RECLAMATION OF AN IN SITU COAL GASIFICATION TEST SITE IN WYOMING[1]

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Abstract: In the late 1980s, two coal gasification concepts were tested at a 15-acre site in the Hanna Basin of south-central Wyoming. Both tests were conducted in the Hanna No. 1 Coal Seam, which is about 30 feet thick and 365 feet below surface at this site. Approximately 4500 tons and 11,300 tons of coal were burned in the two tests, respectively. The Land Quality Division (LQD) of the Wyoming Department of Environmental Quality (WDEQ) issued Research and Development License No. 15 (RD15) to Stearns Catalytic Corporation (now Washington Group International, Inc.) for the tests. Per the license requirements, ground water restoration and surface reclamation were necessary after the tests. Because of the efficiency of the burns and the effectiveness of venting and flushing the burn cavities after each test, ground water restoration was completed in 1989. Once ground water restoration was deemed complete, the 30+ wells were abandoned and surface reclamation began. The reported seed mix included Wheatgrass (western, thickspike, and slender), Indian Ricegrass, Fourwing Saltbush, and Big Sagebrush. In addition, Big Sagebrush seedlings were also planted. Surface reclamation was completed in 1993, with limited repair work (primarily weed control) in subsequent years. The LQD released the reclamation bond and terminated the license in late 2005. Even though this site was tiny in comparison with most in situ noncoal mines and traditional coal mines, it provides a microcosm of reclamation issues, including: drought impacts; selection of areas for evaluation of reclaimed vegetation; and comparison of species planted with species expressed. It also provides information specific to reclamation issues at in situ mining projects, such as extent of ground water contamination, measurement of revegetation success at sites with multiple, relatively small areas of disturbance, and soil sampling for water treatment impacts. The site was one of the first evaluated for bond release under Category 5 of the LQD Coal Rules.

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Introduction

The RD15 Site is one of several sites at which coal gasification experiments were conducted in Wyoming and one of two adjacent sites in the Hanna Basin in south-central Wyoming (Fig. 1). The surface disturbance at the RD15 Site is typical of coal gasification projects, and most of the disturbance is associated with the Facilities Area (Fig. 2a) and the numerous well sites, pipelines, and access roads (Fig. 2b). Prior to reclaiming the surface disturbance, some of the most intensive reclamation work involves quenching the coal burn, ground water remediation, and plugging wells. Once this work is completed, the surface reclamation proceeds in much the same manner as the reclamation for traditional coal mining, including site grading, re-establishment of drainages, spreading topsoil, and seeding. Gasification experiments were conducted at the adjacent Hanna Site prior to those at the RD15 Site, but evaluation of the reclamation success at the Hanna Site was delayed until this year for a variety of reasons. Therefore, this paper focuses on the RD15 Site.

Even though the RD15 Site is very small (about 8 acres of surface disturbance within a 15-acre site (Fig. 3)), issues were encountered during the evaluations of reclamation success that provide insight for future reclamation work at other coal and noncoal sites. Some of the issues were unexpected and could be encountered at larger sites, whether those sites were mined by open pit, underground, or in situ techniques. These issues included: drought impacts; the difficulties of selecting a comparison area for evaluation of revegetation success; and expression of species from the seed mix. Other issues would generally be encountered only on in situ mine sites. Of particular interest at the RD15 Site was the relatively limited extent of ground water contamination, in comparison with other coal gasification experiments, apparently due to: the in situ pressures during the tests; the efficiency of the burn; and the techniques used to quench the burn. However, with respect to surface reclamation, some of the difficulties associated with evaluating reclamation success on multiple, relatively small areas of disturbance and with soil sampling to ensure there were no impacts from the water remediation system were not anticipated.

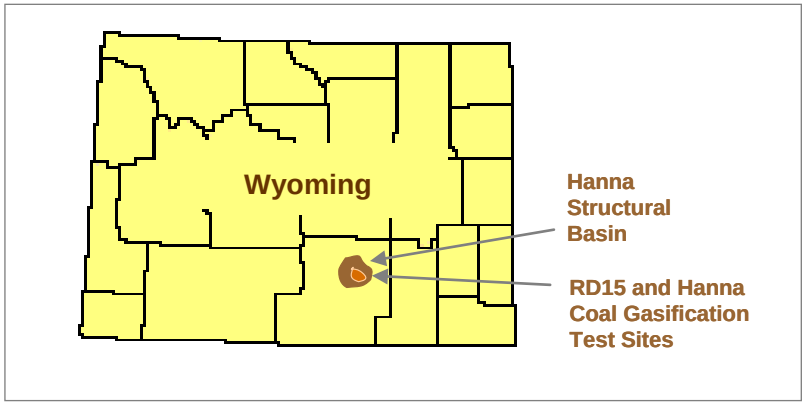

Figure 1. Location of the RD15 Site.

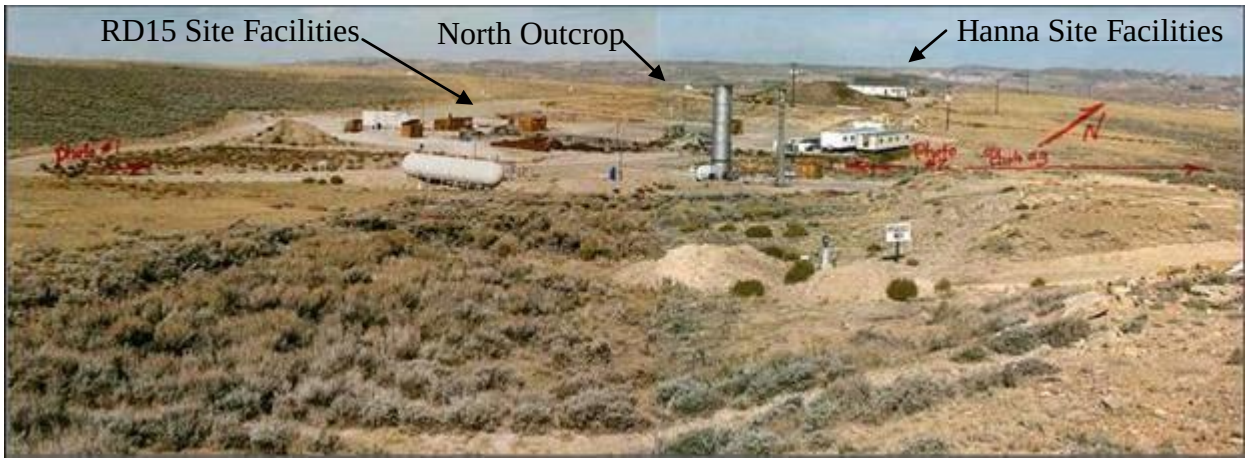

Figure 2a. Location of the Facilities Areas at the RD15 and Hanna Sites, October 4, 1988, looking northwest from the South Outcrop. The North Outcrop, which is between the RD15 and Hanna Facilities Areas, is identified for easier comparison of pictures over time.

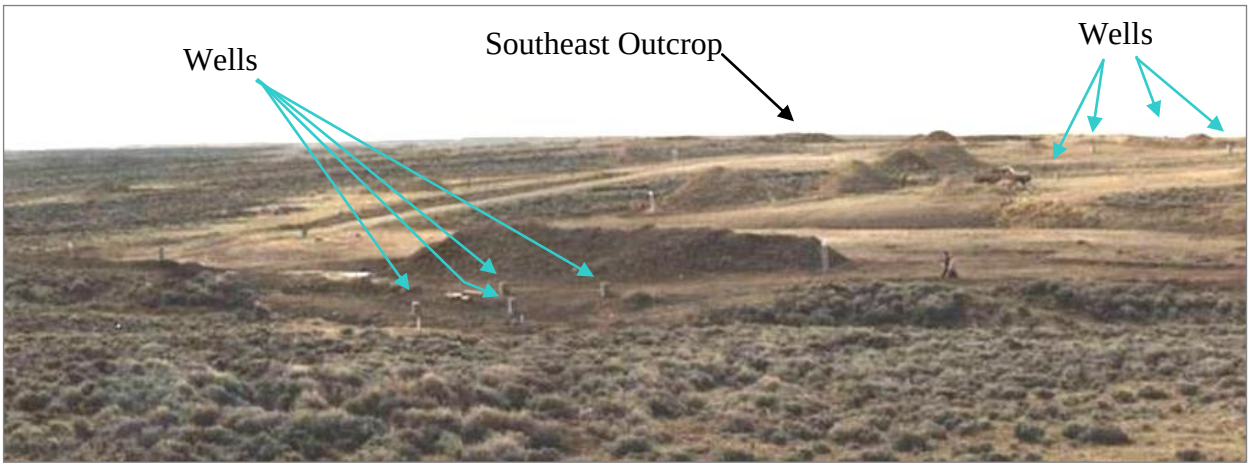

Figure 2b. Some of the wells at the RD15 Site, April 16, 1993, looking southeast. The Southeast Outcrop is just outside the southeast corner of the site.

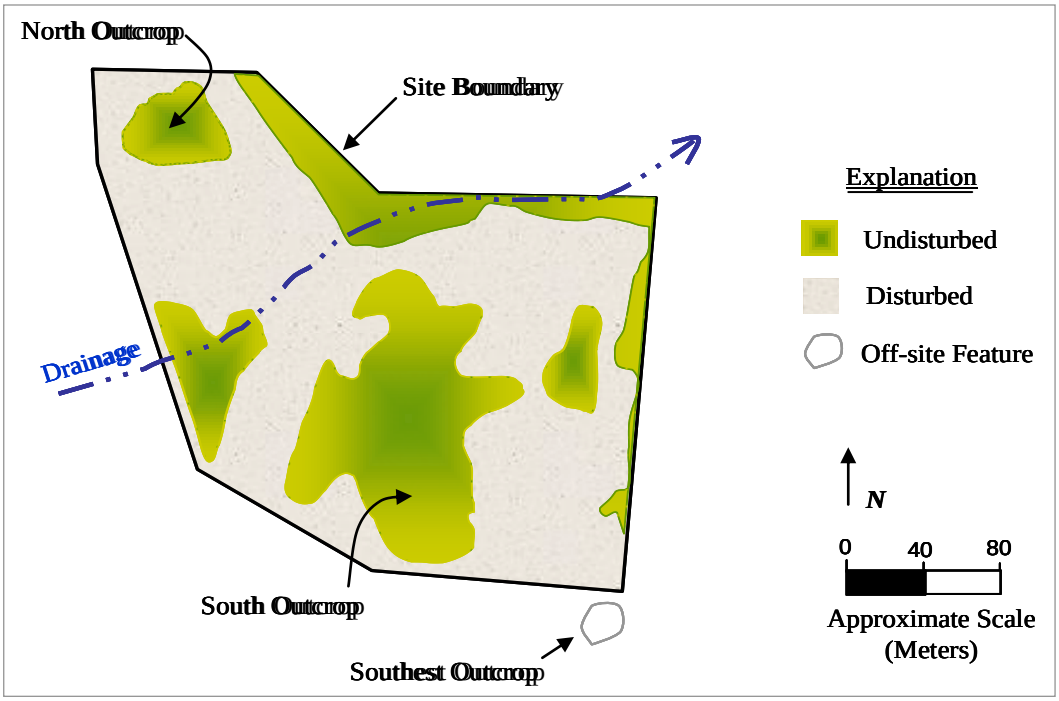

Figure 3. GPS of undisturbed vegetation at the RD15 Site, April 18, 2002.

Microcosm of Issues at Larger Sites

The rules of the federal Office of Surface Mining (OSM, 30 CFR '' 700.5, 701.5, 785.22, & 828) and the Wyoming Statutes (W.S. ''35-11-103(e)(xx)&(f)(iv)) both address in situ coal gasification; therefore, the reclamation was evaluated using the criteria developed by LQD for Bond Release Category 5. This category is applicable to mined lands from which coal was not removed prior to May 3, 1978 or mined lands and support facilities which were used on or after May 3, 1978 to facilitate mining. The date of May 3, 1978 is the effective date of OSM's Initial Regulatory Program under the Surface Mining Control and Reclamation Act (30 USC ''1201 *et seq.*) (Chancellor, 1998). The Category 5 criteria are among the most stringent for surface reclamation in the LQD regulatory program and, for evaluation of revegetation success, require assessment of vegetation cover, production, shrub density, and species diversity. Most of the unanticipated reclamation issues at this site related to revegetation success.

Drought Impacts

The reestablishment of vegetation at this site proceeded as anticipated, with limited expression of the seed mix in the initial years and then progressive improvement in the following years. Other than control of some patches of Canada Thistle and Whitetop, one-time interseeding on a few spots early in the reclamation period, and occasional fence repair, no additional reclamation work was necessary after the initial seeding. Figures 4a through 4d show the progress in the Facilities Area; Fig. 5a through 5d show progress in the area where many of

North Outcrop

Figure 4a. Facilities Area at the RD15 Site after removal of buildings and most equipment, June 18, 1991, looking northwest. TSP refers to Topsoil Stockpile. The "Photo #2 location" is a reference to another photo, not included in this paper, taken during the June 1991 inspection.

North Outcrop

Figure 4b. Facilities Area at the RD15 Site, July 8, 1994, looking northwest. Site was seeded in the Fall of 1993.

North Outcrop

Figure 4c. Facilities Area at the RD15 Site, August 4, 2000, looking northwest. Site was seeded in the Fall of 1993.

North Outcrop

the wells were located; and Fig. 6a through 6c and 7a through 7d show progress along the drainage through the site.

Figure 4d. Facilities Area at the RD15 Site, June 20, 2004, looking northwest. Site was seeded

Figure 5a. RD15 Site after completion of grading and application of most of the topsoil, October 12, 1993, looking southeast.

Figure 5b. RD15 Site, June 6, 1995, looking southeast. Site was seeded in the Fall of 1993.

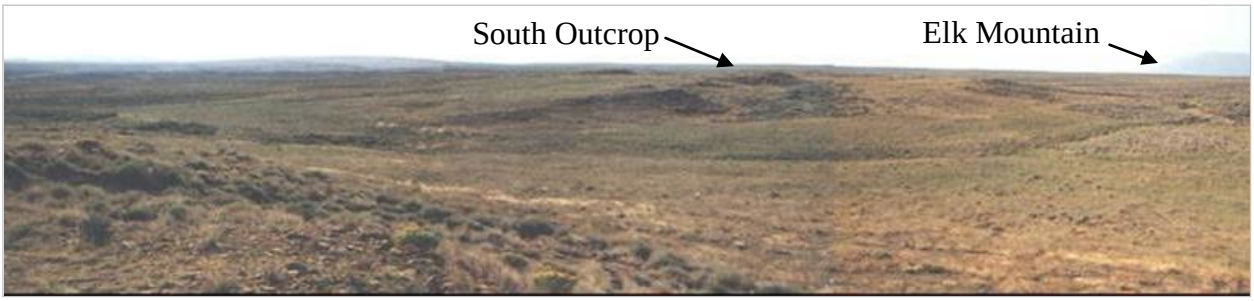

Figure 5c. RD15 Site, August 4, 2000, looking southeast. Site was seeded in the Fall of 1993.

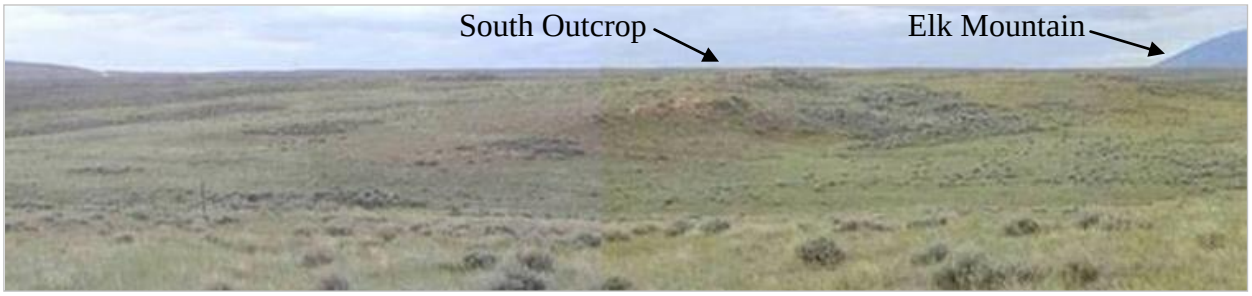

Figure 5d. RD15 Site, June 30, 2004, looking southeast. Site was seeded in the Fall of 1993.

Figure 6a. Drainage through Facilities Area, October 4, 1988, looking west (upstream).

Figure 6b. Drainage through Facilities Area, August 6, 2001, looking west (upstream). Site was seeded in the Fall of 1993.

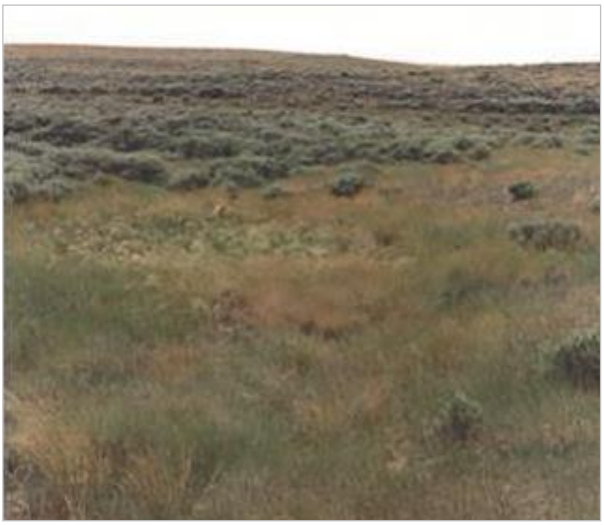

Figure 6c. Drainage through the Facilities Area, July 7, 2005, looking west (upstream). Site was seeded in the Fall of 1993.

Figure 7a. Drainage through Facilities Area, October 4, 1988, looking east (downstream).

Figure 7b. Drainage through Facilities Area, June 6, 1995, looking east (downstream).

Figure 7c. Drainage through Facilities Area, April 18, 2002, looking east (downstream).

Figure 7d. Drainage through Facilities Area, July 7, 2005, looking east (downstream).

Few, if any, of the people who visited this site during the latter part of the reclamation period would have anticipated any issues with revegetation success for cover, production, shrub density, or species diversity. However, the severe drought in 2001 and 2002 (Fig. 8) apparently adversely impacted vegetation growth. Visually, the overall vegetation conditions appear very similar from year to year in the early 2000s (Fig. 9a through 9c), but in 2002, when the results of the first year of vegetation sampling for cover and production were evaluated statistically, the vegetation cover in the reclaimed area was less than that in the comparison area. Consideration was given to the possibilities that sampling results may have been impacted by the difficulties in selection of an adequate comparison area, the relatively small sizes of the various areas, and the lack of grazing (to reduce litter) in the reclaimed area. However, because of the extremely low precipitation in 2001 and 2002, the decision was made to 'wait and see' what the 2003 conditions would be rather than attempt any change in the reclamation to improve the vegetation cover. In 2003 and 2004, the cover and production in the reclaimed area were well in excess of the cover and production in the comparison area.

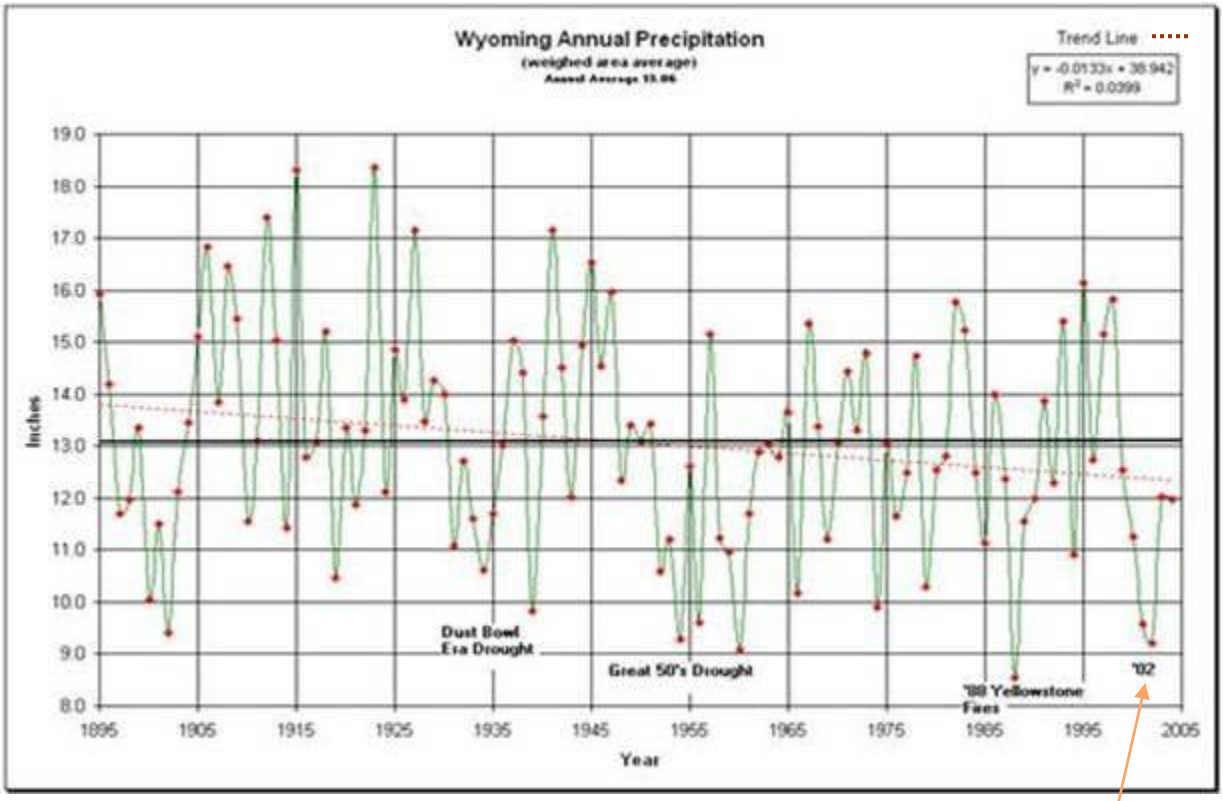

Figure 8. Wyoming Annual Precipitation (1895-2004).
(Figure 6.5 in the Wyoming 2004 Climate Atlas which can be found at: http://www.wrds.uwyo.edu/wrds/wsc/climateatlas/titlepage.html).

1st year of revegetation evaluation at RD15 Site

Figure 9a. Reclamation just to the south of the North Outcrop, August 6, 2001, looking north.

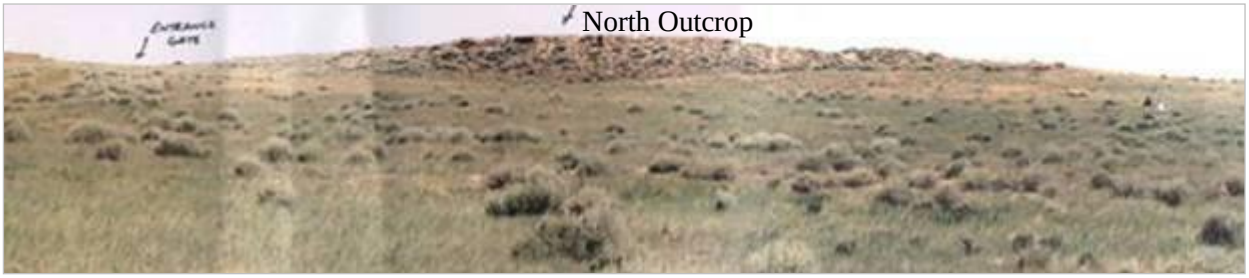

Figure 9b. Reclamation just to the south of the North Outcrop, July 8, 2003, looking north.

Figure 9c. Reclamation just to the south of the North Outcrop, June 30, 2004, looking north.

Selection of a Comparison Area

Prior to site disturbance, no areas had been set aside within either the RD15 Site or the Hanna Site for comparison of native and reclaimed vegetation after reclamation, although some baseline vegetation information was collected for the RD15 Site. This was due in part to the age of these sites, and the research and development aspect of the work. However, as reclamation progressed at the RD15 and Hanna Sites and as there was continued interest in coal gasification at other sites, it became apparent that the methods for evaluating revegetation success at such sites needed to be confirmed, including the methods at the RD15 Site.

In September 1995, two areas were designated within the RD15 Site for comparison of native and reclaimed vegetation to evaluate revegetation success. The area close to the drainage was referred to as the 'lower' comparison area (Fig. 10a), and the area higher on the hillside was referred to as the 'upper' comparison area (Fig. 10b). However, these two areas were subsequently not considered suitable for evaluation of revegetation success for several reasons, including: the reclamation was not differentiated by topography, e.g., there were no separate seed mixes for 'upper' and 'lower' areas; the upper comparison area was in dense sagebrush, even though the approved seed mix resembled an upland grassland community; and the designated areas were too small to provide for adequate sampling. Therefore, in July 1998, an area outside the RD15 Site was designated as the comparison area for evaluation of revegetation success (Fig. 10c). An outside area was considered necessary because the undisturbed areas that were large enough for adequate sampling within the site were primarily rocky outcrops (Fig. 4a and 5a). Selection of an appropriate area was difficult, primarily because of the heavy grazing pressure outside the site, which had been fenced shortly after seeding in 1993 to protect the site from grazing. However, a two-acre upland grassland area was found and fenced in the summer of 1998.

Figure 10a. Upper Comparison Area, July 8, 1997.

Figure 10b. Lower Comparison Area, July 8, 1997.

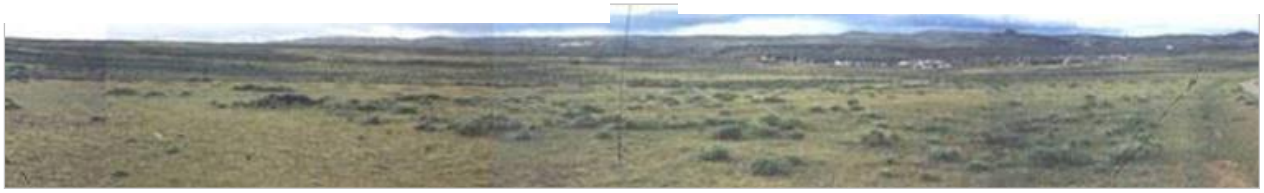

Figure 10c. Off-Site Comparison Area, before fencing, July 17, 1998.

Identification of Disturbed Areas

While several maps of the on-site facilities had been generated, there was no comparable map of the extent of surface disturbance during the gasification activities or during reclamation. In particular, reclamation of areas around wells and the associated access roads generally extended beyond the points and line drawings on the maps, and these areas were very irregular in outline. To help determine the appropriate vegetation sampling methodologies and the areas that needed to be sampled, better delineation of the disturbed areas was necessary. Starting with available maps and photographs of the reclamation (e.g. Figures 5a and 5b), personnel from the LQD and the operator walked the site in 2002 using Global Positioning System equipment to map the disturbance limits as best as possible after several years of regrowth. This map of the disturbed areas (Figure 3) was subsequently used by LQD, the operator, and the contractor selected to evaluate the revegetation success (BKS Environmental Associates, Inc.) to develop a vegetation sampling plan.

Species Expressed

The reported seed mix included Wheatgrass (western, thickspike, and slender), Indian Ricegrass, Fourwing Saltbush, and Big Sagebrush in the following proportions:

Western wheatgrass (*Agropyron smithii*)	4 pounds (lbs)/acre
Thickspike wheatgrass (*Agropyron dasystachyum*)	6 lbs/acre
Slender wheatgrass (*Agropyron trachyconium*)	4 lbs/acre
Indian ricegrass (*Oryzopsis (Stipa) hymenoides*)	3 lbs/acre
Fourwing saltbush (*Atriplex canescena* var. *aptera*)	1 lb/acre
Big sagebrush (*Artemisia tridentata*)	0.05 lb/acre

for a total of 18.05 lbs/acre. In addition, three hundred 6-inch to 8-inch Big Sagebrush seedlings were planted. Subsequent evaluations of the species present at the site, such as the evaluation in Table 1, indicated most of the seeded species were present in the reclamation. However, Fourwing Saltbush was not, although it is not known whether the seeds were inadvertently omitted from the mix or whether the variety seeded could not successfully establish under the site conditions. In addition, although Indian Ricegrass was present in the reclamation, its limited occurrence in comparison with Sheep Fescue (*Festuca ovina*) raises questions about the proportion of Indian Ricegrass in the seed mix and whether Sheep Fescue was present in the mix.

A variety of species also 'invaded' the site, including both beneficial and weedy species, either from introduced materials such as mulch or from the surrounding area. As noted previously, weed control was successfully implemented at the site for Canada Thistle and Whitetop. In the latter years of the reclamation period, concentrations of cheatgrass were noted. While the concentrations were not sufficient to deem the reclamation unsuccessful, the increasing presence of cheatgrass in many areas of the state and its highly invasive nature may increase the difficulty of future reclamation.

Table 1. Field Evaluation of Species Frequency.

FIELD EVALUATION - SPECIES FREQUENCY

Mine/Permit No.: Washington Group International, Inc.(RD 15)

Date: July 8, 2003

Observer(s): Richard Vincent

Page: 1 of 3

Phlox in RD15 reclamation, July 7, 2005.

Species List	Species Occurrence in All Reclamation (1)	Comments
Perennial Grasses and Grass-likes		
Agropyron cristatum (I) (2)	4	Mulch invader.
Agropyron riparium/dasystachyum	4	
Agropyron smithii	4	
Bromus inermis (I)	4	Mulch invader.
Bromus tectorum *(I) (3)	4	Two areas of heavy concentration & then throughout remainder of area.
Elymus cinereus	1	
Elymus junceus (I)	1	
Festuca ovina	3	
Hordeum jubatum	1	
Oryzopsis (Stipa) hymenoides	2	
Phleum pratense (I)	1	Mulch invader.
Poa species (possibly *P. pratensis* (I))	2	Mulch invader.
Sitanion (Elymus) hystrix	1	Native invader.
Stipa comata	1	Native Edge invader.
Carex filifolia	1	Native Edge invader.
Shrubs		
Artemisia tridentata	4	
Chrysothamnus nauseosus	2	
Chrysothamnus viscidiflorus/greenii	1	

FIELD EVALUATION - SPECIES FREQUENCY

Mine/Permit No.: Washington Group International, Inc.(RD 15)

Date: July 8, 2003

Observer(s): Richard Vincent

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Sheep Fescue in RD15 reclamation, July 7, 2005.

Species List	Species Occurrence in All Reclamation (1)	Comments
Sub-Shrubs		
Artemisia frigida	1	Native invader.
Artemisia ludoviciana	1	Native Edge invader.
Artemisia peditifida	2	Native invader.
Ceratoides lanata	1	
Leptodactylon pungens	2	
Xanthocephalum (Gutierrezia) sarothrae (L) (4)	2	Concentrated on NW end.
Native Forb Species		
Antennaria spp.	1	Native invader.
Arenaria hookeri	2	Native Edge invader.
Astragalus spp. (possibly *spatulatus*)	1	Native Edge invader.
Atriplex wolfii	2	Sites with limited perennial vegetation.
Castilleja flava	1	Native invader.
Cryptantha spp.	1	
Heterotheca villosa	1	Native invader.
Linum lewisii	2	
Lupinus spp. (possibly *argenteus*)	2	Concentrated near drainage/road on south side of reclamation.
Machaeranthera (possibly *grindelioides*)	3	
Penstemon humulis	1	Native invader.
Penstemon laricifolius	1	Native Edge invader.
Penstemon spp.	1	Native Edge invader.

FIELD EVALUATION - SPECIES FREQUENCY

Mine/Permit No.: Washington Group International, Inc.(RD 15)

Date: July 8, 2003

Observer(s): Richard Vincent

Page: 3 of 3

Bottlebrush Squirreltail in RD15 reclamation, July 7, 2005.

Species List	Species Occurrence in All Reclamation (1)	Comments
Succulents		
Opuntia polyacantha	1	
Introduced Forb Species		
*Alyssum desetorum**	3	Understory throughout.
Chenopodium spp. #1 (album?) (L)	1	
Chenopodium spp. #2 (rubrum?) (L)	2	
*Chorispora tenella**	2	Two or three small concentrated areas.
*Cirsium arvense**	2-3	Some denser areas, unknown if expanding or similar to previous concentrations observed.
*Descurainia pinnata/richardsonii/sophia**	1	
Erysimum cheiranthoides (L)	1	
*Kochia scoparia**	2	
*Lactuca serriola**	1	One individual.
*Linaria dalmatica**	1	

(1) Species Occurrence: 1=Rare 2=Occasional 3=Frequent 4=Extensive.
(2) An asterisk (*) indicates the species is tentatively classified as a weed by the LQD.
(3) (I) Indicates a species introduced to North America.
(4) (L) Indicates a species that would be less desirable or a weed if it occurred in dense patches, frequently, or extensively.

Issues Primarily at In Situ Sites

A variety of in situ mining activities are being conducted or considered in Wyoming, including coal gasification, uranium extraction, trona dissolution, and oil shale retorting. With respect to coal, there is continued interest in conducting in situ coal gasification experiments, primarily to test the technology in relatively simple geologic settings in hopes of transferring it to more complex settings, such as steeply dipping coal seams. Regardless of the mineral of interest, reclamation of in situ mines raises issues not commonly encountered at conventional surface mines.

Ground Water Contamination at In Situ Gasification and Retorting Sites

Prior to the mid-1980s, the primary contaminants of concern at these sites were generally thought to be phenols and inorganic compounds, such as boron. However, subsequent sampling demonstrated that one of the primary ground water contaminants of concern is benzene. The contaminant transport mechanisms at these sites generally differ from the mechanisms at industrial sites. Therefore, remediation techniques commonly used at industrial sites have not always proven effective at gasification and retorting sites, and some contaminants, such as benzene, have proven more persistent than anticipated.

Simplistically, the magnitude and extent of contamination appear to depend on: the efficiency of the burn: the techniques used to prevent ground water inflow during the gasification or retorting; and the methods used to quench the burn. As with any type of combustion, the combustion products depend on temperature and proportions of fuel and oxygen. In general, the experiments that have had the 'hotter' or more efficient burns have had fewer contamination issues. In addition, those sites at which ground water inflow was controlled by ground water pumping or by pressure just sufficient to counter the hydrostatic pressure had fewer contamination issues than sites with high test pressures because the gases created during the burn were not 'pushed' out into the formation. At the end of an experiment, rapid quenching of the burn followed by venting and flushing of any subsurface cavities created by the burn also seemed to contribute to fewer contamination issues. At the RD15 Site, the gasification experiment was conducted such that the ground water contamination was relatively limited in comparison with other gasification sites in the state. In particular, the efforts to keep the in situ test pressures in line with the surrounding hydrostatic pressure are credited with the relatively limited ground water impacts at this site.

The extent and persistence of the contamination appear to depend on the extent of gas transport away from the burn and the subsequent deposition of 'tars' or similar materials as the gas cools. The gas transport is generally updip and may follow pathways open only when high pressures are applied during an experiment, and the resulting 'tar' deposits provide a long-term contaminant source. Because of the solubility of phenols, the concentrations of these compounds are often dramatically reduced within a relatively short time after an experiment. However, benzene has persisted for decades at some sites. Although biodegradation of the benzene would be expected, it appears that the rate of bioremediation cannot overcome the rate of continued release of benzene into the ground water from the 'tar' deposits. As a result, remediation techniques depending on ground water pumping are generally ineffective, while techniques depending on air sparging and stimulation of bioremediation have proven more effective.

Reclamation & Evaluation of Multiple, Relatively Small Areas of Disturbance

An often-cited advantage of in situ mining is the relatively limited disturbance compared to conventional surface mines. However, the surface disturbance that does occur may complicate efforts to evaluate revegetation success because of the presence of many relatively small areas of disturbance. In general, topsoil is not stripped from wellfields, provided adequate precautions are taken to protect the resource from adverse impacts due to spills of drilling fluids, excessive vehicle compaction, and related concerns. When wellfields are reclaimed, the whole wellfield may be seeded or only portions of it, depending on how well the native vegetation has withstood the mining activities. In addition, there may be numerous roads and pipeline corridors extending between wellfields and the processing facilities. Mapping the extent of the disturbances and reseeding efforts is essential, particularly given the availability of GPS equipment, and development of methods for evaluating revegetation success that take into account the irregularity of the disturbances is also necessary.

Soil Sampling

The ground water treatment system used at the RD15 Site included removal of oils, dissolved metals, dissolved nitrogen, and organic compounds from ground water pumped from the burn cavity and then dispersal and evaporation of the treated water through a spray system. When the WDEQ Water Quality Division approved the ground water treatment system, they did so with the provision that soil sampling would be required in the vicinity of the spray system (Figure 11). The primary concern was the potential accumulation of salts. However, sampling locations were not specified at the time the spray system was in use. Therefore, similar to the mapping of the disturbance at the site, LQD and the operator used available maps and photographs during a field trip 'after-the-fact' to select the required sampling sites.

Figure 11. Spray System for Dispersal and Evaporation of Ground Water after Treatment, September 23, 1988.

The Next Time

The RD15 site was one of the first coal gasification experiments to complete reclamation, and it was one of the first sites evaluated for bond release per the requirements of Category 5 of the LQD Coal Rules. Most of the issues encountered during the evaluation of reclamation success related to the procedures for the evaluation, not the success criteria, and a few issues also related to the relatively unusual activities at the site. Even with a conscientious operator and some continuity in both the regulatory and operator staff, continued review of the proposed evaluation procedures was necessary to ensure that the evaluation procedures originally proposed were complete and still applicable in the 10+ years since the gasification experiments. Despite the challenges and setbacks, the operator persevered and, in addition to gaining valuable information about the in situ gasification process, also successfully restored the site to support the postmine land use, livestock and wildlife grazing (Figures 12a and 12b).

Figure 12a. Caterpillar in reclamation, July 7, 2005.

Figure 12b. Old nest site, July 7, 2005.

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