium 226
Calcium	Radon
Magnesium	Selenium
Sodium	Silver
Potassium	Thorium
Silica	Total uranium
Total dissolved solids	Vanadium
	Zinc

Groundwater tracers for source determination	Analyses to date groundwater
Hydrogen isotopes	Carbon-14
Oxygen isotopes	Chlorofluorocarbons (CFCs)
Uranium isotopes	Sulfur Hexafluoride (SF6)
Sulfur isotopes	
Strontium isotopes	
Nitrogen isotopes	

Chemical analyses of rock and soil samples will focus on metals determination using acid digestion techniques.

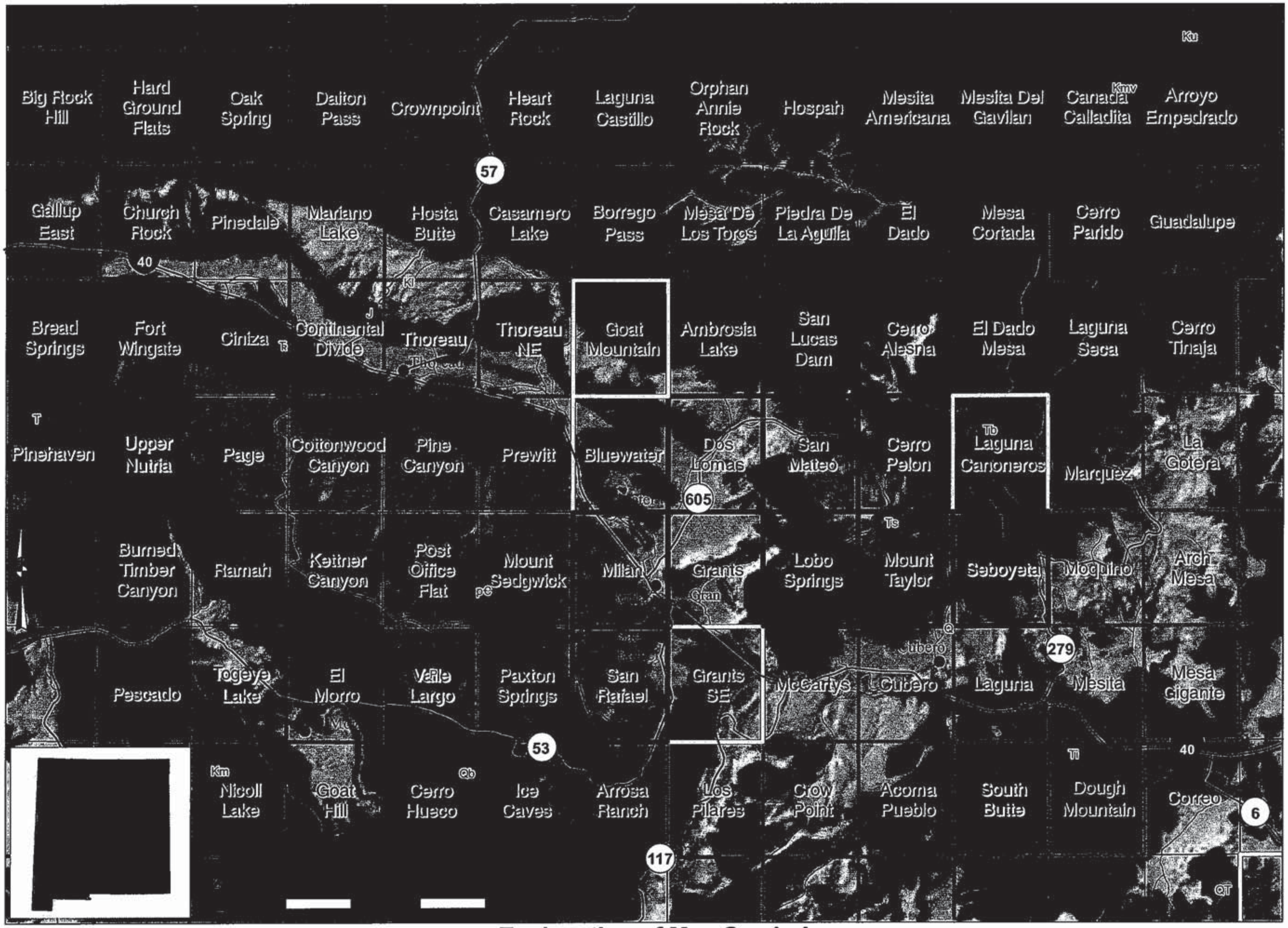


Explanation of Map Symbols

- Active Mines & Mills
- Active & Requested Mine Permits
- Other Superfund Sites Related to Mining/Industry
- National Priority List Superfund Site

Uranium Deposits

- Sandstone
- Igneous
- Limestone
- Other Sedimentary



Explanation of Map Symbols

General NM Geology

- Q - Quaternary sediments
- Qb - Quaternary basaltic volcanic rocks
- QT - Quaternary-Tertiary sediments
- T - Tertiary sedimentary rocks
- Tb - Tertiary basaltic volcanic rocks
- Ts - Tertiary silicic volcanic rocks
- Ti - Tertiary intrusive rocks
- Ku - Cretaceous sedimentary rocks above Kmv
- Kmv - Cretaceous Mesaverde group (incl gallup ss and Crevasse can. fm.)
- Km - Cretaceous Mancos shale
- Kl - Cretaceous sedimentary rocks below Km
- J - Jurrassic sedimentary rocks
- Ꞓ - Triassic sedimentary rocks
- P - Permian sedimentary rocks
- p€ - Precambrian rocks undifferentiated

Quadrangle Mapping Progress

- Statemap Proposed
- Statemap In Progress
- Statemap Complete
- NMBGMR
- USGS