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RESEARCH

Sustainable and responsible mining through sound mine closure

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Abstract
This paper provides an overview of planning requirements, including regulatory, and implementation approaches for achieving ecologically sound reclamation and restoration of mines upon closure in the USA. Mine closure includes mined-out areas, decommissioning of plants and structures, and appropriate monitoring of post-mining land, water, and air resources. Although the discussion provides general guidelines, each mine closure site presents unique challenges. The overall chemical composition of coal and associated strata with mineable coal seams, structural characteristics of the deposit, weather patterns, environmental conditions, processing and scale of mining of the deposit, and public and private infrastructure must be considered. Future land use and water resource requirements are also important considerations. The planning and closure activities must ensure that the resultant site has the appropriate post-mining land and water resources use, and the site does not pose any future environmental and health and safety risks. These requirements suggest that closure activities should be integrated with the mining activity planning process from the start. This paper discusses mine closure issues and describes several practices for a surface coal mine in the Western USA.

Keywords Mine closure · Ecosystem · Planning · Integrated · Health and Safety

1 Background

1.1 General situation

Mining is an important global industry; the products of mining (minerals including metals) are the foundations of human daily life. World Mining Data (2020) indicates that the industry extracts over 10-billion tons of raw materials with a value of about $ 1.5 trillion or about 2% of the global GDP. The industry should continue to grow consistent with the increased population and the needs of the society.

During end-to-end mining-related unit operations of exploration, minerals extraction, processing of minerals, and getting final products to the market, our land, water, air, and ecosystems are disturbed short-term and can also be negatively impacted long-term unless activities are undertaken to appropriately reclaim and restore disturbed areas. The society permits mining since its significant economic, social, and political impacts advantages outweigh the likely negative impacts. Historically, the mining industry has been conservative to change because of large capital expenditures involved, high risk, and unclear or ambiguous government regulations. However, the industry continues to undergo transformation due to global competition, and environmental regulations that require introduction of cost-cutting strategies, productivity improvement, consistency in product quality, addressing environmental impacts and transparency to all stakeholders. Reclamation and restoration of lands disturbed during the entire life cycle of the mine are critical to global competitiveness and ensuring that mining is sustainable long term. Mine closure may be defined as the "permanent cessation of mining operations and all subsequent activity related to decommissioning and site rehabilitation and monitoring", Mroueh et al. (2008). Through careful planning, it is possible to successfully reclaim and restore the disturbed ecosystems and close a mine with minimal or no long-term impacts.

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1.2 "Reclamation" or "restoration"

Prior to the main contents of the paper, the authors offer this as an item to consider and would welcome feedback from the readers. Many opinions have been written regarding which is the proper term to use, i.e., reclamation, restoration, rehabilitation or some other "R" word. These terms are often loosely used or used interchangeably without a good understanding of their academic meaning. It becomes almost which word is most popular to use in today's culture. Often the term "reclamation" is associated with mining only which has many stereotypic connotations.

The authors have chosen to use the terms "reclamation and restoration". We believe these terms capture the essence of the current state of coal mining in the USA from the initial planning phase to the mine closure phase. The coal industry under the Surface Mine Control and Reclamation Act (SMCRA) of 1977 has incorporated the need for understanding the ecosystem in which its activities occur and ways to minimize those short-term impacts while looking long-term at the sustainability of these lands post-mining. SMCRA allows for flexibility in post-mining land uses and, with that flexibility, industry can work with local and regional governments to ensure an appropriate vision for all stakeholders through education and collaboration.

1.3 Environmental impacts of coal mining

Undeniably, coal has fueled global industrial development over the last 250 years. Its use will continue to be important for several more decades for both existing and developing economies. Life of mine coal operations, including exploration, removal, processing, and shipping, disrupt the existing land, water, and air environments. Historical mining areas that were in existence prior to today's regulations and knowledge, such as abandoned mine lands, may leave society dealing with longer-term negative impacts. These may include disrupted lands that have not been reclaimed, loss of agricultural lands, increased erosional rates on lands, subsiding lands with associated structural damage, hydrological modifications resulting in altered quality and quantity of water resources, long-term geochemical degradation of mining and processing wastes, disturbed environments that impact wildlife, and air and noise pollution. Some of these impacts were recognized as early as in early 1600 s but strong advocacy in support of coal for industrial growth delayed policy shifts on regulating the mining and use of coal to deal with environmental impacts. Over the years as environmental impacts were better understood, federal and state regulations were implemented to control and set standards for dealing with such impacts. The ever-increasing global need for extracted minerals in more difficult environments requires that the extractive mineral industries put significant efforts to make them sustainable long-term from an environmental point of view.

Over the last 20 years or so, the broader term "sustainable mining" (whether coal or other minerals) has evolved. Although several definitions for sustainable mining have been coined, briefly, the goals of sustainable mining in authors' opinion should be to:

(1) Meet current needs for socio-economic development while maintaining stable regional and global environments.
(2) Ensure balanced social and environmental legacy for future generations with the understanding that resource development can have short-term impacts on the ecosystems that could be tolerated without substantial long-term damage. However, the long-term goal should always be minimal environmental impact and restoration of any imbalances, wherever possible. During the mining operations phase, it is impossible to avoid some impact on the mining environment (surface topography, land use, water quality, air quality, etc.).
(3) Through planning and careful reclamation activities, and removal of physical and chemical hazards, a diverse ecosystem and land use can be developed for sustainable use after mining operations cease. This can generally be done at reduced costs, if done concurrently as mining progresses.
(4) Mining operations do benefit socially and economically by providing jobs, and prosperity in proximity to the mining areas and potentially over a much larger area. However, long-term stability and well-being of a community after mining operations cease requires careful planning. Society must assess the net-benefits of mining operations development on community stability and prosperity.
(5) There are strong moral and economic incentives for the mining industry to demonstrate socially and ecologically sustainable practices. Technological solutions are available and additional costs for implementation can be small.

2 Regulatory environment

In the USA, mining on federal lands is regulated and overseen by the National Environmental Policy Act (NEPA). All relevant federal agencies have input into an Environmental Assessments (EA) prior to federal actions with one agency taking the lead. Where impacts are likely to be significant, the lead agency must also prepare an Environmental Impact Statement (EIS) that details characteristics of assessment prior to decision making and considers more than one management option. It is a means for stakeholders to be involved and informed. State laws may also require similar additional assessments prior to issuing mining permits in a parallel process to the EIS. In this permitting process, state and federal agencies also have a voice. Public hearings and feedback and sometimes litigation ensure that all relevant issues are duly considered.

Coal mining on all lands is regulated through the federal Surface Mining Control and Reclamation Act of (1977) (SMCRA) under the direction of the Office of Surface Mining (OSM). SMCRA is a federal law generally meant to provide a balance between resource development and environmental protection. It provides a regulatory framework for individual states to follow. SMCRA requires operators to submit comprehensive mining and reclamation plans, as part of the permitting process, that provide details necessary to describe what the pre-mining environmental conditions and land uses are, how the mining and reclamation operations will meet the SMCRA/State performances standards, and how the land will be used after reclamation has been complete.

Where state regulations mirror SMCRA, it allows individual states to seek primacy in regulating such activity within their own boundaries. While performance-based, it also provides flexibility in adapting to change within the three main coal regions in the USA-Eastern, Midwestern, and Western. These regions have different pre-mining environments and land uses and, thus, post-mining land reclamation and restoration needs. Bonding is required and provides the safety net to achieve reclamation success.

Air emissions from stationary and mobile sources are regulated by the Clean Air Act (CAA). Similarly, pollutant discharges into public waters are regulated by the Clean Water Act (CWA). The CWA is administered by the U.S. Environmental Protection Agency (USEPA), US Army Corps of Engineers, and states with delegated authority. Threatened and endangered species environments are protected by the Endangered Species Act (ESA). States also have wide ranging environment protection regulations within their boundaries that meet or exceed these federal requirements, especially on coal mined lands.

Federal and state laws regulate management of processing wastes (tailings), mining wastes, and closure of mines. The mine reclamation plan, required as part of the mine permit application, must include an appropriate mine closure plan. These laws typically require financial guarantees (bonding) prior to initiation of mine development to ensure appropriate mine closure and reclamation costs.

Mining activities on public lands managed by the U.S. Forest Service (USFS), including national grasslands, are also regulated through earlier mentioned federal regulations. These address erosion, water run-off, toxic materials, surface grading and vegetation, and fish and wildlife habitat.

Mining activities on public lands managed by the Bureau of Land Management or BLM (lands that are typically more rangeland than forested) are also regulated through earlier mentioned federal regulations. Many of the hard-rock sites, however, are under mining laws that date back to the mid to late 1800's. Reclamation and restoration of such lands can mirror requirements in more recent reclamation laws. Clark and Clark (2005) and Garcia (2008) have reviewed international regulatory framework for mine closure. Scannell (2012) has discussed similar information for the European Union.

3 Mine closure

3.1 Overview

During the industrial revolution and post-industrial era, large scale mining of minerals, including coal, evolved primarily through open-pit mining. Underground mining was present, but its impact was not discernable to the degree surface operations were. Such large-scale surface operations can result in disruptions of land, water, and air resources due both to mineral extraction and processing, as well as management of overburden and coal wastes. Such operations require industry and governments (on abandoned sites) to conduct reclamation and restoration projects on a much larger scale so that the mined-out sites could be productive for pre-existing or alternative uses. Mitigation of the impacts of mining through reclamation and restoration activities has been included in governmental actions on mine closure through research and development, policies and regulation, and enforcement.

Mine closure definitions are many and evolutionary. Industry considers mine closure to primarily focus on environmental issues which focus on activities related to “reclamation and restoration” of the impacted area. That should lead to no further environmental damage and the reclaimed site could allow alternative future development and use. Governments, however, take a much broader view in this matter that include not only environmental but also social, economic, and development issues. They have the responsibility to ensure that industry operates in a sustainable manner while the mine is in operation. However, it must also ensure that the mine is closed to the satisfaction of local and regional stakeholders, as well as the government. Thus, a “comprehensive or integrated mine closure” approach (……, 2019) has evolved in most government permitting processes which integrates mine closure as part of the mine operations plan, and "mine closure" begins" the day "mine operations start".

Gankhuyag and Gregoire (2018) have summarized United Nations guidelines for sustainable mine development activities. The Council on Mining and Metals (2019) has developed a sourcebook for integrated mine closure. The next section summarizes objectives and performance criteria for closing mines according to the authors.

3.2 Objectives and performance criteria

3.2.1 General

(1) Reclaim and restore the site environment to a state, resembling as close as possible, to that which existed *prior* to commencement of mining; (2) Secure the land for existing and/or alternative future uses; (3) Ensure that there are no discharges from mining areas; (4) Harmful waste deposits should not remain at the site or impact soil; (5) The site should provide no long-term risk to environment and human health and safety; (6) Reclamation and restoration should be adequate to allow establishment of a diverse and functional ecosystem in the area; and, (7) Landscaping should appropriately blend with that in the adjoining areas.

3.2.2 Requirements for landscaping at reclaimed sites

The reclaimed areas should blend with adjacent topography. Landforms appropriate to adjoining areas and as close as possible to pre-mining landscape should be planned. They should allow for revegetation programs appropriate for future land use planning.

3.2.3 General safety criteria

All structures associated with and remaining at the mine site (infrastructure, waste disposal areas), should be made physically and chemically stable. Any legacy of mining operations that may pose safety risk of any kind (tunnels, slopes, silos, etc.) must be removed or made permanently inaccessible. Safety criteria must include all types of risks (geological, airborne, etc.) to ensure public safety. Risk assessment and management must be an integral part of the mine closure plan. These include assessing and managing risk of landslides and slope failures, and other rare events of earthquakes and floods, removal of sediments and failure of tailings dams.

3.2.4 Surface and groundwater quality

Water quality and quantity can be negatively impacted from processing waste and mining waste deposition areas that may contain sulfur compounds and heavy metals, chemicals, etc. In achieving chemical stability, highest priority should be given to "contain" or if possible, to remove the contamination source.

Where discharge from sulfide containing ores and minerals is a problem, reclamation and restoration can be more problematic. Channeling the water into ponds for treatment may be a better solution. Mine reclamation and restoration and mine closure activities must ensure that water resources and its quality will not be impacted long-term.

Assessment and monitoring of water quality must be based on the quality of water entering the site (baseline water quality). The considered parameters may include pH, trace elements, solids concentration, and other appropriate testing required by regulatory agencies.

3.2.5 Achieving functional ecological environment

Reclamation and restoration should be appropriate to allow establishment of a diverse ecosystem in the area. It requires a good knowledge of physical and chemical characteristics of the soil and unconsolidated overburden, availability and quality of surface and ground water, and efficiency of water supply and drainage system. Mine operations permitting requires good pre-mining investigations of such resources and potential impacts of mining per SMCRA and state regulations.

3.2.6 Efficient approach to mine closure

Successful mine closure can be achieved more economically if mine closure is planned and implemented as part of mining operations from the day the mine opens and closure activities are done concurrently with mining, i.e., Integrated Mine Operations. The goal should be to end and decommission mining operations responsibly while working cooperatively with local communities for viable, long-term post-closure land uses.

3.2.7 Social and economic objectives of mine closure

These are difficult to define since there are no binding regulations covering obligations to society in a post-mining setting. There are only general references to socio-economic implications of mine closure and ongoing business and commerce in the area. Mining provides considerable socio-economic benefits to surrounding communities. Strategies to maintain stability of benefits should be developed with community leaders and community organizations.

3.2.8 Criteria for contribution of mine closure to regional sustainability

Economic indicators, cultural heritage, environmental values, and closure are good guidelines for planning and implementing closure activities.

3.2.9 Individual and community welfare

Stakeholder involvement is critical to developing and closing a mining enterprise during its entire life. Effective channels for ongoing communications are necessary and should be considered both at the individual mine level and for the region. Authors suggest that a regional advisory group "could be" considered in providing the interface between the mining administration and the regional stakeholders.

4 Summary

Appropriate mine closure planning delineates all activities throughout the life of the mine that would lead to successful mine closure and is performance based on criteria discussed above. The planning may identify research needs for waste management and post-management monitoring to ensure the success of management techniques developed. As the time approaches near for mine closure, plans for decommissioning and closure for infrastructure (removal of equipment, closure of haul roads, access openings to the mine, tunnels, facilities, etc.) must be implemented. Where acid mine drainage is anticipated, its mitigation, maintenance and monitoring must also be implemented.

The goal of mine closure planning is to return the mined-out area to a state that is close to a pre-mining state as possible or better in cooperation with all stakeholders for the benefit of the community. Therefore, the "Mine should begin to close the day it opens". Proper mine planning can and does influence the closure plan, cost of closure and its performance.

Some of these concepts outlined earlier are illustrated in the following case study of a surface coal mine in the western USA.

5 Mine closure case study of Dave Johnston mine of Glenrock coal company

5.1 History of mining at the Dave Johnston mine

Coal mining in the area began near Glenrock, Wyoming in 1847. Historical records show the majority of the coal

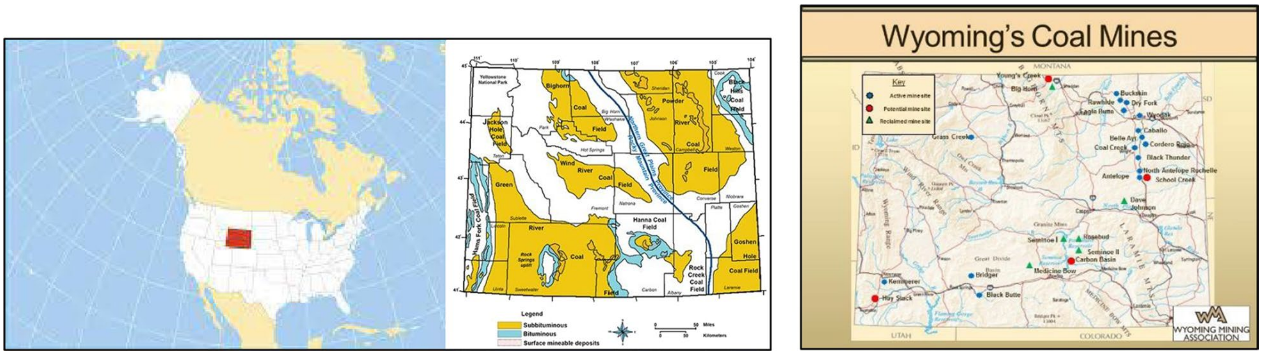

Fig. 1 Case study mine location

Fig. 2 Power plant and coal transport from the mine

produced in the late 1800's was marketed to states of the Dakotas and Nebraska in the USA. The case study mine began operations in 1958 and it was located at the southern end of the Powder River Basin (PRB) coal fields (Fig. 1). When the nearby Dave Johnston Power Plant was built in 1959, the mine marketed the coal to run that plant (Fig. 2). In 1998, the owner of the mine, PacifiCorp, announced closure and initiated final reclamation and restoration operations. By 2005 these operations were completed, and all mining disturbed lands 1940 ha (4798 acres) were restored back to their prior land uses of domestic livestock grazing and wildlife habitat.

The case study includes both pre-SMCRA and post-SMCRA reclamation. SMCRA has allowed the orderly reclamation and restoration of this surface coal mine through Wyoming Department of Environmental Quality, and Land Quality Division (http://deq.wyoming.gov/lqd/resources/rules-and-regulations/) adding another land use to the existing landscape by installing wind turbines that complements the pre-mining domestic livestock grazing and wildlife habitat. The case study also includes reference to Montana State University efforts to analyze and control early Acid Mine Drainage (AMD) issues at the mine. Some creative efforts to provide sources of water for wildlife habitat are also noteworthy.

5.2 Pre-mining environmental setting of the mine

The Dave Johnston Coal Mine permit area contains 5490 ha (13,588 acres) and is located 22 km (14 miles) north of Glenrock, Wyoming on the southwestern edge of the Powder River Basin Coal Field. Surface topography in the area is characterized by low rolling hills and sandstone capped buttes. Soils range from sand to sandy loam with finer soil textures common in the drainage area alluvial deposits. Surface elevations range from 1645 to 1768 m (5400–5800 feet).

The climate around the area can be characterized as a semi-arid interior continental climate with local variations due to surface topography. Typically, this climate zone yields cold dry winters and hot summers with temperatures ranging from − 34 to 35 °C (− 30.0 to 98.0 °F). Winds blow constantly at about 23.5 km/hour (14.7 miles/hr.). Annual precipitation averages of 26.5 cm/year (10.4 in./year). Seventy percent (70%) of this precipitation falls during April through September, with the maximum falling in May.

No perennial streams flow within the mine permit area. The area is drained entirely by ephemeral watersheds. Flows from these watersheds are very sporadic with most stream flow occurring during the months of March through September as a result of snowmelt runoff or infrequent intense thunderstorms. However, it is not uncommon for these watersheds to experience no flow during one or more consecutive years. The only pre-mining aquatic habitat found in the mine permit area are small stock ponds (constructed earthen dams) that get filled during the spring/summer rain events.

Fig. 3 Pre-disturbance native Shrubland community

Fig. 4 Aerial view of the mine in 1958

Baseline hydrology data also indicate that there were no surface springs or wetlands within the mine permit area. Overburden drilling concluded that the coal seams contained no water. Similarly, the strata above, between and immediately below the coal seams (from the surface to about 60 m (200 feet) depth also display minimal subsurface water. Mine- facilities water is obtained from two wells more than 400 m (1200 feet) deep. While lack of water provided little or no need for mine seam dewatering, it also presented challenges to reclamation and restoration.

Pre-mining vegetation around the area is typical of the Northern Great Plains ecosystem complex. Big sagebrush (*Artemisia tridentata* spp. wyomingensis), western wheatgrass (*Elymus smithii*), thickspike wheatgrass (*Elymus lanceolatum*), needle-and-thread (*Hesperostipa comata*), green needlegrass (*Nasselia viridula*), blue grama (*Bouteloua gracilis*), prairie junegrass (*Koeleria macrantha*) and western yarrow (*Achillea millefolium*) are common plant species associated with the sagebrush shrubland and

Fig. 5 Aerial view of the mine in 1975

Fig. 6 Pre-SMCRA reclaimed land

grassland community mosaics (Fig. 3) according to Dorn (2001).

Mining operations began in 1958. Aerial views of the mine in 1958 and 1975 are shown in Figs. 4 and 5. In October 2000, the last coal was shipped from the mine. Over 100 million metric tonnes of coal were mined over 40 years and disturbed 1940 ha (4798 acres) of short-grass prairie ecosystem.

5.3 Land reclamation

The reclamation began in 1965 (pre-SMCRA). Reclamation and ecological restoration had not been planned and were not done concurrent with mining operations. The reclamation activities generally consisted of backfilling pit areas, reestablishing drainage and vegetation with a basic seed mix to stabilize the reclaimed areas, as well as to promote the land use primarily for livestock grazing.

Much of the above reclamation and restoration 675 ha (1665 acres) was completed by 2005. SMCRA rules and regulations had taken effect, and there was some reclamation that occurred during previous mining operations. Figures 6 and 7 depict these Pre- and Post-SMCRA mining and reclamation activities.

Fig. 7 Post-SMCRA reclaimed land

Fig. 8 Reestablished grassland community (2005–2007)

Historical acid mining drainage problems in the southern Powder River Basin were observed in the early reclamation under SMCRA at the mine in the 1980’s. Acid producing geologic material, present in the 6 m (20-foot) clay layer above the mined “School” seam produced an acid-forming backfill if it was deposited too close to the surface. Pyritic materials present in the clay layer upon oxidation produced water pH of 3.2 resulting in Acid- Base accounting potential from − 620 to 805 t of lime per ha. Initial bare spots of dead or dying vegetation would grow on the backfill over a relatively short period of time.

Montana State University researchers estimated the amount of lime requirements needed to neutralize this material. They performed laboratory experiments to simulate several wet-dry cycles. They recommended about 12.5 tons/ha of lime for long-term control of AMD. The use of local sugar beet waste as a barrier of about 0.7 m between the underlying acidic backfill and the overlying 0.75 m of suitable plant growth material (including topsoil) was used to alleviate the surface acidification problems. Research was continued on this potential long-term acid mine drainage

Fig. 9 Reestablished Shrubland community (2005–2007)

Fig. 10 Landscape mosaic of multiple communities

problem over a 20 year period to ensure that acidification problems will not occur.

The remaining 1265 ha (3133 acres) were reclaimed from November 2000 through November 2005. Under the SMCRA approved permit, land uses included wildlife habitat, as well as domestic livestock grazing. Seed mixes were much more diverse, as wildlife habitat required that shrubs, including native big sagebrush, were planted. Figures 8, 9 and 10 taken between 2005 and 2007 show the reclaimed plant communities. Such diverse plant communities allow greater sage grouse (*Centrocercus urophasianus*) and other sagebrush-dependent wildlife species to survive and thrive. Species such as mule deer (*Odocoileus hemionus*) and pronghorn (*Antilocapra americana*) depend heavily on these restored big sagebrush plant communities for their habitat (Figs. 11 and 12).

Fig. 11 Strutting activity of the greater sage grouse males (2005–2007)

Fig. 12 Mule deer and pronghorn on reclaimed lands (2005–2007)

The Powder River Basin (PRB) is a transition area between the prairie region to the east and to the north with the Sagebrush Steppe region to the west and south. This is particularly true for the Dave Johnston Coal Mine. Sometimes you see re-established grassland communities, and sometimes you see shrublands. It can be difficult to re-establish the shrub component of the pre-mining environment. Under SMCRA rules and regulations, innovations since 1977 have allowed use of different approaches as well as new technologies, including use of innovative seeding equipment.

5.4 Hydrological restoration activities

As described earlier, the case study mine pre-mining water resources were scarce, seasonal, and dependent on spring snow melts and fluctuating, often intense, precipitation events. Therefore, creativity was required to provide much needed surface water in reclaimed areas to enhance wildlife habitat. Weeps or “seeps” that were present naturally were a result of a “perched water zone” within a clay layer between the coal seam and overlying sandstone. This source of moisture never produced flow but did represent potential for collection or catchment over a relatively large area

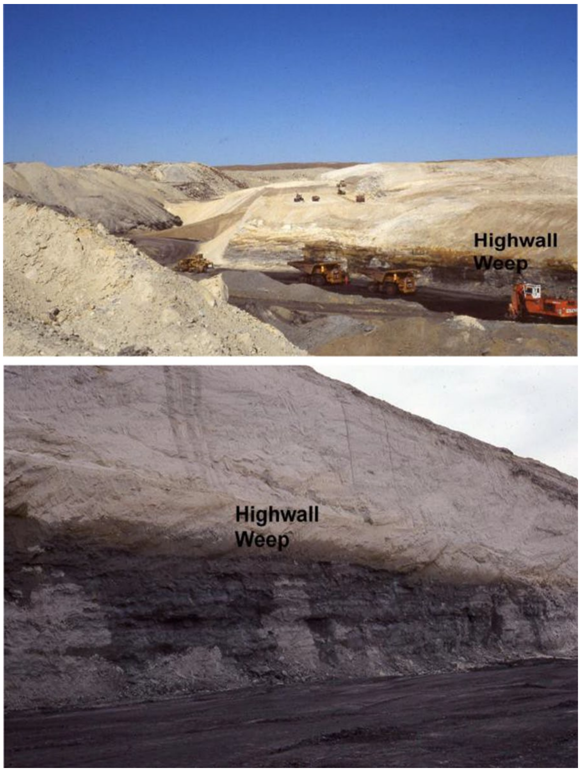

Fig. 13 Development of highwall weeps or “seeps”

Fig. 14 Discharge and vegetation on reclaimed area (May 2002)

Fig. 15 Surface boulders and discharge containment area (2010)

Fig. 16 A reclaimed site with hydrological restoration (June 2011)

that would feed specific locations around the surface. With the mine closure and existing highwalls prior to backfilling, small weeps or “seeps” were identified (Fig. 13). Six of these areas were developed into man-made springs between 2001 and 2004.

Man-made springs were developed using four different approaches depending on differing sub-surface water collection and conveying strategies to move the collected seepage to the reclaimed surface areas. These were: (1) Catchment basins underlain with clay with deeply buried perforated pipe (protected by ballast) to outlets with truck tires cut in half; (2) Large rock underlain with clay at the toe of reclaimed highwalls to outlets with truck tires cut in half; (3) Pond liners instead of clay with perforated pipe with ballast and straw on top to outlets with truck tires cut in half; and (4) Perforated pipe in 1 m diameter (36 inch) culverts overtopped by ballast to outlets with truck tires cut in half.

The above strategies included varying use of plastic liners, perforated 15 cm (6 inch) diameter polypropylene pipe, culverts and large rock. Much of the overburden material remaining from the mining operation was available and useable for the purpose. In addition, leftover railroad ballast was also used. All outlets were fenced to exclude domestic livestock grazing while allowing wildlife access. The volume of water produced at each spring was relatively low but sufficient for wildlife and hydrophytic plant development. These were still producing water in 2018 (Figs. 14, 15, 16, 17 and 18).

Development of such springs was critical to provide enhanced wildlife habitat in a normally dry portion of the PRB where little or no dependable sources of surface water were present. Geologically, this portion of the PRB is up dip and the general recharge is to the north. In addition, as part of the uranium roll front, the area is generally sandy which

Fig. 17 Greater sage grouse (2007)

Fig. 18 Mule deer on a reclaimed site (2007)

Fig. 19 Wind turbines on reclaimed lands

allows for percolation through near-surface layers, including topsoil and subsoil.

SMCRA has also allowed reasonably alternative land uses, based on a variety of factors, one of which is a beneficial use to the USA Society. Once reclamation performance bonds were released by the State of Wyoming, the owner/operator chose to install wind turbines on reclaimed lands. About 158 wind turbines within the footprint of the original mining permit area were installed by PacifiCorp in 2008–2009. Forty-five (45) of these turbines are located on reclaimed mined lands. The 1.5 MW turbines capable of generating total of 237 MW of power are on the original mining permit area (Fig. 19).

6 Concluding remarks

This paper has presented several of the general concepts of mine closure in coal mine settings with reinforcement of concepts at a mine in the Powder River Basin in Wyoming, USA. The case study included pre-SMCRA and post-SMCRA disturbed lands. The cooperative efforts between the regional academic institutions, the regulatory agencies, and the coal company to solve long-term AMD problems, creations of water resources for wildlife, and the flexibility offered by SMCRA in planning post-mining land use for renewable energy installations are worthy of note.

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