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Evaluating Alternate Post-Mining Land-Uses: A Review

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Abstract

The ultimate objective of post-mine land-use and reclamation planning is to identify appropriate alternate land uses to which mined land could be put. This will ensure that land-use and morphology of the location will be capable of supporting either the prior land-use or pre-mining environment. The main challenge is usually, the choice of variables that must be considered in deciding a particular post-mining land-use. Literature reviews were conducted to identify the major factors needed to be considered in the selection of a post-mining land-use. This paper also looks at the most commonly practiced and accepted post-mining land-use techniques. Factors identified as important in the selection process include land resources (e.g. physical, biological and cultural characteristics), ownership, type of mining activity, legal requirements, location, needs of the community, economic, environmental, technical and social factors. In a broad categorization, all post-mining land-uses could be placed under one of the following land-use: agriculture, forestry, lake or pool, intensive recreational land-use, non-intensive recreational land-use, conservation and pit backfilling. However, the objective of any particular post-mining land use should be achieving economic and sustainable outcomes which meet human wants and needs, and protect life and the environment.

Keywords: post-mine land-uses, reclamation, sustainability, environment, mining, livelihood

1. Introduction

The lifespan of a mine depends on the economic viability and availability of extractable resources. In other words, mining is a temporary land-use activity. That is, the mineral deposit is limited and ultimately gets depleted (Cooke & Johnson, 2002). It is established that mining activities are increasing and their impacts are more severe than other types of disturbances (Walker & Willing, 1999). Waste disposal activities in mining result in an extensive and long-lasting land disturbance (Cooke & Johnson, 2002). Society however, requires the environmental impacts of mining to be temporary (Maczkowiack, Smith, Slaughter, Mulligan, & Cameron, 2012).

The concept of mine sustainability in general mandates attaining an acceptable land-use (Bowman & Baker, 1998; Cao, 2007; Maczkowiack, et al., 2012; Ross & Simcock, 1997). Laws and regulations by Federal, State and Local governments (all over the world) requiring mining companies to ensure safe environment and reclaiming mined lands to an acceptable state reflects the concern of the society for the environment (Maczkowiack, et al., 2012). It is required that reclamation will be considered and integrated into the mine planning so as to make it a key ruling factor in the mining operations, waste disposal, and site closure (Johnson, Cooke, & Stevenson, 1994). Nevertheless, some reclamation practices have been poor, such that they do not provide any successful ecosystem development, and at worse, has caused continual environmental damage (Berger, 1990). The reclaimed land surface remains indefinitely and is required to meet the key goal of sustainability, which is the maintenance of the land use alternatives for future generations (Haigh, 1993).

Mining activities over the years have had massive positive impact on world civilization. These benefits however, are sometimes overshadowed by the considerable negative impacts on the environment, health and safety of mine workers and mining communities (Cao, 2007). Blinker (1999) reports that the continual increase in society's awareness of the cost and the challenge of sustainable development has heightened the expectation on the mining industry to uphold best practices of environmental, safety and community management through advanced technologies and management tools available. Indeed, while the activities of mining have historically affected the surrounding environments, technological advancement and changes in management techniques over the years indicate that many negative impacts are now avoidable. Increasingly, mining companies are making efforts to reduce the environmental impacts of mining, and to minimize the footprint of their activities throughout the mining cycle, including working to restore post-mining ecosystems. And as Maczkowiack, et al., (2012) put it, the big question of sustainability relates to the environmental legacy of the mining activity: "Is our mined land able to support its prior land-use, and if not, what are the alternatives?" As cited by Cooke & Johnson (2002), the decision regarding what to restore the mined land continues to change.

Weber-Fahr, Andrews, Maraboli, & Strongman (2002) in a World Bank Global Mining report observed that governments of both developed and developing countries over the years have been working to provide clear, stable and transparent legislations for environmental management with emphasis on monitoring and enforcement systems to seek increased foreign investment. The choice of post-mining land-use is driven firstly by government legislation (Maczkowiack, et al., 2012). The various legislations generally demand that land affected by mining activities be restored to a state where the adverse environmental, social and economic impacts are minimized so as to sustain the pre-agreed end use beneficial to the society. However, it is important to note that the adherence to these legislations and their enforcement is likely to be different for developed and developing countries. For instance, the Surface Mining Control and Reclamation Act (SMCRA) in the United States of America requires mining operators to restore the mined land to a condition capable of supporting the uses it could support prior to mining, or to higher or better uses. The SMCRA is the main Federal regulation for active surface coal mines and surface effects of the underground coal mines. Under the law, the operator is required to: restore the approximate original contour of the land; avoid acid mine drainage and prevent erosion to minimize impacts to nearby waters; reclaim the land in a timely manner; and establish appropriate vegetation that will cover the previously disturbed area. SMCRA provides the public with the right to file written objections to any permit application, and to request the right to a public hearing or a mine inspection. The Office of Surface Mining, Reclamation and Enforcement (OSMRE) of the Department of the Interior is responsible for the implementation of the Act. The situation is not different in other developed countries such as Australia, Canada, and Germany among others. In Queensland, Australia, the Environmental Protection Act (1994) mandates that post-mining rehabilitation (reclamation) should be able to sustain an agreed land-use (Environmental Protection Agency, 2008). In South Africa the Mineral and Petroleum Resources Development Act 28, of 2002 requires that any prospecting or mining operation must be conducted in accordance with generally accepted principles of sustainable development by integrating social, economic and environmental factors into the planning and implementation of prospecting and mining projects in order to ensure that exploitation of mineral resources serves present and future generations. Under the Act, environmental liability, pollution or ecological degradation, and management are the responsibilities of the holder of a prospecting right, mining right, retention permit or mining permit until the Minister has issued a closure certificate to the holder concerned (Parliament, Republic South of Africa, 2002).

One can therefore conclude that irrespective of a country's status in terms of development, environmental issues in relation to activities such as mining are paramount. The observations from literature also indicate that the main objective of Local, State and Federal governments, international organizations, the mining industry and the society as a whole is to ensure that lands used for mining become beneficial to the affected communities after mining. Thus, the benefits must be measurable in terms of the economic impacts, social justice and positive environmental impacts.

In order to meet the tough environmental requirements in the modern day mining environment, mine planners must do a careful evaluation to determine the key parameters required to successfully plan mine operations that will satisfy all interested parties. For instance, the benefit of mined land rehabilitation (reclamation) planning includes identifying attainable condition describing post disturbance landscapes and a careful outline of the range of ecosystems that may be established under these conditions, instead of perfect or hopeful target. In fact, investigating conditions of post-mining landscape allow a more thoughtful method to determining what range of outcomes is possible on a mine site rather than what is desired of it (Audet & Doley, 2015). Temeng & Abew (2009) discovered that post-mine land-use projects are not usually successful due to lack of due diligence in assessing the markets, communities' livelihood systems, experiences and knowledge base, and absence of community participation. Eventually, mine planners should evaluate and select a post-mining land-use consistent with ownership, local needs and legal requirements (Awuah-Offei, 2015).

This paper reviews relevant literature to identify:

- The major factors affecting post-mining land-use selection and mine land reclamation;

- Some major post-mining land-uses; and
- Provides a case study that illustrates some success.

2 Sustainable Post-mining Land-use Practices

This section presents a literature review of sustainable post-mining reclamation and land-use. It also highlights and discusses important considerations for post-mining reclamation and provides a case study of a successful reclamation project conducted in the USA.

2.1 Major Post-Mining Land-uses

Mining companies in their efforts to attain sustainability must pursue policies and programs that improve the socio-economic growth and development of the communities in which they operate, and also ensure improved environmental protection and pollution controls (Hilson & Murck, 2000). As noted by Cao (2007), disturbed lands resulting from mining activities still have some potential for economic, recreational and aesthetic use. Indeed, properly reclaimed mined lands have found many uses, and are well reported in literature.

Some major uses of reclaimed mine lands include:

- Pasture, hayland, recreational areas, wildlife habitat, wetlands, fish ponds/farm, bricks and blocks making and swimming pools (Cao, 2007; Alexander, 1996);
- Agriculture and forestry as dominant post-mining land-uses (Miao & Marrs, 2000);
- Aquaculture as reported by Miller (2008) for West Virginia.

From Miller (2008), benefits such as financial savings in site reclamation, increased positive media attention and new biosecure water sources for commercial aquaculture operations in the region were some of the major benefits highlighted by the study. Indeed, different post-mining land-uses have been chosen and practiced in many mines around the world. For example, Errington (2001) indicated that 53% of the post-mining land-uses in British Columbia were to be used for wildlife habitats, 22% for forestry, 9% for pasture and the remaining 16% were to be used for other land-use purposes. Due to the special characteristics of natural stone quarries (which include physically stable quarry faces and benches created by quarrying, a water pond at the bottom of the quarry, and piles of leftover stone material), post mining uses such as scuba diving, climbing, forestry, fish or crab farming, rock building, storing and amusement parks have also been recommended as appropriate alternate land-uses (Lintukangas, Suihkonen, Salomaki, & Selonen, 2012). The study again identified culture, learning, and research purposes as other uses to which post mined quarries could be put.

Some other researchers (Narrei & Osanloo, 2011; Soltanmohammadi, Osanloo, & Bazzazi, 2010; Bangian, Ataei, Sayadi, & Gholinejad, 2012; Masoumi & Rashidinejad, 2011) have provided a framework of classification which groups all feasible post-mining land-uses that literature has addressed under an eight-group orderly form, containing 21 or more individual land-uses. The eight groups (Table 1) as reported by these researchers are: agriculture land-use; forestry land-use; lake or pool land-use; intensive recreational land-use; non-intensive recreational land-use; construction land-use; conservation and pit backfilling. It is therefore obvious that there are countless alternatives available for post-mining land-uses. However, the decision leading to the choice of any particular alternative must be carefully evaluated based on sound engineering, economic, environmental and social analysis leading to the betterment of the community and the environment. The fulfillment of these factors is essential for sustainable development of mining and the society as a whole.

2.2 Factors Affecting Post-Mining Land-use Selection and Mine Land Reclamation

The ultimate objective of post-mine land-use and reclamation planning is to identify appropriate alternate land-uses, and to ensure that land-use and morphology of the location are capable of supporting either the current land-use or the pre-mining environment. The important stages in restoration (reclamation) planning as cited by Cooke & Johnson (2002) include: (i) restoration goal (possible and sustainable, meeting local needs at reasonable cost); (ii) restoration objectives (ecosystem attributes priorities); and (iii) measurable success criteria (what criteria over what time scale). It can therefore be stated that in practice, site restoration requires that factors such as speed of attainment, economics, achievability, and long-term stability with on-going management at low cost are considered (Bradshaw, 1990). According to Bangian, et al. (2012), the most appropriate alternative of post-mining land-use for each section of mined land is presented as the optimum post-mining land-use. Doley et al. (2012) suggested four useful steps for the planning stage of a proposed mining or industrial development to reduce the level of disturbance and possibly increase the land use value among post-industrial ecosystems. They include: (i) identification of landscape and soil characteristics that would be required to re-establish the original native or commercial ecosystem; (ii) assessment of the resource inputs required to achieve a sustainable ‘original’ ecosystem or an alternative suitable ecosystem; (iii) estimation of the resource gap between original and alternative ecosystems; and (iv) modification of the nature or degree of disturbance impact in relation to the target ecosystem to attain a sustainable final outcome.

However, the ability to select the most optimum post-mine land-use and the reclamation method is multi-dimensional in nature and has several influencing factors. Land-use planning is considered a duty of governmental agencies concerned with guiding growth and preventing conflicts. Due to more stringent environmental controls in recent times however, mine planners have had to spend a great deal of time in assessing and developing appropriate post-mining land-use alternatives acceptable to the communities in their operational areas (Sweigard & Ramani 1984). Post-mining land-use is the most fundamental parameter that establishes the costs of closure and reclamation activities of a given mine site (Bangian, et al. 2012). Soltanmohammadi, et al. (2010) and Morrey (1999) on the other hand noted that since it is the choice of post-mine land-use that informs the methods, measures, and the cost of mine reclamation, a major implicit objective of mine reclamation is to carefully evaluate and determine end use options. There is the need for industry, regulators, and the general public to recognize the basic nature of the science of restoration ecology and what it can and cannot achieve (Cooke & Johnson, 2002). It is believed that resilience, which is defined as the ability of an ecosystem to recover from disturbance, is an essential concept in restoration (reclamation) (Hobbs, 1999; Walker, 1999). In other words, it is likely that ecosystems with low resilience cannot be restored structurally and functionally after mining, even with costly restoration approaches. According to Green (2001), sustainability depends on the structure, composition, and function of the ecosystem operating within the bounds of natural or historic range of variations and economic developments. Preserving ecological integrity and economic developments are essential for ensuring equity between present and future generations. Again, identifying the best options in the presence of many alternatives is the key to successful post-mining reclamation and land-use. Audet & Doley (2015) argue that the requirements for veritable restoration as compared to alternative ecosystem should be refined so as to avoid costly and undesirable outcome. This definition will help establish clearer specifications for the design, construction, and operation of mine sites and probably more total efficiency for the mining industry.

According to Sweigard & Ramani (1984), factors such as the geomorphic, climatic, hydrologic, stratigraphic, and soil characteristics of a site which are classified as natural land-use factors, and factors such as geographic, demographic, and economic characteristics that are the results of human activities and classified as cultural factors, are key factors required to determine the appropriate post-mine land-use. It is indicated that natural factors are considered the most significant in the determination of the appropriateness of a location or site for any particular usage, while the practicality of the usage is determined by the cultural factors. Though, both factors are considered important, it is observed that cultural factors are the fundamental factors upon which final decisions are made after discarding unsuitable uses informed by a review of the natural factors. Again, land resources, ownership, type of mining activity and legal requirements (e.g. zoning laws) have also been identified as key factors that affect the selection of post-mining land-use (Awuah-Offei, 2015). After a review of available literature, Masoumi (2014) provided four main groups of factors with attributes and sub-attributes to be considered in the post-mining land-use selection: Economic, environmental, technical and social factors were the broad titles used in the categorization. The economic factors were identified as the most critical factors in the planning of the post-mine land-use process. The economic factors form the basis for any decision making after one has reviewed all alternatives from the economic point. Also, Narrei & Osanloo (2011) provided eight groupings of possible alternative post-mining land-uses and stated that the groupings were made after analyzing them based on economic, social, technical and mine site factors. The eight groupings according to Narrei & Osanloo (2011) are shown in Table 1. Zavadskas & Antuchevicience (2006) in a study on the development of derelict buildings and abandoned sites emphasized the importance of the environmental, social and economic aspects in deciding land-uses after they have been used for activities other than their original use. Though the level of importance of each of these factors varies, they must all be carefully evaluated in order to achieve a sustainable post-mine land-use acceptable to all parties affected by the mining activity.

From the reviewed literature, it is obvious that one must consider an array of factors in planning the choice of a post-mine land-use and reclamation. However, the literature on the subject directly or indirectly highlights the importance of evaluating each of these factors based on sound analysis influenced by location, needs of the community and the financial implications of the choices.

Table 1. Possible alternative for post-mining land-uses (After Narrei & Osanloo (2011))

No	Land-use Types	Exercised Post-mining Land Uses
1	Agriculture	Arable farmland, garden, pasture or hay-land, nursery.
2	Forestry	Lumber production, woodland, shrubs and native forestation.
3	Lake or Pool	Aquaculture, sailing, swimming, water supply.
4	Intensive Recreation	Sport field, sailing, swimming, fishing pond, hunting.
5	Non-intensive Recreation	Park and open green space, museum or exhibition of mining innovations.
6	Construction	Residential, commercial (e.g. shopping center), industrial (e.g. factory), educational (e.g. university), sustainable community.
7	Conservation	Wildlife habitat, water supply (surface and groundwater).
8	Pit Backfilling	Possibility of landfill (as last resort).

2.3 A Case Study of a Successful Post-Mine Land-Use

A successful reclamation exercise that is well documented is the National Reclamation Award winning Peanut Mine reclamation at Gunnison County in Colorado. Innovative partnerships and technical reclamation methods were adopted for environmental restoration of the 16 acre Peanut Mine. The mine is located about one mile north of Crested Butte in Gunnison County, Colorado and it is approximately 9,000 feet above sea level. It receives about 56 inches of moisture annually, with primarily mountain big sagebrush shrub grasslands with interspersed trees as vegetation cover adjacent to the mine. It was an active coal mine in the late 1800's and early 1900's. The abandoned coal mine contained coal refuse and silver mill wastes. While the coal refuse had a propensity of spontaneously undergoing combustion, the silver mill wastes generated acid and thereby contaminating water with metals. Figure 1 shows the location of the Peanut Mine.

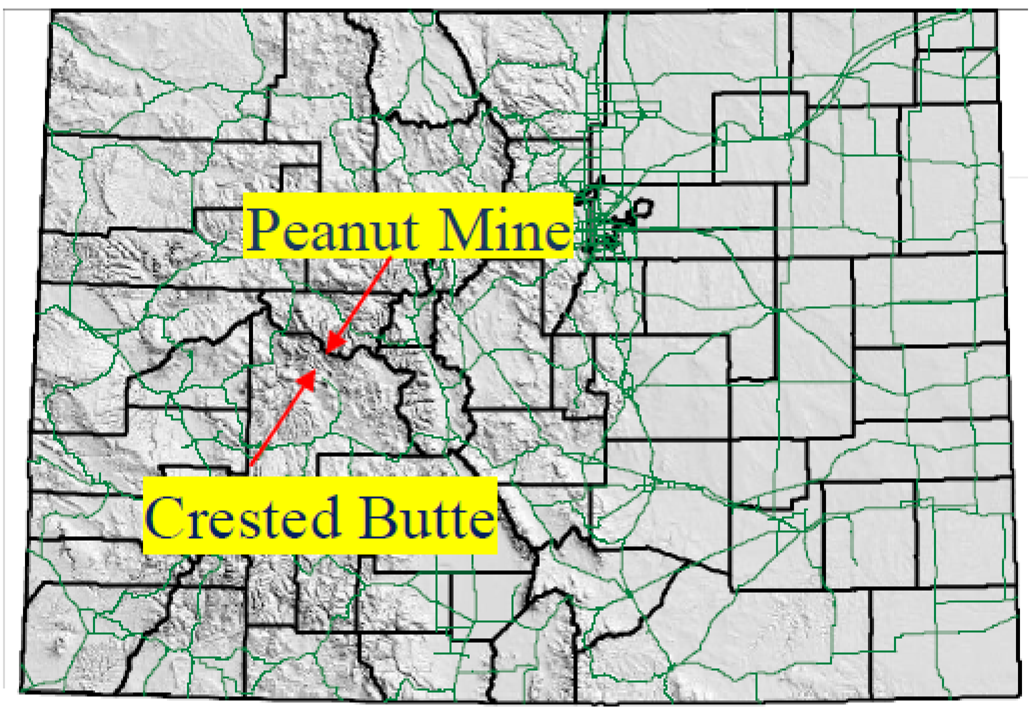

Figure 1. Location of Peanut Mine (Renner, 2011)

The Colorado Inactive Mine Reclamation Program (CIMRP) conducted investigations and characterized the abandoned coal mine site. The characterization provided the basis for a reclamation plan which addressed the coal and non-coal problems at the mine. The CIMRP involved the community in all steps of the reclamation planning and construction processes. The federal, state and local governments were also involved in all the stages of the reclamation planning and construction processes to avoid conflicts and encourage project acceptability. The success of this project can be attributed to the fact that the concepts of ownership, regulations, and community participation as reported in literature were utilized. Figure 2 shows pre-reclamation state of the site.

Figure 2. Pre-reclamation state of the site (OSMRE, 2014)

The reclamation process comprised the excavation of the coal and silver mill waste, mixing them in a specific ratio, and placing them in a disposal facility (OSMRE, 2014). Geochemical testing outcomes indicated that coal buffers the acid production potential of the silver mill waste. Also, mixing of materials caused the dilution of the coal such that the potential for spontaneous combustion was minimized.

The reclamation process is described by Renner (2011). The reclamation concept for the site included the following concepts (Renner, 2011):

- Excavation of coal refuse until natural ground was encountered;
- Excavation of 2 feet of native ground surface below the mill tailings;
- Construction of channels to accommodate mine adit drainage, snowmelt and stormwater runoff;
- Use of plant materials to aid in channel stabilization and runoff velocity control;
- Establishment or re-establishment of wetland areas;
- Distribution of imported fill at a nominal twelve-inch depth across the site;
- Incorporation of organic material into fill material prior to revegetation;
- Establishment of shrub islands in small but distinct areas across the site;
- Hand distribution of grass and forb seed outside the shrub islands;
- Planting cluster of seedling trees around the site after all other reclamation activities are completed.

Construction activities were conducted such that the ground surface was geomorphically compatible with the surrounding topography. Dirt was mixed with organic matter and spread over the contoured site. Vegetation including grasses, shrub islands, and tree plantings was introduced. It is also noted that 4,500 trees were planted on the site at the end of the reclamation exercise.

It is observed that the primary objectives of the reclamation at the Peanut Mine of isolating acid producing silver mill wastes from the environment to prevent acidic drainage, and eliminating the potential spontaneous combustion of coal were successfully achieved. Other goals that were achieved included reclaiming an unused, plagued land into a useful public open space; elimination of sediment transport from the site; creation of aesthetically acceptable and stable landform among others (Renner, 2011). Figure 3 is a post-reclamation view of the site. Other successfully reclaimed mined lands around the world are described by Krutka & Jingfeng (2013).

Figure 3. Post-reclamation view of the site (OSMRE, 2014)

3 Conclusions

Mine operation in any society is time bound, hence requiring that post-mining activities meeting the needs of the society as well as the environment are clearly identified and properly planned before mining begins. A number of literatures on the subject of post-mining land-use have been reviewed with the objective of identifying factors that affect the selection of post-mining land-use as well as the major post-mine land-use practices that have been reported. The study identified several factors and uses which can be used as guide for the industry as well as researchers. However, the chief driving force that must guide the usage of any particular post mining land-use should be aimed at providing prudent economic, environmental and social benefits to the people affected by the activities of mining. The study has shown that great amounts of information on the subject are available in literature and that many successes have been achieved in communities all over the world. A case study of a successful post-mining reclamation was also presented. Community involvement in reclamation planning and implementation process remains one of the key factors to a successful reclamation project.

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