6.4 Rocky Mountain Arsenal, Colorado

The Rocky Mountain Arsenal (RMA) is a former chemical weapons manufacturing facility located just outside and northwest of the Denver, Colorado metropolitan area (Figure 21). The facility was built in 1942, in response to the outbreak of World War II in Europe. Approximately 27 square miles of arid prairie land northwest of Denver was appropriated by the U.S. War Department for construction of RMA facilities, which were built in the center of the property. This area was strategically chosen because it was unpopulated, landlocked deep into the continent's interior, inaccessible, and outside the flight range of enemy aircraft.

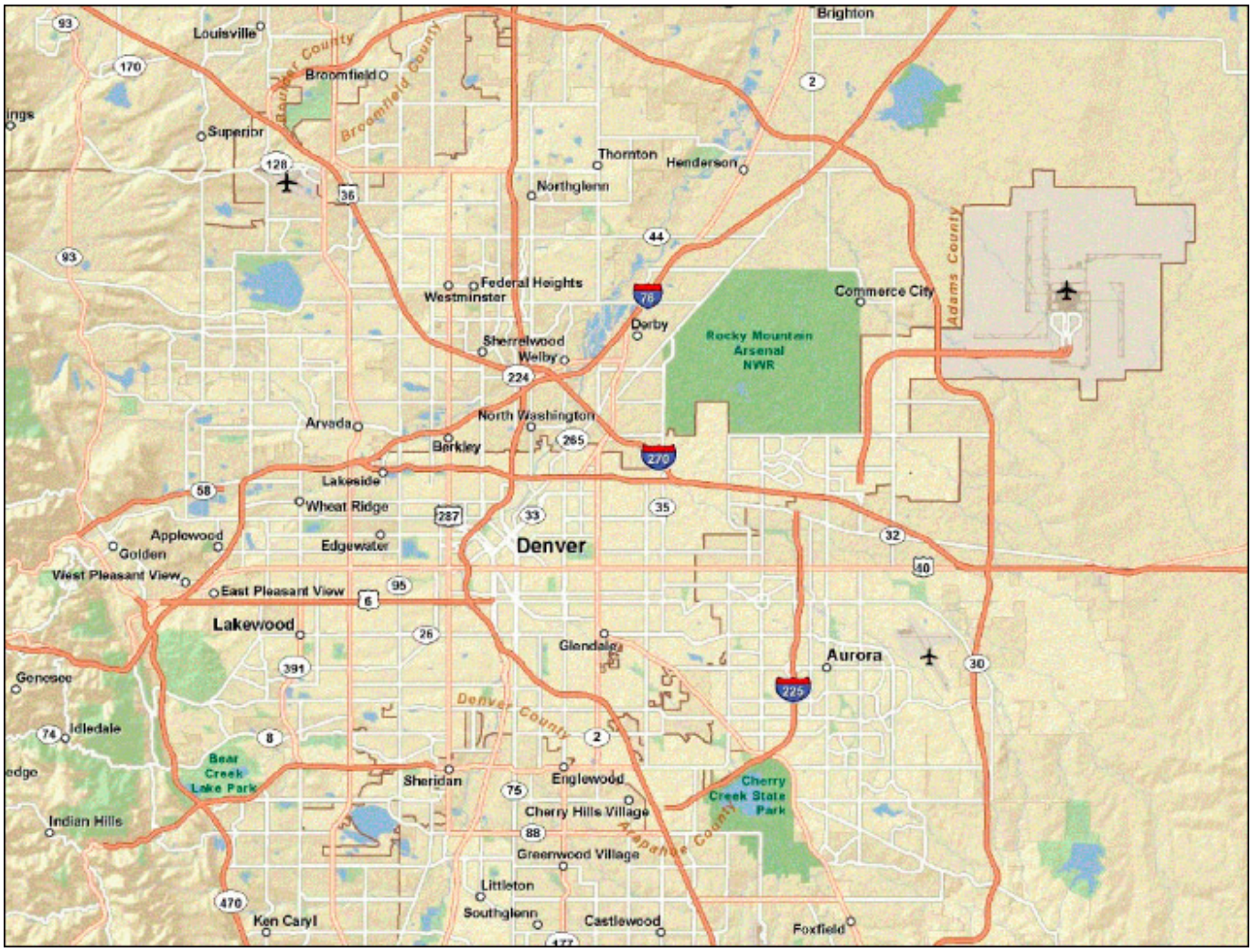

Figure 21. RMA location (GoogleMaps 2017)**.**

RMA manufacturing complexes were large and the extensive construction was completed in a short time. Only six months elapsed from the time that the land was acquired to the time the RMA facilities were physically completed. Crews worked around the clock to construct the facilities referred to as the "South Plants" (Figure 22).

Figure 22. Photo of the South Plants with the old Stapleton Airport runways in the background and the Denver skyline in the background, c. 1980 (CDPHE 1980)**.**

Mustard agent, Lewisite, and other chemical agents were manufactured at the South Plants (SPs), stored in bulk, and injected into munitions. Manufacturing capability was extended to include napalm, white phosgene, and rocket fuel. During the 1950s, a second complex, the North Plants (NPs), was built on the north central portion of the property to manufacture Sarin gas. Sarin gas (O-isopropyl methylphosphonofluoridate), also called GB, is one of the most dangerous and toxic chemicals known. Sarin belongs to a class of chemical weapons known as nerve agents, all of which are organophosphates. Venomous Agent X, also known as VX gas (O-ethyl S-[2-(diisopropylamino)ethyl] methylphosphonothioate), one of the most dangerous chemicals created, was also manufactured at NPs (Figure 23). VX gas is a nerve agent containing organic phosphorous compounds and sulphur. The NPs facility was a windowless, five-story concrete monolith. By this time, war technology had improved to the point that the area could be reached by aircraft. Consequently, the five-foot thick concrete walls were built to withstand a direct hit from a nuclear warhead.

Figure 23. North Plants looking north toward Wyoming, c. 1990 (CDPHE 1990)**.**

Also during the 1950s, the War Department attempted to recoup some of the costs to construct the North and South Plants facilities by leasing certain portions of the RMA to XXX Oil Company. The XXX Oil Company used the facilities to manufacture pesticides. By then, the RMA was also being used as a weapons research/military base, and munitions testing and exercises were conducted on site (Foster Wheeler 1996).

Napalm and rocket fuel (hydrazine) were also manufactured at RMA. A rail spur in the southwest portion of RMA transported the manufactured products off site. Spills occurred within the SPs buildings and during the transfer of chemical materials to the rail cars.

In aggregate, the operations at RMA were large-scale, complicated endeavors, involving explosive materials and over 650 different chemicals over the course of several decades. During this time, waste chemical releases into the environment were unregulated, and waste disposal practices were somewhat ad hoc.

Initially, the Army discharged chemical waste from North and South Plants into a large, open lagoon (Basin A). Basin A was created by enhancing a large natural depression in the ground surface. At first, chemical wastes were transported by truck to Basin A. Open ditches were also used to convey waste chemicals to the Basin A. Eventually chemical sewers were constructed to transport the wastes from the plants to Basin A directly. When Basin A overflowed, Basin B was constructed. When Basin B reached capacity, Basin C was constructed, followed by Basins D and E. These new basins required more sewers and more ditches.

By the time even more waste storage was needed, problems were beginning to surface north and northwest of the RMA boundary. Chemicals had spread into groundwater and far past RMA's boundaries. Farms and ranches north and northwest of RMA began to suffer crop damage and livestock deaths. The Army tried to construct Basin F, another open lagoon but lined with asphalt. Unfortunately, the asphalt liner failed because it was not resistant to the chemicals it was designed to contain. By this time, the contamination footprint was massive: Basin F alone was 93 acres. To reduce the volume of liquid waste material in Basin F, spray nozzles were installed in the lagoon to spray waste chemicals in the air. This activity resulted in a widespread, diffuse surface soil contamination footprint downwind of the lagoon. In addition to the six basins (A-F), other chemicals and solid wastes were disposed of and stored at RMA.

In the central/east portions of the RMA, Army and Complex Trenches were used to dispose of all types of wastes, from surplus desks and vehicles to off-spec munitions and chemicals. Wastes were placed in the trench, covered with napalm, and burned. XXX Oil Company had its own set of trenches (the XXX Oil Company Trenches) for the same purpose. Soil was pushed over the trenches as backfill when waste burning was complete. In addition to the trenches, several one-acre unlined pits were also constructed in central RMA to dispose of off-spec mustard and Lewisite, waste mercury, and other chemicals. The chemical waste was mixed with caustic lime to neutralize the agent; these pits were known as the Lime Basins. Mercury

was dumped into similar pits (M1 Pits). Large quantities of a tarry chlorinated material, hexachlorocyclopentadiene, a process intermediate, were placed in unlined Hex Pits.

Chemical sewers crossed the site, emptying into Basins A and F; eventually, they too leaked. A large storage yard contained rows of palettes of waste chemicals and off-spec pesticides in drums, many of which leaked and were subject to wind-blown dispersion. Another large storage yard stored chemically configured munitions that were brought out of the bunkers because they were leaking. Other portions of the site were used as a firing range for testing munitions.

In 1962, the Army attempted a pilot project to manage the increasing quantities of chemical wastes that were being produced at the RMA. A 12,000-foot deep injection well was installed at RMA. The Army injected more than a million gallons of chemical wastes into the well at high pressure and set off a series of earthquakes that began to rock the Denver metropolitan area from the long-dormant Golden Fault. Injection activities ceased.

In 1982, the Army and XXX Oil Company ceased all manufacturing and storage functions at RMA. The only remaining mission at the RMA was cleanup. The physical, scientific, legal, social, and political issues left by facility operations and waste disposal were so complex and severe, however, that a ROD was not signed for another 14 years. Completing remedy construction took an additional 14 years after the ROD was signed.

Several Interim Response Actions (IRAs) were implemented on an emergency basis to stabilize the most pressing and immediate areas of RMA. One of these IRAs, Basin F stabilization, was problematic because the stabilization process created its own set of severe environmental problems, elicited public concern about the safety of the cleanup efforts, and affected ROD negotiations.

The RMA has two RODs: (1) On-Post ROD (Foster Wheeler 1996) and (2) Off-Post ROD (Harding Lawson Associates 1995). The On-Post ROD addressed the extensive contamination found at its source on site in Operable Unit 4. The Off-Post ROD primarily addressed the vast groundwater plume that had spread off site, affecting domestic wells in the largely rural farm and ranchland north and northwest of RMA, known as Operable Unit 3. The Off-Post ROD was signed in 1995, about a year before the On-Post ROD. The Off-Post ROD established a water treatment plant and a replacement municipal water supply for the residences north of RMA and established a water quality testing program for the domestic wells that still exist in the area. This testing program is implemented through Tri-County Health Department and is ongoing.

During the late 1970s, groundwater P&T systems had been installed at the north and northwest boundaries of RMA. During the 1980s and early 1990s, fourteen interim response actions (IRAs) were completed by the Army and XXX Oil Company on an emergency basis in an initial attempt to halt exposures and prevent the spread of contamination. Some efforts were eventually incorporated into the final remedy; others were enhanced or subjected to another, final remedy project. Although the IRAs were successful in breaking immediate pathways to the most grossly contaminated parts of the RMA, the final ROD was not signed until 1996. Some of the IRAs were incorporated into the remedy; others were only temporary solutions that were redesigned into more permanent projects for the ROD.

These IRAs are briefly described as follows (Foster Wheeler 1996):

1. Groundwater Intercept and Treatment Off-Post, North of RMA – This IRA addresses groundwater contamination that had migrated off post prior to installation of the boundary extraction and treatment systems on post. This system was constructed downgradient and well north of the RMA Boundary, in the middle of the most highly contaminated portion of the plume, and continues to operate. Construction of this IRA was completed in 1993; treatment of groundwater at the north boundary continues.
2. Enhancement/Improvement of Groundwater P&T Systems (North Boundary Containment System, (NBCS) Northwest Boundary Containment Systems (NWBCS), Irondale Containment System (ICS)
    1. The NBCS was originally designed to remove and treat contaminated water reaching the north boundary of RMA. Although originally installed in the 1970s, this system still operates and will continue for the foreseeable future. Groundwater is extracted, treated by granular activated carbon (GAC), and reinjected into the ground. The primary contaminants at this location are chloroform, dieldrin, DIMP, DCPD, and organosulfur compounds. The original system consisted of extraction wells, a 6,740-ft slurry wall, a recharge sump, filters to remove particles from water, three large (20,000 lb) carbon adsorbers to treat organic contaminants to containment system remediation goals (CSRGs) from groundwater, and reinjection wells. Operational improvements were implemented as part of the IRA and the reinjection system for treated water was improved by addition of recharge trenches along the entire portion of the extraction well system and the slurry wall. The improvements to the NBCS were completed in 1993; treatment is ongoing.
    2. The Northwest Boundary Containment System (NWBCS) was designed to remove and treat contaminated groundwater migrating toward and beyond the northwest boundary. The original

system included extraction wells, GAC treatment, and a reinjection system as well as a slurry wall to control contaminant migration. The slurry wall, which originally measured 1,425 ft, was extended by 665 ft. Five new extraction wells were added to the original 15, and the number of reinjection wells was increased from 21 to 25. The IRA modifications increased the amount of water treated in the NWBCS from approximately 900,000 to 1.4 million gallons per day. Groundwater is treated to CSRGs for organic contaminants and reinjected. Construction of the improvements to the NWBCS was completed in 1993, but use of this system is ongoing.

    3. The Irondale Containment System (ICS) was designed to remove and treat contaminated groundwater migrating from the Railyard and the Motor Pool toward the western boundary. The original system included two parallel rows of extraction wells, one row of reinjection (recharge) wells, and GAC treatment, and improved during the IRA. Groundwater was treated to CSRGs for organic contaminants. Construction of the improvements was completed in 1991. Groundwater in this area has since attained standards and this boundary P&T system has been shut off.

3. Groundwater Intercept and Treatment North of Basin F (interior of RMA) – The purpose of the Basin F Groundwater IRA was to intercept and remove contaminated groundwater migrating from the Basin F area toward the northern boundary. The IRA included extraction, treatment to CSRGs, and reinjection of groundwater. Water was extracted from a well north of Basin F at a rate of 1 to 4 gpm, or approximately one million gallons per year. The extracted water was piped to a treatment system located at Basin A Neck for removal of volatile contaminants (solvents) by air stripping and the remaining contaminants, such as pesticides, by GAC. Treated water was reinjected in recharge trenches at the Basin A Neck area. Construction of this IRA was completed in 1990.
4. Closure of Abandoned Wells – At numerous locations throughout RMA, old or deteriorating farm wells and unused on-post wells have been located and cemented shut. This IRA was completed in 1990.
5. Groundwater Intercept and Treatment System in the Basin A Neck Area – The Basin A Neck IRA, located on the interior of the RMA, was designed to capture and contain contaminated groundwater migrating from Basin A. The system uses extraction wells for removal of groundwater from the aquifer, has a slurry wall to minimize migration of contaminated groundwater, a water treatment system, and a reinjection system consisting of several recharge trenches. Approximately 5 to 10 million gallons per year of groundwater are extracted and treated to CSRGs by GAC at the Basin A Neck IRA treatment system. The contaminants removed from water include solvents and pesticides. Construction of the Basin A Neck system was completed in 1990; treatment of groundwater is ongoing.
6. Basin F Liquids, Sludges, and Soil Remediation – The Basin F IRA was an emergency action to stabilize Basin F. This IRA was noteworthy because of problems encountered during its implementation. These issues were severe and complicated the negotiation and drafting of the final ROD (see below for details). The IRA included transfer of the basin liquids and decontamination water into temporary storage tanks and a lined, covered surface impoundment (Pond A); construction of a 16-acre lined waste storage pile with a leachate collection system; excavation of 600,000 cubic yards of Basin F soil, air drying of the wastes, and subsequent placement into an unlined waste pile; and incineration of the stored liquids by Submerged Quench Incineration (SQI). All field and administrative closure activities were completed by May 30, 1996.
7. North Plants Building 1727 Sump Liquid – Liquid in the Building 1727 sump was treated by activated alumina and GAC to remove contaminants that included arsenic and DIMP (by-product of degraded sarin nerve agent). This IRA eliminated any remaining threat of liquid release from the sump; it was completed in 1989.
8. Closure of the Hydrazine Facility – This facility was used as a depot to receive, blend, store, and distribute hydrazine fuels. Wastewater stored at the facility was treated on post at the SQI facility, the structures demolished, and the debris removed. Uncontaminated materials at the site were salvaged for recycling and reuse, and contaminated materials were disposed at an off-post permitted hazardous waste landfill. The area encompassing the former facility was regraded and revegetated following demolition and debris removal. This IRA was completed in 1992.
9. Fugitive Dust Control – In 1991, the Army completed the reapplication of a dust suppressant in Basin A as part of this IRA. Hydroseeder trucks were used to spray a nontoxic, water-based dust suppressant. This action minimized off-site transport of windblown dust.
10. Sewer Remediation – As part of this IRA, sanitary sewer manholes were plugged to eliminate the transport of contaminated groundwater that may have entered the sewer system via cracks or loose connections. This IRA was completed in 1992.
11. Asbestos Removal – This IRA is part of the Army’s ongoing survey of asbestos on post, including removal and

disposal activities. The survey and removal of friable asbestos from occupied buildings were completed in December 1989. The Asbestos IRA activities continue as part of the final structures remediation.

12. Remediation of Other Contamination Sources – Under this IRA, the following contamination sources were addressed:
    1. Motor Pool – A groundwater extraction system was constructed to remove trichloroethylene (TCE) in groundwater in the Motor Pool area. Approximately 100 gpm of water is extracted from the Motor Pool area. A soil vapor extraction (SVE) system was also constructed to draw vapors containing volatile contaminants from the soil. Extracted vapors were sent first to a separation tank to remove the water vapor and then to a treatment system where the volatile contaminants were treated. Soil vapor extraction was conducted at the Motor Pool area between July and December 1991 to remediate TCE-contaminated soil.
    2. Rail Yard – The Rail Yard IRA extraction system consisted of a row of five wells that extracted approximately 230 g/min of groundwater containing low levels of dibromochloropropane (DBCP) resulting from spills at the Rail Yard. The water is piped to the ICS where DBCP is removed by GAC. Two additional wells further downgradient acted as a backup system. Currently, the system is being evaluated for shutoff.
    3. Lime Settling Basins – Workers constructed a soil cover over the Lime Settling Basins area to isolate the basins from the ground surface and minimize the amount of rainwater seeping into the basins. The construction of the cover was completed in 1993.
    4. South Tank Farm Plume – This area included tanks used for storage of alcohol, BC1HPD bottoms, DCPD, D-D soil fumigant, and sulfuric acid. Records indicate benzene was also used or stored in this area. The South Tank Farm Plume, located between South Plants and the South Lakes area, consisted of two separate groundwater plumes extending toward the lakes, one of which consists of light nonaqueous phase liquids (LNAPLs). The IRA alternative consisted of continued groundwater monitoring to verify that no further actions were necessary due to the natural degradation of the contaminants. Alternative assessment activities were completed in 1994. In 1991, an SVE field demonstration, which included collection and analysis of soil, LNAPL, SVE off-gas, and soil gas samples, was designed for specific application to the South Tank Farm Plume. The resulting data were used to evaluate the performance, effectiveness, and operating parameters for an SVE system. Based on the results of the demonstration, it would take more than 10 years for the SVE process to remove most of the mass of contaminants that would remain after LNAPL recovery was no longer feasible.
    5. Army Trenches – Soil samples collected from representative trenches showed elevated concentrations of ICP metals and relatively low concentrations of arsenic, mercury, and many organic contaminants, including members of all the analyte groups except pesticide-related organophosphorous compounds and organo-nitrogen compounds. Several tentatively identified compounds were also detected in the trench soil. High concentrations of some organic contaminants exist in groundwater in portions of this area. The IRA alternative consisted of continued groundwater monitoring in this area. Alternative assessment activities were completed in 1994.
    6. XXX Oil Company Trenches – Under this IRA, the trenches were covered with soil and revegetated. A slurry wall that surrounds the trench area reduces the lateral movement of contaminants away from the trenches. Construction of this IRA was completed in 1991.
13. CERCLA Hazardous Wastes – The initial action was pretreatment of CERCLA liquid wastes. This IRA was later expanded to include identification, storage, and disposal of a variety of CERCLA wastes. The initial action and expanded elements are as follows:
    1. Wastewater Treatment Plant – A wastewater treatment plant was constructed by 1992 under the first phase of the CERCLA Liquid Waste IRA. This facility is currently used to treat wastewater generated from laboratory operations, field sampling, decontamination, and other sources such as equipment washing. Several treatment technologies are used at the CERCLA Wastewater Treatment Plant including activated GAC, advanced oxidation using ultraviolet light, air stripping, chemical precipitation, and activated alumina adsorption. This facility will be used to treat similar wastewater streams during remediation.
    2. Waste Management – Waste streams were managed on an emergency basis, including miscellaneous wastes from vehicles, grounds, and building maintenance, and items found on post.
    3. Polychlorinated Biphenyls (PCBs) – The purpose of this element was to inventory and sample PCB

contaminated equipment followed by remediation off post. This IRA included characterization of spill sites (soil and structures) associated with PCB contamination and is ongoing. PCB contamination not addressed in this IRA was addressed as part of the final remedy.

4. Waste Storage – This element included an on-post facility for temporary management of solids that are bulk hazardous wastes, primarily, contaminated soil and building debris. Analysis resulted in the decision to eventually dispose of the wastes in the on-post hazardous waste landfill when it became available during remedy.

14. Chemical Process-Related Activities – Agent-related and non-agent-related process equipment and piping located in North Plants and South Plants was sampled, decontaminated, and dismantled. Although much of the equipment in these areas was removed and recycled under the IRA, the process-related equipment not remediated as part of this IRA was disposed in the on-post hazardous waste landfill. Asbestos-removal activities as required for equipment removal continued as part of the final response action at RMA.

The implementation of the Basin F IRA was especially challenging because of the number of problems encountered and the effect of those problems on the future course of the project**.** During the winter of 1988, the Army drained the liquid off the 93-acre Basin F (Figure 24) and stored it in three large tanks to later be incinerated. Highly contaminated sediment that had accumulated at the bottom of the impoundment was piled in large piles and stacks with the intention of drying them before their secondary impoundment into a waste pile. These contaminated sediments were hazardous and odorous. The attempts to dry the sediments resulted in chemical odors and thick, noxious fumes. These fumes quickly accumulated and spread into nearby neighborhoods, causing illness in residents. The arrival of winter, and Denver's notorious poor atmospheric dispersion conditions, coincided with the maximum areal extent of the excavation. The entire 93 acres were exposed and there was no means by which it could be covered. The resulting trapped odors and fumes that had spread into the neighboring communities, at one point, resulted in closure of major thoroughfares in and out of the surrounding community.

News media provided daily coverage of the story. There was no public outreach and no clear communication with the surrounding community about what was creating the toxic fumes that were making residents ill. Because the RMA site was associated with secret military activities and the actual excavation was located too far into the interior to be viewed, fear and panic spread throughout the community. Neighbors knew only that the facility manufactured "nerve gas."

The situation became a state of emergency, further confused by legal ambiguity about whether the state could enforce its newly delegated RCRA authority on federal facilities. As the situation escalated into a crisis, the governor attempted to visit community members to speak directly to them. The governor tried to calm the neighborhood's anxiety, but instead was chased down the street by angry civilians (KMGH-TV 1988).

This situation was resolved by completion of the IRA, but it complicated the eventual signing of the ROD. Not surprisingly, the Basin F IRA created uncertainty and concern among surrounding residents and stakeholders that the RMA could in fact, be safely excavated and cleaned up without exposing the surrounding communities via the air pathway. Eventually, concern about Basin F was resolved in the ROD by including certain requirements in the ROD. Most notably, the ROD established a medical monitoring program that consisted of several key requirements:

- Extensive air quality monitoring was conducted at sites around the RMA perimeter, interior, and within the surrounding community.
- An innovative air modeling system using local air data was incorporated into the design for each project. This system identified "no dig' days for each project based upon forecast meteorology, and employed a full-time meteorologist to develop a daily forecast that would guide the rate of excavation for that day.
- Extensive odor monitoring 24/7 at the fence line provided immediate feedback about the potential for any emissions to reach the fence line or beyond.
- A hotline was set up for the Rocky Mountain Poison and Drug Center. Staff were trained to respond to calls from concerned citizens around RMA during the cleanup.
- Local physicians were trained to look for any potential effects in their patients that might relate to the Rocky Mountain Arsenal.
- Newsletters were developed and sent to the local communities on a regular basis to keep them informed about the RMA cleanup, and a Citizens' Advisory Group was set up specifically to respond to citizen health concerns.

These efforts were largely effective and successful. With the remedy underway and the ROD projects implemented, these measures alleviated citizen concerns. The remedy was implemented without any further significant impact to the community (Figure 25).

Figure 24. Image of Basin F, prior to the 1988 IRA, c. 1980. From archived files of Colorado Attorney General's Office (CDPHE 1980)**.**

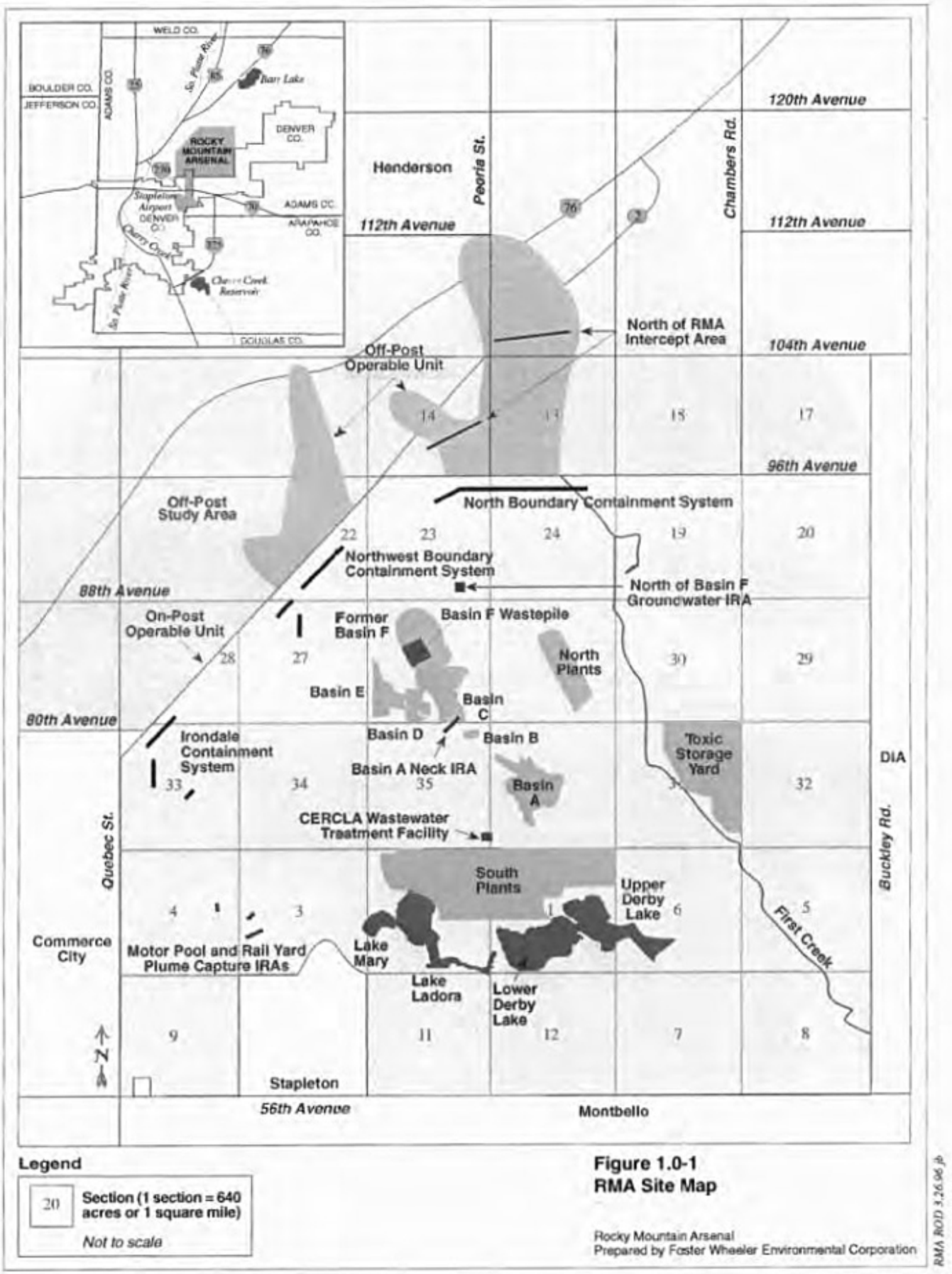

Figure 25. Map of project areas and IRA at RMA (Foster Wheeler 1996)**.**

6.4.1 Technical Basis for Remedial Action

Under the On-Post ROD, the RMA was broken into 36 separate projects for eventual cleanup. Some of these projects

incorporated or improved upon the IRAs. Overall, the selected remedy at RMA was essentially a large-scale “dig-and-haul” operation, with several opportunities for innovative technologies selected for certain projects. Due to the extensive amounts of contaminated soils and their depth, excavating to the water table was considered impractical (over 40 feet in most locations). It was eventually decided only to excavate the upper 10 feet of soil at RMA, and to leave the remaining waste under caps and covers.

Because of the sheer volume of soil to be disposed, the remedy was negotiated as a fixed volume, which meant that only a predetermined amount of soil—that for which the landfills could be designed—would be excavated. All structures with no future use were demolished. Less contaminated soils and less contaminated debris from structures were placed as grade fill over the footprint of South Plants, Basin A, and Basin F. More contaminated soils were excavated to 10 feet and placed in one of two on-site landfills built specially for this purpose. The basins with the consolidation debris and other areas where most highly contaminated soil remained at depth were interred under RCRA-equivalent evapotranspiration covers with geotextile capillary break liners and a biota barrier filled in with chokestone (Figure 26). Less contaminated soils with no consolidation debris were covered with two and three-foot covers without the biota barrier.

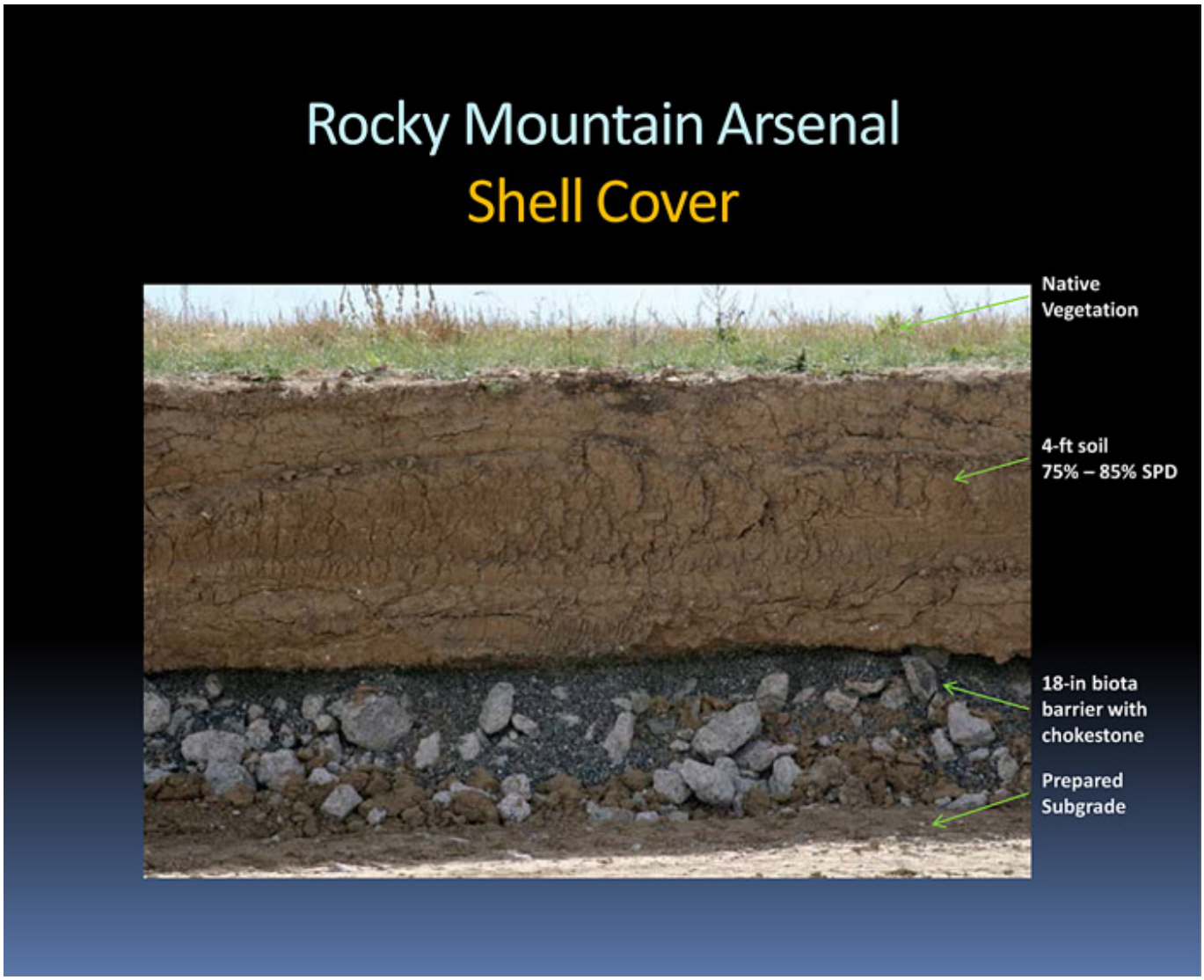

Figure 26. Image of RCRA-equivalent cover cross-section exposed while under construction (CDPHE 2000)**.**

The most highly contaminated structures, including those with known agent history, were demolished, caustic washed, or both and the debris placed in the on-site landfills.

Munitions were located using geophysical methodology and archived aerial photographs. Extensive unexploded ordnance (UXO) removal was conducted. Areas that had been lightly contaminated by the windblown spray from the Basin F aerator spray system were tilled to redistribute surface contamination. The groundwater P&T systems that had been installed to intercept the contaminated plumes at the site boundary were enhanced, expanded, and incorporated into the final remedy. These systems continue to operate, and will continue to treat groundwater until it is no longer necessary (estimated to be another 100 years). Chlorides and sulfates are expected to attenuate naturally.

Off-post, the Army set up a municipal wastewater treatment plant and all off-site users of domestic wells were allowed a

hookup to the new municipal system at no cost. Additionally, remaining off-site domestic water wells may be sampled annually at the owner's request under a contract with the local county health department (this program is PRP funded). Any remaining wells found to exceed standards will be eligible for a hookup. Some soils on properties that lie on the immediate north boundary of the RMA off site were tilled to redistribute surface contamination (Harding Lawson Associates 1995).

Because the scope of cleanup of the site is limited and waste remains in place, the RMA site is subject to land use restrictions in perpetuity that restrict residential development and use, restrict any agricultural use or human consumption of fish and game from the RMA, and limit access to capped and covered areas (Navarro Research and Engineering Inc. 2013). The RMA site has been inducted into the USFWS refuge system in perpetuity as a wildlife refuge (Congress 1992). Because of the nature of the cleanup and the prospective future use of the land, the ROD did not call for confirmatory sampling of excavations at RMA. Some limited further sampling was conducted, but the samples were only identified during final inspection and the locations based only upon a visual assessment (for example, visible soil staining).

6.4.2 Decisions

Initial characterization of the RMA was hampered by its sheer size and number of chemicals involved. Efforts were made to streamline the areas to be investigated by using archived aerial photography to identify the former use areas and known areas of severe contamination, mostly within the RMA's core. Soil sampling was concentrated in those areas, leaving sparser areas of sampling at the RMA's perimeter. Many of the samples were composites, both horizontal and vertical. Twenty-seven risk driving chemicals of concern were identified out of over 660 compounds originally known to have been used or disposed of at the Arsenal, including VOCs, pesticides, and more.

Most importantly, in 1987, before site or remedial investigations had been completed for RMA, a Federal Facility Agreement (FFA) was signed for RMA—the first in the country (USEPA 1989c). In a reversal of what would later become standard procedure for most sites, a series of land use restrictions, to be imposed in perpetuity on the RMA, were agreed upon and adopted into the FFA. At that time, the future use for the site began to be envisioned as open space/wildlife refuge. As such, these land use restrictions that were originally established in the Federal Facility Act of 1987 became a foundational basis for all future use assumptions. The rest of the Superfund process, including RI/FS, Risk Assessments, and eventually, the On-Post ROD, was designed around these restrictions.

The land-use restrictions served to limit the number of samples and influenced the selection of chemicals that would be selected as COCs (for example, the prohibition on consumption of fish and game caused the chemicals known to present a bioaccumulation hazard not to be included as COCs). Presupposing the land use restrictions and building the remedy around them caused a chain of events that affected the remedy all throughout its life cycle and beyond.

Timeline of Decisions

Inception and Completion Dates for Major RMA Documents

Document	Start Date	Finish Date
Federal Facility Agreement	February 1987	
Remedial Investigation	October 1984	January 1992
Human Health Exposure Assessment	October 1986	September 1990
Human Health Exposure Assessment Addendum	August 1990	December 1992
Human Health Risk Characterization	September 1992	May 1990
Ecological Risk Characterization	October 1987	July 1994
Development and Screening of Alternatives	February 1989	December 1992
Detailed Analysis of Alternatives	January 1993	October 1995
Rocky Mountain Arsenal National Wildlife Refuge Act	1992	

Document	Start Date	Finish Date
Off-Post ROD	July 1995	
On-Post ROD	1996	

At RMA, direct and indirect future exposure pathways were evaluated, and ROD removal criteria were developed to accommodate the presumed future exposures only. The direct pathways included ingestion (consumption of contaminated soil), dermal absorption (contacting contaminated soil), and inhalation (breathing contaminated dust particles). The indirect pathways included inhalation of contaminated vapors in open areas (such as during work performed outdoors) and enclosed spaces (such as in basements). Dermal contact with metals in soil was not evaluated for any receptor population because of negligible contaminant absorption through this exposure pathway.

The five potentially exposed populations/subpopulations and their respective current and future exposure pathways included the following:

- biological worker, for example, a wildlife biologist working on the refuge—all direct pathways and open space vapor inhalation
- regulated/casual visitor, for example, someone (adult or child) visiting the wildlife refuge—all direct pathways and open space vapor inhalation
- recreational visitor, for example, someone (adult or child) jogging or playing on areas of the wildlife refuge—all direct pathways and open space vapor inhalation
- commercial worker, for example, a person working inside a building on the wildlife refuge—all direct pathway and enclosed space vapor inhalation
- industrial worker, for example, a person working outside and potentially exposed to soil—all direct and indirect pathways

6.4.2.1 Summary of the FS Process

The FS process involved two phases: (1) development and screening of alternatives and (2) the detailed analysis of alternatives. Contaminated media at RMA, including water, structures, and soil, was subdivided into several groups with similar contamination to organize and streamline the FS process.

RAOs were identified at the outset of the development and screening of alternatives. These goals provided general guidance for the FS by identifying the contaminants and media of interest, potential exposure pathways, and preliminary remediation goals. For the On-Post OU, RAOs were developed for water, structures, and soil based on ARARs specified in federal and state environmental laws and regulations, and the provisions of the FFA. The human health and biota remediation goals aimed to achieve appropriate remediation so that the selected remedy was protective of both humans and biota. Further specific considerations taken at RMA include Army safety procedures and USFWS guidance regarding the future land use of the site as a national wildlife refuge.

A range of alternatives was developed for each of the water, structures, and soil medium groups, including: no action (NA), no additional action (NAA), institutional controls, containment, and treatment options. The NA alternative (as required by USEPA) and the NAA alternative were also developed and used as a baseline against which other alternatives were evaluated. The NA alternative represents current site conditions with no remedial actions undertaken, ongoing, or planned. The NAA alternative involved no action beyond the IRAs currently being implemented on post.

No Action and NAA alternatives were developed for each contaminated medium. These alternatives were eliminated from consideration during the comparative analysis conducted for site-wide alternatives because they were not sufficiently protective. The identified alternatives had several features in common:

- *Land Use Restrictions*. The Rocky Mountain Arsenal National Wildlife Refuge Act of 1992 restricts current and future land use, specifies that the U.S. government shall retain ownership of RMA, and prohibits certain activities such as agriculture, use of on-post groundwater as a drinking source, and consumption of fish and game taken at RMA. Continued restrictions on land use and access were included as an integral component of all on-post alternatives. Long-term management includes access restrictions to capped and covered areas to ensure the integrity of the containment systems.
- *Five-Year Review.* In accordance with CERCLA, a review will be performed a minimum of every five years after initiation of remedial action to ensure that the various remedial actions where contamination continues to exist,

such as the capped areas or the hazardous waste landfill, remain protective of human health and the environment and comply with ARARs.

- *Site Monitoring*. The Army will continue to conduct air, groundwater, and surface water monitoring programs at RMA. The Army will continue to fund USFWS to conduct on-post wildlife monitoring programs. Samples will be collected periodically to assess the effectiveness of the remedy for protection of human health and the environment. The actual compliance monitoring program for each of the environmental media will be finalized during the remedial design.
- *Revegetation*. When vegetation is disturbed during remedial construction, the disturbed areas will be revegetated consistent with a USFWS refuge management plan.
- *Long-Term O&M*. Areas remediated will be operated and maintained as required. Management activities may include maintaining capped and covered areas or operating the on-post hazardous waste landfill or groundwater treatment systems.
- *On-Post Water Supply*. A sufficient on-post water supply will be maintained.

Other additional components included in the overall on-post remedy were considered in the selection of the preferred alternatives include:

- provision of $48.8 million held in trust to provide for the acquisition and delivery of 4,000 acre-feet of potable water to SACWSD and the extension of the water-distribution lines from an appropriate water supply distribution system to all existing well owners within the plume footprint north of RMA
- an RMA Medical Monitoring Program (implemented by CDPHE, discussed above)
- a trust fund requested by members of the public and some public officials to address concerns about the stability of long term O&M costs (a joint trust fund between XXX Oil Company and the Army was unsuccessful due to regulations regarding joint federal and private funds)
- biomonitoring
- UXO disposal

An expanded discussion of remedial alternatives is presented in the Rocky Mountain Arsenal On-Post ROD.

6.4.3 Cost Assessment

The estimated cost for the selected On-Post Remedy for the RMA was $2.2 billion. The Army assumed 80% of that cost and XXX Oil Company assumed 20%. Table 18 gives a rough breakdown of estimated cost for the remedy.

Table 18. Total estimated cost of the selected RMA remedy[1,2]
(adapted from DOE, USEPA, and CDPHE 2003)

Cost Element	Capital ($ M)		Operating and Maintenance ($ M)		Total Cost ($ M)	
	Total[3]	Present Worth	Total[3]	Present Worth	Total[3]	Present Worth
Soil	530	380	41	17	570	400
Water	19	18	130	85	150	100
Structures[4]	7	6.5	140	130	150	140
Pre-ROD Costs[5]	750	750	—	—	750	750
PMRMA Mission Support	550	430	—	—	550	430
Total Cost ($ M)	1,900	1,600	310	230	2,200	1,800

[1] Detailed cost information is provided in the Detailed Analysis of Alternatives report
[2] All costs are presented in 1995 dollars
[3] Total cost does not account for inflation over the time frame for remediation
[4] Structures cost includes $35 million to complete ongoing IRAs
[5] Pre-ROD costs include RI/FS and IRA costs and are listed to illustrate the total costs for complete remediation of RMA

6.4.4 Monitoring/Optimization

Currently, the RMA remedy construction has been completed by the Army as lead agency, in cooperation with XXX Oil Company and the U.S. Fish and Wildlife Service, with oversight provided by USEPA, Colorado Department of Public Health

and Environment, and Tri-County Health Department. Air monitoring is no longer necessary and has been discontinued. The landfills and covers are in postclosure care. All munitions and explosives of concern/UXO clearances have been completed. Groundwater continues to be monitored on and off-post and the groundwater P&T systems are still operating at the boundary as well as the off-post and on-post P&T systems. Off-post plume maps are generated every few years. Resident domestic wells continue to be monitored for RMA contaminants upon request. Groundwater on- and off-post is sampled every 2.5 years for RMA COCs. Biota continues to be monitored for residual contamination.

Understanding postremedy soil conditions is hampered by a lack of confirmatory sampling post-excavation. This decision, originally negotiated in the on-post ROD, created a data gap that has hindered some postremedy optimization efforts. The remedy envisioned that the land use restrictions would remain in place in perpetuity; lack of data makes it unclear whether land use restrictions are still necessary. ICs are now hampering USFWS land management activities in ways not anticipated by the original remedy.

Other postremedy management challenges have arisen. In 2007, USFWS introduced 13 bison onto RMA from another Western wildlife refuge. The herd has grown exponentially; excess bison will be an ongoing problem. USFWS wishes to make excess bison available to the public for human consumption. This situation brings USFWS needs for managing the RMA refuge into conflict with the long-standing prohibition on human consumption of fish and game from RMA. Furthermore, USFWS wishes to use hunting and fishing as a tool to manage wildlife populations in the increasingly urban-locked Rocky Mountain Arsenal National Wildlife Refuge. Additionally, the RMA National Wildlife Refuge is increasing in popularity, receiving over 1 million visitors per year in 2016. There is increasing public pressure for more intensive uses of the RMA National Wildlife Refuge as a recreation area. Figure 27 shows RMA today.

Figure 27. XXX Oil Co.: Trenches RCRA-equivalent cover, postremedy, 2010 (CDPHE 2010)**.**

Additionally, land values in and around the RMA have changed dramatically since the signing of the ROD and original vision for a wildlife refuge. Commerce City, which now owns some portion of RMA with the original land use restrictions intact, would like to develop the property for residential use. Any future investigation into the suitability of these lands for residential use will require a comprehensive risk assessment.

6.4.5 Regulatory and Stakeholder Involvement

The RMA has a long history of regulatory involvement—a history almost as old as CERCLA and RCRA themselves. Of interest, RMA was the subject of a Supreme Court ruling that recognized the state's authority to enforce state environmental law on federal lands. A brief history, taken from the On-Post RMA ROD, is provided below. Currently, USEPA and state of Colorado,

as well as Tri-County Health Department, all provide ongoing oversight of the RMA as it transitions from active remedy status to long term O&M. The RMA still has closure/post-closure ongoing issues that will continue to require federal, state, and local involvement for the foreseeable future. Roles and responsibilities, as well as dispute resolution procedures for the Army, XXX Oil Company, USFWS, and the agencies are still defined by the Federal Facility Agreement of 1987. The state, wishing to retain its enforcement discretion and rights, was not a signatory to the FFA.

At the height of its active remedy, the RMA hosted a Remediation Advisory Board (RAB) which consisted of local community representatives and local officials. The RAB was disbanded after the active remedy operations were completed in 2010. In addition to the RAB, a Citizen Advisory Board (CAB) was convened to provide guidance and advice to the Medical Monitoring Program. The CAB voted to disband itself in 2008, in response to vastly diminished concerns about the remedy's impact to the community. Currently, a third group, the Site-Specific Advisory Board (SSAB) still exists and is an active participant during the Five-Year Reviews and on specific issues as needed.

6.4.5.1 Regulatory and Legal Site History of CERCLA Enforcement Activities (from RMA ROD)

In December 1982, the USEPA, Army, XXX Oil Company, and Colorado Department of Health entered into a Memorandum of Agreement outlining joint participation in the Amy's study of decontamination at RMA. Although the parties followed the process outlined in the Memorandum of Agreement until 1986, they also pursued litigation with respect to issues relating to legal authority over RMA remediation efforts, payment of natural resource damages (NRDs), and reimbursement of costs expended for cleanup activities (response costs).

USEPA, the Army, Department of Interior, and XXX have established a protocol for resolving disputes that arise at RMA concerning CERCLA cleanup actions. This dispute resolution process is set forth in the FFA (USEPA 1989c). The state of Colorado became a party to the FFA dispute resolution process on June 13, 1995, when it signed, along with the above entities, the Agreement for a Conceptual Remedy for the Cleanup of the RMA (Conceptual Remedy). The only provisions of the FFA that are binding for the state are those related to dispute resolution. The state declared its intention to use the FFA dispute-resolution process in a good-faith effort to resolve all issues informally. For issues that were not subject to dispute resolution under the FFA, and for those issues over which the state has independent authority pursuant to U.S. v. State of Colorado and the Colorado Department of Health, Civil Action No. 89-C-1646, 990 F. 2d 1565 (10th Cir. 1993), cert. denied 114 S. Ct. 922 (1994), the state reserved any rights and authorities it may have.

6.4.5.2 State Enforcement Activities

The state of Colorado has been involved in two civil actions related to RMA activities:

- *State of Colorado v. Department of the Army, Civil Action No. 86-C-2524*. The state filed an action against the Army in state court in 1986. The state's original complaint alleged violations of the Colorado Hazardous Waste Management Act (CHWMA) groundwater monitoring regulations. The complaint was amended in 1987 to include claims of failing to close Basin F in accordance with the closure plan issued under CHWMA and later conducted under CERCLA as well as failure to pay fees due under CHWMA. In 1989, the Court held that CHWMA enforcement was not precluded by CERCLA (State of Colorado v. Department of the Army, 707 F. Supp. 1562, 1569-70, D. Colo. 1989).
- *United States v. State of Colorado and the Colorado Department of Health, Civil Action No. 89-C-1646.* Following inspections of the Basin F site in 1989, CDPHE issued a compliance order against the Army, citing 42 violations of CHWMA and its implementing regulations regarding hazardous waste management. The U.S. filed suit in federal court seeking a judgment that CDPHE had no authority to enforce the compliance order and that the U.S. was not liable for civil penalties under RCRA or CHWMA. In 1991, the Court ruled in the U.S.'s favor. The state appealed and the Tenth Circuit Court of Appeals reversed the ruling (United States v. State of Colorado and the Colorado Department of Health, 990 F. 2d 1565, 10th Cir. 1993). In 1993, the U.S. petitioned the U.S. Supreme Court to review the Tenth Circuit court's decision but their petition was denied (114 S. Ct. 922 1941). In 1994, the U.S. and the state of Colorado entered into a Consent Decree to resolve remaining litigation issues. The Army agreed to submit closure plans for Basin F and the Basin F Waste-pile for CDPHE approval.