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Development of a Decision Support System for Post Mining Land Use on Abandoned Surface Coal Mines in Appalachia

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A Research Paper

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And accepted on the recommendation of

Samuel Ratick, Ph.D., Chief Instructor

ABSTRACT

Development of a Decision Support Systems for Post Mining Land Use on Abandoned Surface Coal Mines in Appalachia

Matthew Zimmerman

Decision support systems are diverse and have been used to solve multiple problems ranging from the complex to the simple. With the complexity of environmental decisions today, these systems provide a logic based approach to evaluating and choosing environmental solutions. Abandoned mining lands (AML) are an issue for the environment in the Appalachian region. Given this a decision support system was designed using previously created frameworks and indices from other systems created. The system is comprised of two main sections, selecting the ideal post-mining land-use (PMLU), and maximizing the potential of land to be reclaimed under budgetary constraints. This system incorporates stakeholders, and takes into account the regulations governing reclamation of AML in Appalachia. The system could potentially be adjusted and used in other land use decision situations.

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DEDICATION

This paper is dedicated to my family and friends.

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Introduction:

Extractive industries, such as coal mining, have major environmental impacts across the globe. These impacts occur not only at the physical extraction site in the form of contaminant leaching and runoff, but also across the non-adjacent environment through the post mining use of extracted material, such as air pollution through burning coal for energy production. Driven by rising demand for energy production the Appalachian region coal mining industry supported the economy for many generations. Environmental stewardship during the mid-20th century and the push towards cleaner energy during the 21st century, has focused global attention on remediating the pollution and environmental degradation caused by coal mining, specifically surface or strip mining (Craynon et al., 2013). Despite these efforts extraction of coal by strip mining in Appalachia pre-1977 continued to pollute the environment as mines closed and company operations ceased through poor or absent mine reclamation plans. Decisions about how best to use the proposed reclaimed lands are complex and involve contribution, input, and collaboration from stakeholders to satisfy a myriad of sometimes conflicting values and goals.

Prior to the passage of the Surface Mining Control and Reclamation Act of 1977 (SMCRA), mined lands saw little to no cleanup. After the passage of the SMCRA, plans for reclamation became operational requirements for mining companies in the United States. The basic tenet of this regulation was to “establish a nationwide program to protect society and environment from the adverse effects of surface mining operations” (Surface Mining Control and Reclamation Act of 1977). The SMCRA also provided protection for lands that were affected by mining pre-1977, stating an objective “to promote the reclamation of mined areas left without adequate reclamation prior to [1977]”. Under the SMCRA, taxes were collected from the mining industries and put in a trust for the cleanup of lands that were not returned to pre-mining conditions after extraction, also known as Abandoned Mining Lands (AML).

Evaluating how to fix environmental problems evokes many complex questions, such as: How do we quantify important attributes that the land might provide to society and which may not normally be adequately expressed?; How do stakeholder’s opinions and social group aspects such as political leanings affect the decision maker’s preferences?; How do we use value systems to make decisions that will enhance public resources and private ownership? To do this, decision support systems can be used.

Decision support systems allow for a logical tracking of stakeholders views through weights for criteria and attributes, whilst finding the best solution given the multitude of criteria and attributes (Bascetin, 2007). The use of decision support systems when dealing with post extraction related land issues is not a new concept (Bascetin, 2007). Two most widely discussed and utilized systems for decision support in evaluating post mine land use are: the analytical hierarchy process (AHP), and the fuzzy analytical hierarchy process (FAHP). AHP is a decision method for multi criteria problems allowing qualitative and quantitative information to be evaluated by using a set of values from one to nine and requiring pairwise comparisons (Saaty, 1994). Instead of using a scale of zero to nine like for AHP, FAHP uses a spectrum of numbers from zero to one, across a range (Bangian et al., 2011). The position along the range then allows a value from zero to one to be given for the attribute, allowing most attributes to be put on a normalized scale. “FAHP is capable of capturing human’s appraisal of ambiguity when complex multi-attribute decision making problems are considered” (Erensal et al., 2006). These systems ensure logic based decision making when determining the best use of, and reclamation process for, post mining land and AMLs.

However the use of these decision support systems has not been all encompassing, as previous applications of the systems only accounted for an individual piece of land, not taking on the aspect of multiple pieces of land being reclaimed under the same initiative. Also, systems did not relate to the specific objectives of the SMCRA regarding public safety and health, the previous systems were created to just show a process. Expanding on previously used decision support systems for reclamation of AML helps in the development of a new decision making model that would take into account equity in public and private decisions as well as federal expenditures, for which previously utilized systems did not account.

The purpose of the decision support system developed in this paper is to find the optimal reclamation activity to use on AML, such as agriculture or industry. The second part of the purpose is to optimize the choice of lands to reclaim that would have the highest benefit for the state. This enhanced decision support system will combine various features of previously used decision support systems for Post Mining Land Use (PMLU) determination, including the indexes/frameworks for attributes and criteria. It is built upon the social, economic and environmental background and current state of coal mining in Appalachia. This is then followed by an overview of the SMCRA and successful reclamation projects. Then the previous decision support systems are discussed in detail, followed by the development and recommendation of a new decision support system; that synthesizes parts of these other systems and develops some new features. The paper will conclude with an analysis of public and private use of AML lands, highlighting the limitations and advantages of the decision support system that was developed.

Background:

Coal Mining in Appalachia

Comprised of 12 states, the Appalachian region stretches from New York in the North to Mississippi in the South (ARC, n.d.). Described as highly impoverished due to the rurality of the region and the poor paying industries that are usually found there, the Appalachian region has had a "historic dependence" on the coal industry (Partridge et al., 2012). With coal beds extending from Western Pennsylvania to Northern Alabama the coal mining industry has been extremely influential in Appalachia, both socially and environmentally (Burger, 2011). The central region, especially Virginia, West Virginia and Kentucky are bountiful in high grade coal (Crayon et al., 2013). As energy demand has increased through the years, so has the value of coal. Although a relatively new form of mining that first appeared about 30 years ago, surface mining or mountaintop mining (MTM) quickly became a lead driver in land cover change in the region (Townsend et al., 2009). Continued and increased demand for coal from Appalachia, and the associated mining activities, will continue to affect the people of the region.

Social and Economic Impact of Coal Mining

With a decline in poverty from 1961 to the present in the region, Appalachia seems to be doing well economically; however, the effects and location of current and historic coal mining greatly impact the people of Appalachia (Partridge et al., 2012). A number of studies have argued that the dependence on coal has contributed to the issue of poverty across the region (Deaton and Niman, 2012; and James and Aadland, 2011). A paper by Hendryx states, that there is a connection between high poverty and high mortality risks in areas where surface mining is prevalent (2011). A study by Partridge et al. (2012) found that surface mining, a more modern and prevalent form of mining alternative to underground mining, is not closely related to poverty in Appalachia as of post-2000. Which, perhaps diminishes the impact that mining has on poverty in the region. Regardless of the current effect of the mining industry on poverty levels, the fact that poverty continues to be an issue in Appalachia should be a factor involved in PMLU decisions.

Environmental Impact of Coal Mining

Coal mining is harmful to the environment and with increased energy demand these environmental harms are likely to continue. The topography and geology in Appalachia along with advancement in technology and technique, has made surface mining the primary method for coal extraction (Crayon et al., 2013). However, surface mining is extremely harmful to the environment due to the removal of overburden, or soil, to reach the coal seams. The overburden is typically moved to an area adjacent to the mined areas thus creating another area which has been disturbed by mining.

Secondary impacts to the environment from mining include, air pollution, water pollution - such as acid mine drainage (AMD) and runoff, waste disposal, and landscape change. The issues of air pollution, water pollution, and waste disposal are significant and encompass a wider geographic area than the immediate mining vicinity. These can be lingering issues from AML’s and current mining projects. The impact of mining on the landscape is undeniable in Appalachia, surface mining has caused a decline in forested area of 420,000 hectares in the region, despite some reported transition from reclaimed lands to vegetated areas (Drummond and Loveland, 2010).

Surface Mining Control and Reclamation Act of 1977

Reclamation of mining lands has been a continually evolving technique. In an article by Skousen and Zipper (2014); the progress of reclamation policy and activities “can be viewed as a progression from rehabilitation toward restoration”. Prior to the SMCRA, there were no legal obligations to clean up after mine closure, with the early laws only requiring some soil to be returned to the disturbed area. Few AML sites, prior to the passing of SMCRA, saw natural succession of species over time and a return to a “natural state”.

History

The SMCRA was passed in 1977 to protect the environment and society from the effects of surface mining, reclaim dangerous lands that were not reclaimed prior to the legislation, and to balance the need for coal as an energy source with the protection of the environment (Menzel, 1981). Under this act, and the Office of Surface Mining (OSM) and a trust fund operated by the OSM for the reclamation of AML’s, were created. The trust is supported by a tax on extraction of coal based on type of coal (Kalt, 1983).

In 1939, West Virginia was the first state to initiate a plan to control surface mining. Prior to this states would not propose or implement reclamation plans. The main reason for the delayed state implementation of these coal mining regulations was due to the perceived cost burden on coal operators, and the concern that firms would move operations across state boundaries in search of reduced extraction costs. There were some failed attempts to pass legislation, which could have dealt with some environmental issues of mines, from 1968-1977. These failed because of the concern over lost jobs and higher energy costs. By 1975, 38 states had already passed laws to regulate surface mining. Eventually, it was determined that uniform minimum standards were needed so that states could compete fairly. Following the years post-legislation, there was much disagreement over how far the federal government's authority extends (Green et al., 1996). The OSM used incentives and rules to enforce the act; incentives such as money for reclamation projects and grants for the states (Menzel, 1981).

Details of the Law Concerning Abandoned Mining Lands

Under the law, the money in the trust fund may be used for restoration of AML's. The money is distributed to each state based on the plan or plans that are submitted for AML reclamation. Section 405 (e) states that:

> "Each State Reclamation Plan shall generally identify the areas to be reclaimed, the purposes for which the reclamation is proposed, the relationship of the lands to be reclaimed and the proposed reclamation to surrounding areas, the specific criteria for ranking and identifying projects to be funded, and the legal authority and programmatic capability to perform such work in conformance with the provisions of this title." (Surface Mining Control and Reclamation Act of 1977)

For the development of the proposed decision support system, this is interpreted to mean: for the State Reclamation Plan to be approved, a system for determining eligibility that includes logical reasoning, should be used in developing that plan.

Future Progress of the Law

President Obama’s Budget for the 2016 fiscal year covers the topic of “Investing in the Coal Communities, Workers, and Technology: The POWER+ Plan”. The POWER+ Plan focuses on investment in the job market, coal technology, and the legacy of coal mining. One purpose of this plan is to focus on diversifying the industries and jobs in the areas of coal mining. The federal government plans on doing this by budgeting money to a variety of departments, including the Appalachian Regional Commission (ARC) specifically, to develop the “entrepreneurial ecosystems" purposing the environment to be sustainable and profitable. In addition the plan makes available $1 billion over 5 years from the unappropriated budget of the AML fund, to states and tribes, specifically to fund reclamation of AML’s in a sustainable manner in areas with economies that are suffering.

Successful Reclamation Projects

Concern over environmental and financial sustainability of reclamation of coal mining sites has been prevalent since legislation for reclamation of coal mining was first introduced (Brooks, 1966; Goldstein & Smith, 1975; Spore & Schlottmann, 1976; Randall et al, 1978; Misiolek & Noser, 1982; Kalt, 1983; Mishra et al., 2012). However, David Humphreys (2001), an economist, concluded that it is possible to have a balance between profitability of mining and sustainable development. The main issue is whether or not the mining companies’ values aligns with those of the rest of societies. In the United States, typically there are six types of PMLU as categorized by Skousen and Zipper (2014): “(1) prime farmland, (2) hay land and pasture, (3) biofuel crops, (4) forestry, (5) wildlife habitat, and (6) building site development”. According to the EPA’s website for AML’s: “Revitalization and Reuse,” there has been a push to use the AML’s and adjacent contaminated sites, for example mine tailings, the material leftover after separating desired minerals from undesired, for renewable energy systems. Most of the examples from the EPA’s website are located outside of the Appalachian Region (Abandoned Minelands Team, 2012).

In the Appalachian region there has been a push to shift from grassland vegetation restoration towards reforestation efforts, specifically by the Appalachian Regional Reforestation Initiative (ARRI). The ARRI promotes planting of trees that would prove to be productive towards the ecosystem and restore native forests (Angel et al.; Groninger et al., 2007). In addition to the focus on reforestation, section 711 of the SMCRA allows for experimental practice for PMLU. Some states have used this section to allow for industrial use of AML’s (Zipper & Yates, 2009). In fact, the Powell River Project by Virginia Tech has delved deep into PMLU, including enhancing the understanding of the processes’ prerequisite to making the land useable for industry (Zipper & Winter, 2009). There is push today, and for the future, towards reclamation of AML’s for alternative uses related to social and environmental development. In the next section the previous decision support systems relating to PMLU will be discussed.

Previous Decision Support Systems

Environmental decisions are complex, and can be classified as multi criteria decision problems. According to Better Environmental Decisions: Strategies for

Governments, Businesses, and Communities by Sexton et al (1999) there are six key questions when solving environmental decisions:

> "1. At what social level does the environmental decision occur?
> 2. What are the important substantive aspects of the environmental decision?
> 3. What is the social setting for the environmental decision?
> 4. What is the mode of environmental decision making?
> 5. What are the assumptions about basic underlying causes of the environmental problem?
> 6. What criteria are used to evaluate the environmental decision?"

Each of these questions narrows down the decision process by creating rules per se for the support system. Question one is the most basic to understanding who is a stakeholder/participant. Questions two and three, help determine the mode of environmental decision making, which is the focus of question four and of this paper. There have been six characteristic modes, as identified by the National Center for Decision-Making Research: emergency action, routine procedure, analysis-centered, elite corps, conflict management, and collaborative learning. These modes are not to be determined as "pure type," meaning that actual practice might vary and modes may well be mixed. However, these basic modes allow for the determination of how stakeholders interact in the decision making process (English, 1999).

The fifth question about the assumptions of underlying environmental issue, involves the background knowledge of the situation. Why does the problem exist or why is it happening? The sixth question is a complex one because this is where it all comes together. The basis of how to evaluate the process, who is included, the method, and on what you will evaluate the outcome. The criteria on which you base the success or failure of the outcome should be more than just if it was successful, other considerations could be: is the solution sustainable, what is the longevity, and is it socially equitable.

The need for decision support systems in the area of reclamation has been realized. As stated previously, the state must provide a detailed plan for the reclamation of AML's in order to have access to the tax fund. To aid in the realization of the optimum PMLU, the state must provide criteria for ranking projects and determining the proposed reclamation strategy. A multitude of systems which vary in the attribute ranking system, the logical ordering of steps or the background framework are presented. The various methods include using a cost-benefit analysis, geographic information systems (GIS), AHP, FAHP, linear programming or a combination of the methods. Each system however, incorporates logical steps that in the designer's opinion allow the user to make a decision about PMLU.

Systems using GIS and Cost Benefit Analysis

Some methods or tools for decision making for PMLU include; cost-benefit analysis and GIS. Cost-benefit analysis has been used in the past to determine if the SMCRA was going to impact the coal mining industry. It is a key component to many current reclamation decision support systems. The basis of making decisions using cost-benefit analysis is that if the benefits are greater than the costs, that project should be chosen. Another way to determine which solution, and to what extent it is to be used, by cost-benefit analysis is when the marginal net benefit equals zero, or the closest to zero. The marginal net cost and benefit are calculated by dividing the cost and benefit respectively from the difference in output of the project (Mathematical Model 1.). The marginal net benefits can be calculated by subtracting the marginal net cost from marginal net benefits. The limitation with this method is the valuation one puts on non-quantitative attributes of the decision problem. A prime example of this is the perceived valuation of a person’s life. There are many ways to solve the valuation of non-market items, specifically, hedonic pricing, travel cost analysis, and contingent valuation surveys to name a few. To understand the effect of these choices a sensitivity analysis should be undertaken to test how robust the solutions are to the values of the parameters that have been used to obtain that solution (Easter et al., 1999).

Output	Total Benefits (TB)	Total Costs (TC)	Net Benefits (NB)	Marginal Benefits (MB)	Marginal Costs (MC)	Marginal Net Benefits (MNB)
0	0	0	0			
5	11.4	4	7.4	2.28	0.8	1.48
10	14	6	8	0.52	0.4	0.12
15	18	8	10	0.8	0.4	0.4

$$(1) NB = TB - TC$$

$$(2) MB\ or\ MC = \frac{\Delta TB\ or \Delta TC}{\Delta Output}$$

$$(3)\ MNB = MB - MC$$

Mathematical Model 1. Marginal Net Benefit Calculations: (1) Calculating Net Benefits, (2) Calculating Marginal Benefits or Costs, and (3) Calculating Marginal Net Benefits. In this example the choice for output 10 would be chosen, since it is closest to zero, out of the choices available.

GIS is a tool used to analyze and manage spatial data. The main limitation of GIS, more so in the past than now, was the specialization of knowledge to use the software. GIS has been used to solve many environmental problems (Osleeb & Kahn, 1999). In the context of mine reclamation, GIS is used to prioritize mine reclamation sites through extrapolation of spatial information. By using spatial information such as distance to transportation and availability of certain materials, a list of sites by priority level can be produced (Gorokhovich, 2003).

The Analytical Hierarchy Process (AHP) and the Simple Multi-Attribute Ranking Technique (SMART)

The AHP has been used extensively for decision making, including determination of PMLU. Created by Thomas Saaty, AHP uses pairwise comparisons of criteria and alternatives to suggest the best choice. The AHP is useful when the decision maker has a problem that is characterized by multiple decision criteria and multiple alternative choices, sometimes noted as a multi- objective decision problem (Goodwin and Wright, 1998, Miori et al, 2016). It differs in method, but not purpose, from another multi-criteria decision method, called SMART or the Simple Multi-Attribute Ranking Technique. SMART uses direct ranking of criteria based on importance to help select the best option. AHP uses a 1-9 rating system to do pairwise comparisons through matrix multiplication (Table 1.). SMART's criteria scores are always transitively consistent, while AHP are not necessarily so (Miori et al., 2016). The basis of AHP is to break the overall decision problem down into simple sections: objective, criteria, and alternatives. The rationality, as described by Saaty, is to focus on solving the problem by structuring it using background knowledge and experience to determine values of criteria and alternatives (1994). An example showing the use of SMART and AHP will be demonstrated in the proposed decision support system section.

Intensity of Importance (Ratings)	Definition	Explanation
1	Equal importance	Two activities equal
3	Moderate importance	Favor slightly one over the other; Experience and judgement
5	Strong importance	Strongly favor one over the other; Experience and judgment
7	Very strong importance	Favored strongly over the other; Dominance in practice
9	Extreme importance	Highest possible affirmation of favor
2, 4, 6, 8	Compromise between values	Compromise between numerical values, because of judgement
Reciprocal of above	Inverse of a relationship	The reciprocal for matrix completion
Rationals	Ratios arising from scale	For expanding the scale to maintain consistency
1.1-1.9	Tied Activities	When elements are nearly equal; 1.3 for moderate, 1.9 for extreme

Table 1. Taken from Saaty (1994). The rating system for use in the pairwise comparisons of criteria and alternatives.

The steps to AHP are:

1. State the objective and identify criteria and alternatives.
2. Create a hierarchal decision tree showing criteria and alternatives.
3. Give values for each alternative.
4. Calculate importance weights of the criteria.
5. Calculate inconsistency ratio, and if need be reevaluate criteria matrix values.
6. Calculate preference weights for alternatives.
7. Calculate inconsistency ratio, and if need be reevaluate alternative matrix values.
8. Calculate multi-criteria score for each alternative, best score is the solution.

(Miori et al., 2016)

These steps allow for an orderly and easily to follow logic system. The process and equations will be gone into more detail and each step demonstrated in the expansion of decision support system section.

As stated previously, many of the decision support systems have incorporated the AHP for mine reclamation (Table 2.). For example in 1984, Uberman and Ostrega used AHP to determine the best method for revitalization of a mining region by utilizing two groups of experts to make judgments on criteria and alternatives. These findings revealed that AHP was useful in designing the revitalization of the area. Bascetin also used the AHP to determine the optimal environmental reclamation for an open pit mine in 2007. Bascetin chose AHP because of its capability to handle both the quantitative and qualitative information that is involved in the reclamation process. The study determined AHP to have a viable use in determining the best reclamation plan. A brief review of the literature using AHP, FAHP and decision making tools for mine reclamation is provided in Table 2.

Author (year)	Approach	Advantages
Cairns (1972)	Using ecological considerations to recognize the most suitable reclamation procedure and PMLU	Presenting ecological criteria to classify mined-land uses
Bandopadhyay and Chattopadhyay (1986)	Using a Fuzzy algortithim to select PMLU	Presenting an Fuzzy algorithm based on the previous experimental considerations
Alexander (1998)	Using the effectiveness of small-scale irrigated agriculture in the reclamation of mine land soils	Presenting different procedures to successfully apply small-scale irrigated agriculture as PMLU
Chen et al. (1999)	Using a limiting factor for defining restoration procedure ofsoil fertility in a newly reclaimed coal mined site in Xuzhou	Presenting some criteria to define reclamation procedure for a specific case of coal mined land
Joerin et al. (2001)	Using GIS and outranking multi criteria analysis for assessing suitability of PMLU	Presenting a multi criteria structure to outrank suitability of PMLU by using GIS
Mchaina (2001)	Using environmental planning considerations for the decommissioning, closure and reclamation of mined land	Presenting environmental considerations to select suitable PMLU
Uberman and Ostrega (2005)	Using Analytical Hierarchy Processing (AHP) in the revitalization of post-mining regions	Presenting an analytical hierarchy process to select PMLU
Osanloo et al. (2006)	Using AHP to select PMLU through consideration of the primary and secondary factors	Presenting an AHP structure to select PMLU by introducing and considering the primary and secondary factors
Mu (2006)	Using developing a suitability index for residential land use	Presenting suitability indexes to implement residential land use
Bascetin (2007)	Using AHP to create a decision support system to define the PMLU	Presenting an AHP structure to recognize PMLU
Cao (2007)	Using to regulate mined-land reclamation in developing countries: the case of China	Presenting a classification for issued regulations to analyze suitability of PMLUs
Soltanmohammadi et al. (2008a, b, 2009a, b)	Using multi criteria decision-making methods to rank suitability of PMLUs	Presenting a MCDM structure to outrank suitability of PMLU, developing effective criteria

Table 2. Literature pertaining to various methods used for PMLU determination (Bangian et al., 2012)

In a study by Soltanmohammadi et al. (2010), the AHP accompanied a mined land suitability analysis (MLSA), a previously created framework for determining feasible PMLU (Figure 1.). The industrial land use was determined to be the best use. This study used a compilation of multi-attribute decision making (MADM) techniques to determine final preference order of PMLU. The MLSA used economic, social, technical, and mine site factors to create a suitability framework for mining lands (Table 3.). The purpose of the MSLA was to take into account participating stakeholders' preferences, a comprehensible algorithm for stakeholders, and mathematical procedure that can effectively produce a solution based on stakeholder's values (Figure 1 and Table 3).

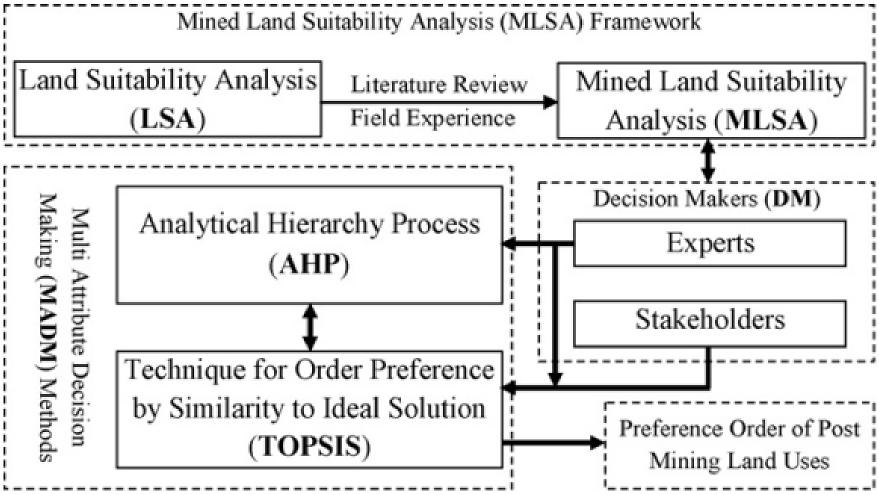


Figure 1. Decision support system using MSLA for PMLU choice (Soltanmohammadi et al., 2010)

Criteria	Attributes	Sub-Attributes
Economical Factors	Costs	Maintenance and monitoring costs
		Capital costs
		Operational costs
	Potential of investment absorption	
	Increase in governmental incomes	
	Increase in income of local community	

	Changes in real estate value	
Social Factors	Effects on immigration to the area	
	Need to specialist workforces	
	Changes in livelihood quality	
	Employment opportunities	
	Serving the public education	
	Frequency of passing through mine site	
	Eco-tourism	Ecological acceptability
		Tourism attraction
	Land ownership	
	Proximity of mine site to population centers	
	Geography	Location towards nearest town
		Accessibility or road condition
		Mining company policy
		Government policy
		Zoning by-laws
	Consistency with local requirements	
Technical Factors	Shape and size of mined land	
	Availability of reclamation techniques	
	Closeness to nearest water supply	
	Market availability	
	Current land-use in surrounding areas	
	Prosperity in the mine area	
	Structural geology	
	Distance from special services	
	Outlook of future businesses	
	Environmental contaminations	
	Extreme events potential	
	Reusing potential of mine facilities	
	Landscape quality	
Mine site factors	Soil	Soil’s physical properties
		Soil’s chemical properties
	Climate	Evaporation
		Frost free days
		Precipitation
		Wind speed
		Air moisture
		Temperature
		Hydrology of surface and groundwater
	Topography	Surface relief
		Slope
		Elevation
		Exposure to sunshine
		Physical properties of mine components

Table 3. MSLA framework, criteria attributes and sub attributes (Soltanmohammadi et al., 2010).

SMART uses a ranking system rather than pairwise comparisons to create weights that are transitive. The advantage of this is the decision maker is able to identify how much more an attribute is valued over another much easier than with AHP since the rankings are direct and will result in transitive values. The process for SMART is:

> "1. Order and list the decision criteria from least important to most important.
> 2. Determine the ratio of relative importance between successive criteria.
> 3. Develop the cascading product for each criteria.
> 4. Divide the values in step 3 by the total to obtain relative importance weights" (Miori et al., 2016).

The relative importance weights for the criteria, can then be multiplied by the attributes or options to achieve multi-criteria scores. The attributes however need to be normalized to have a logical choice, as to not skew the scores and overwhelm other attributes. An example of this would be to normalize the value of land measured in dollars and the size of land in acres, these two units of measure need to be made into a similar unit to be compared, by a process called normalization. As stated previously, SMART will be demonstrated in the recommendations section as part of an example.

Boolean Logic and Fuzzy Sets

Boolean logic or algebra is where variables are either true or false, and described in values of 1 or 0 respectively, as stated previously. Where a value of 1 represents complete truth or acceptance and a 0 represents false or a negative. An example of this would be if I want to identify only people age 35 and above in a sample population. My logic statement would read like this:

$$Input: if\ x > age(35), then\ 1; 0$$
$$Output: all\ ages\ above\ 35$$

Another unique decision method for PMLU incorporates AHP and fuzzy sets (see Table 2. for literature using fuzzy and AHP). Fuzzy sets allows for any real value from zero to one, in case of truth values based on a condition. This is in contrast to Boolean, which give a value of zero *or* one based on a logical true or false condition. Growth curves or functions allow for transition from value zero to one or vice versa (Figure 2.). Fuzzy sets is excellent for mathematical modelling because it allows for uncertainty (Alavi & Alinejad-Rokny, 2011). For example using distance from roads where zero value is given right next to the road and a value of one is given at one mile from the road. Any distance in between the road and one mile will have a real value on the scale of zero to one. However, the growth of the number as distance increases from the road may take on a few mathematical functional forms: for example, linear, exponential, and sigmoidal are a few options, based on decision maker preference for the growth or decrease of attributes along the x-axis in relation to the value of zero to one on the x-axis (Figure 2). This logic is useful when determining land suitability scores. This can be done in a GIS such as TerrSet (Eastman, 2015). Using the module FUZZY, IMAGE CALCULATOR, and then OVERLAY or simply MCE using weighted linear combination, based on fuzzy logic and weights for joining can produce a suitability score for parcels of land.

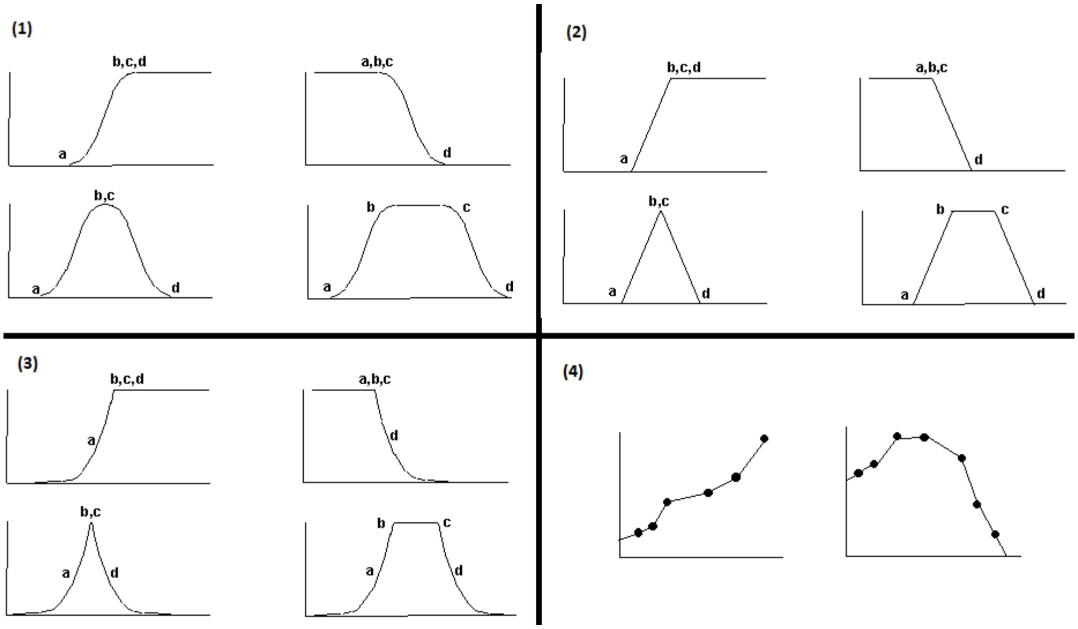


Figure 2. Examples of functions that could be used for fuzzy sets. A, b, c, and d represent values or thresholds. (1) Sigmoidal, (2) Linear, (3) J-shaped, and (4) User-defined. From the previous example of distance from roads, the x-axis would be the distance from roads while the y-axis will be the values of the scale zero to one. (From TerrSet User Help)

Additional Techniques

In addition to the use of fuzzy sets and AHP, linear programming will be discussed briefly. Linear and Integer programming is a technique used for optimizing an objective function based on constraints. Linear and Integer programming have five components to any problem (1) the available choices, (2) criteria of alternatives, (3) weights on the criteria, (4) scores of alternatives by criteria, and (5) constraints. An example of this use would be, if an organization, with limited funds, was trying to determine which land to develop based conservation scores (Stokey & Zeckhauser, 1978). Both of these techniques will be employed in the next section as part of the decision support system for PMLU of AML.

Proposed Decision Support System:

The end goal of the decision support system, developed based on previous systems (Figure 3.) was to have a number of parcels of AML's to reclaim with an identified best PMLU. The system builds upon previous decision support systems and adds new functions to get more than just the typical one parcel solution. The system includes; the previously discussed MSLA framework accompanied with GIS to identify land suitability scores, a Boolean logic/algebra to obtain viable land PMLU options, AHP, and Linear Programming with SMART used to determine the relative importance weights for the criteria and to optimize the choices of land parcels to be reclaimed and PMLU for each individual parcel.

Part one of the systems deals with individual parcels of land, while part two assesses how many and which options are viable under the budget. This system can be used at the state level to prioritize reclamation of lands, and provide sound reasoning and logic to apply for funding from the trust fund controlled by the federal government, with regards to the requirements under section 405 (e), to provide sound logic and ranking of criteria and attributes. To better follow the system, hypothetical numbers will be used in the example for the steps concerning AHP, linear programming and SMART for the criteria importance weights. The logic flow for this decision support system is presented in Figure 4.

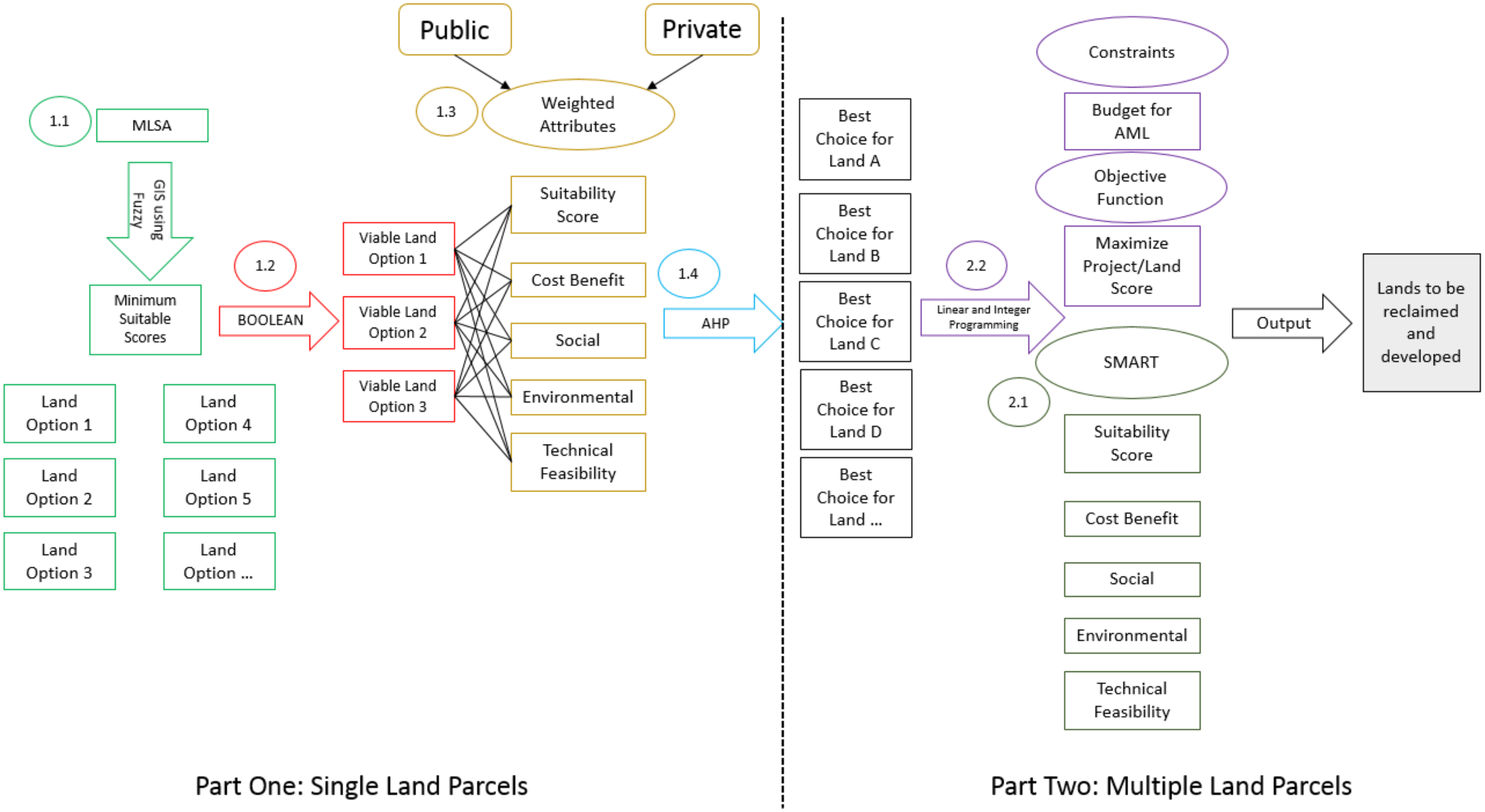


Figure 3. Proposed decision support system for PMLU identification and prioritization.

Step 1.1. MSLA, GIS, and Fuzzy

The MSLA framework does an excellent job at identifying key factors to assess suitability of the land. With 50 attributes for land assessment under four criteria, applicable suitability scores can be obtained. In addition the MSLA framework identifies eight possible land use types, and possible post mining land uses. Due to the previous condition under section 711 of SMCRA, it is also advisable to make this framework adaptable in case new land use activities are possibly identified in the future, or if attributes are determined to be unimportant or not mutually exclusive. This framework is not to be considered the final word on a land use decision, and should be reevaluated in the future once more data is compiled.

The criteria for the MSLA framework are economic, social, technical and mine site factors. The economic factors deal with attributes such as monitoring costs, capital expenditures, and operational costs. The social factors deal with issues such as employment, education, and policy. The technical factors include items such as shape and size of the land, distance to resources like water and roads, and environmental effects. Finally, mine site factors including slope and exposure to sunlight are taken into account.

With the 50 attributes available to be scored (Table 3.), GIS would be extremely useful in giving spatial context and value scores for each criterion. Most spatial data collected from state databases, allows for the mapping of the defined attributes. Combined with fuzzy logic, suitability scores can be created for the parcels of land centered on spatial data analysis. As previously stated, GIS software such as TerrSet has a module called FUZZY, that can attribute values from zero to one based on the growth curve. With these values attributed to frameworks attributes and criteria, the next step will make only the viable options available for AHP.

Step 1.2. Boolean Logic for Viable Options

The second step of part one takes into account the aspect that some of the parcels might not meet all PMLU options requirements. For example, if the land does not have the proper amount of sun exposure or slope, it will eliminate options such as arable farmland. With that considered, a Boolean logical statement is applied. The statement would eliminate any of the PMLU options from that particular parcel if they do not meet all minimum scores. This will reduce the number of options to be compared in the AHP, theoretically allowing for a better decision to be made for each parcel of land in the end.

Step 1.3. Stakeholder Participation

Based on the states and federal government's requirements for stakeholder participation, this step can be complex, due to the mandate by the government and the desire for equity, to involve many significant stakeholders and have their opinions and values accounted for. The basis of this is to tackle the steps one to three of the AHP. Allowing for public participation and expert knowledge of the process of reclamation and societal demands opens up the decision process and theoretically allow for perhaps a better compromise to be chosen. During this step, the stakeholders will discuss the importance of the criteria of the PMLU options for the AHP, as it relates to their values and needs. The criteria include suitability score, cost/benefit, social, environmental, and technical feasibility. Each of these criteria, except for suitability score, which will come from the GIS component, will be based on a score to be determined through another framework, and then will be normalized. Stakeholder participation is extremely important to coming to a decision, because the final decision will most certainly affect those in the immediate vicinity. This allows for qualitative and quantitative factors to be involved and taken into consideration.

Step 1.4. AHP

The AHP will allow for the best PMLU to be chosen based on the previous criteria. After developing the hierarchical decision tree (Figure 4.), the criteria will be given values based on stakeholder and expert knowledge, also known as importance weights.

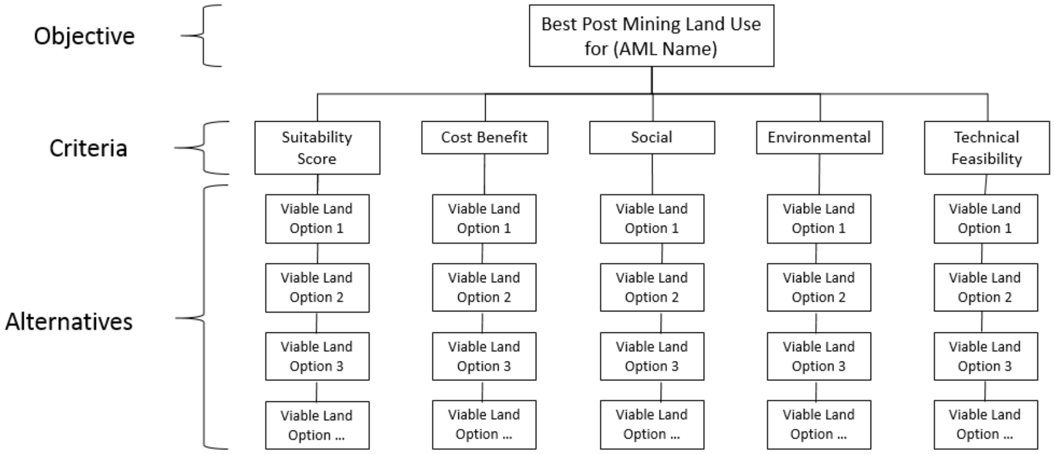
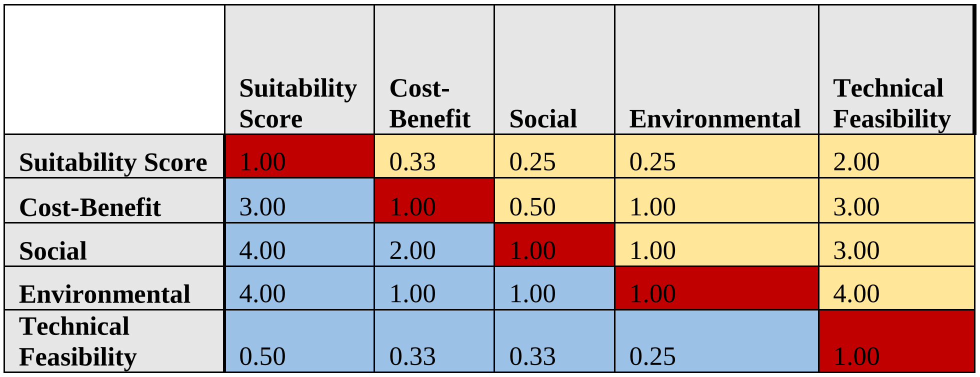


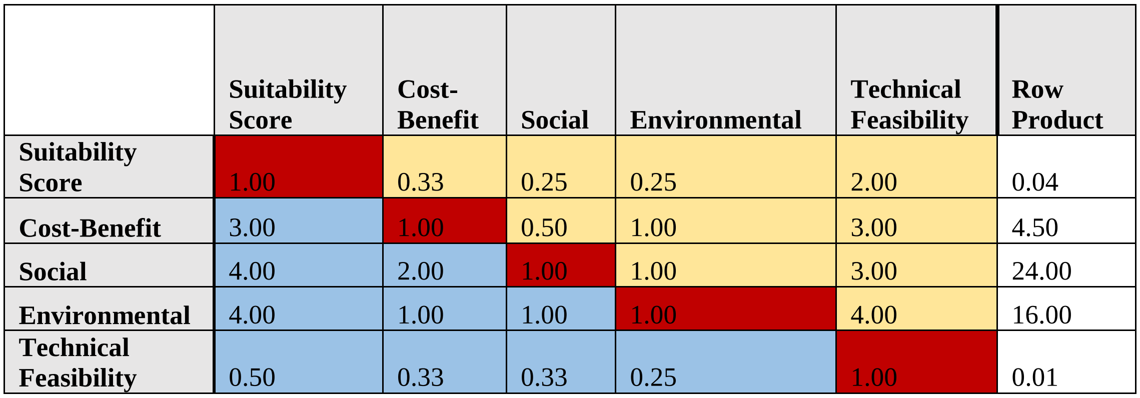
Figure 4. Hierarchal decision tree for PMLU, Step 2 of AHP.

In order to do this values 1-9 are introduced into a matrix of the criteria (Figure 5.) based on the previously discussed rating system (Table 1.). For example, cost-benefit criteria in the example, are judged to be moderately more important than the suitability score, and environmental is slightly more than moderately of greater importance than technical feasibility. To obtain the criteria importance weights that will be used to obtain the multi-criteria score for each parcel, a few steps are taken with the pairwise comparison data in the matrix. First the product of each row needs to be calculated (for example, the matrix in Figure 6.).



	Suitability Score	Cost-Benefit	Social	Environmental	Technical Feasibility
Suitability Score	1.00	0.33	0.25	0.25	2.00
Cost-Benefit	3.00	1.00	0.50	1.00	3.00
Social	4.00	2.00	1.00	1.00	3.00
Environmental	4.00	1.00	1.00	1.00	4.00
Technical Feasibility	0.50	0.33	0.33	0.25	1.00

Figure 5. Importance weights, pairwise comparison of criteria.



	Suitability Score	Cost-Benefit	Social	Environmental	Technical Feasibility	Row Product
Suitability Score	1.00	0.33	0.25	0.25	2.00	0.04
Cost-Benefit	3.00	1.00	0.50	1.00	3.00	4.50
Social	4.00	2.00	1.00	1.00	3.00	24.00
Environmental	4.00	1.00	1.00	1.00	4.00	16.00
Technical Feasibility	0.50	0.33	0.33	0.25	1.00	0.01

Figure 6. Calculating the row product. Multiply each value in the rows.

Next the geometric average of the row values is calculated by taking the nth root of the row product. This is the 5th root of the row product or $^{5}\sqrt{rowproduct}$, because there are five criteria. After that's calculated for each row, calculate the sum of the nth root column. Then to calculate the criteria weights divide each of the nth roots by the column total; the sum of those criteria weights should equal one (Figure 7.).

	Suitability Score	**Cost-Benefit**	**Social**	**Environmental**	**Technical Feasibility**	**Row Product**	**nth root**	**Criteria Weights**
Suitability Score	1.00	0.33	0.25	0.25	2.00	0.04	0.530	0.089
Cost-Benefit	3.00	1.00	0.50	1.00	3.00	4.50	1.351	0.228
Social	4.00	2.00	1.00	1.00	3.00	24.00	1.888	0.318
Environmental	4.00	1.00	1.00	1.00	4.00	16.00	1.741	0.293
Technical Feasibility	0.50	0.33	0.33	0.25	1.00	0.01	0.425	0.072
							5.935	**1**

Figure 7. Table for calculating the n^{th} root and criteria weights.

This next step is used to confirm consistency, since the rating system does not preclude that the rankings are transitive or that the criteria weights do exactly match the decision makers’ relative preferences for the decision criteria. The desire is to keep the values chosen as consistent as possible for a proper decision. This will be done for the criteria and then again for the pairwise comparisons of the alternatives. To calculate if the values are consistent is to first calculate the eigenvector. This is done by multiplying the row of each criteria by the criteria weights. For this situation it is multiplication of a 5X5 comparison matrix with the 5x1 column matrix for the criteria weights resulting in the eigenvector column. Then divide each of the eigenvectors by the corresponding rows criteria weight; find the average of these numbers in Figure 8.

	Suitability Score	**Cost-Benefit**	**Social**	**Environmental**	**Technical Feasibility**	**Row Product**	**nth root**	**Criteria Weights**	**Eigenvector**	**Eigenvector/ Criteria Weights**
Suitability Score	1.00	0.33	0.25	0.25	2.00	0.04	0.530	0.089	0.461	5.169
Cost-Benefit	3.00	1.00	0.50	1.00	3.00	4.50	1.351	0.228	1.163	5.108
Social	4.00	2.00	1.00	1.00	3.00	24.00	1.888	0.318	1.639	5.151
Environmental	4.00	1.00	1.00	1.00	4.00	16.00	1.741	0.293	1.483	5.054
Technical Feasibility	0.50	0.33	0.33	0.25	1.00	0.01	0.425	0.072	0.372	5.186
							5.935	**1**		**5.133**

Figure 8. Table for calculating eigenvector and λ max (highlighted in green).

To finally calculate the consistency of the values, the consistency index must be calculated.

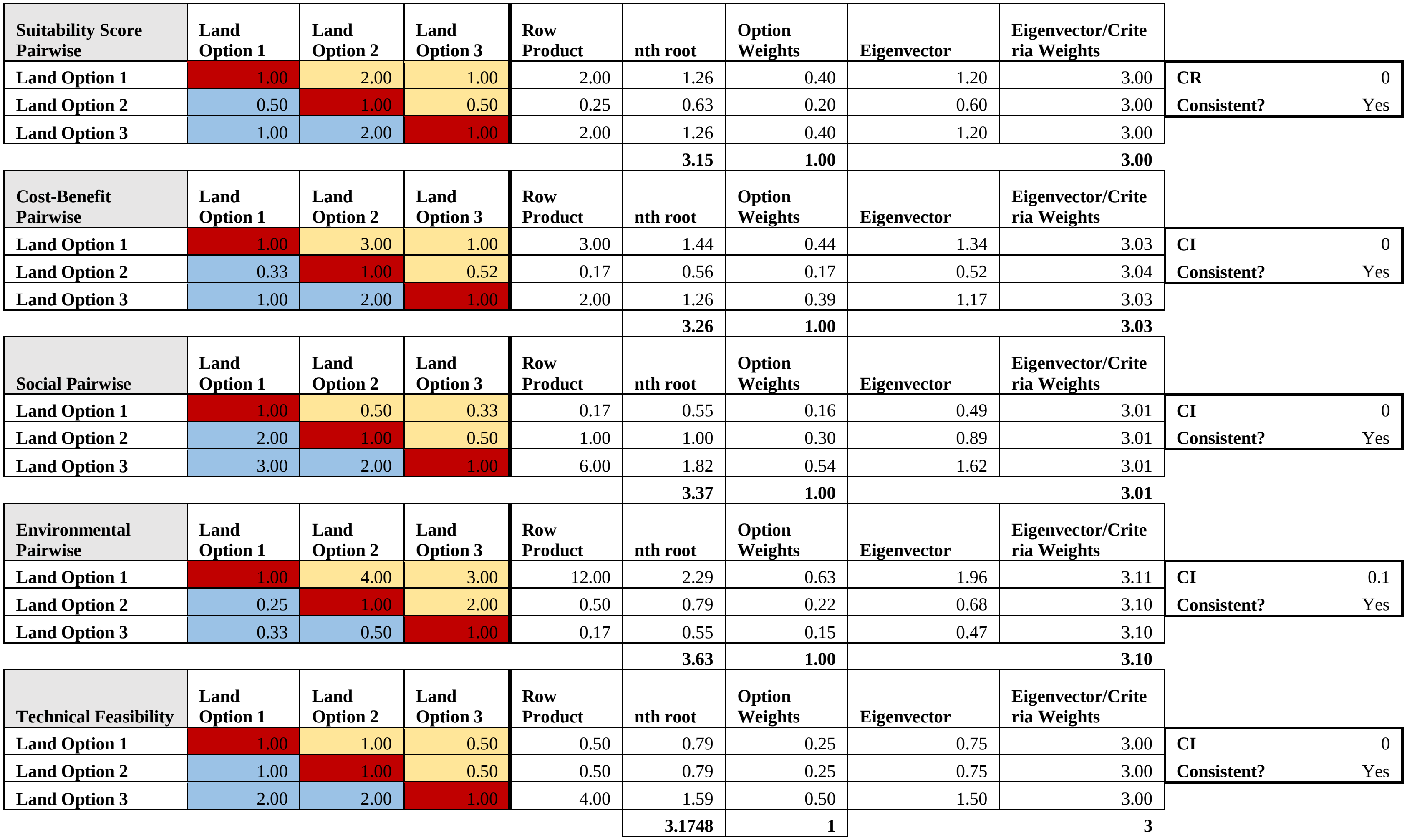
$$CI = (\lambda\text{max} - \text{n})/(\text{n} - 1)$$

If the consistency ratio is less than 0.10 then the pairwise comparisons are acceptable. The consistency ratio is calculated by, $CR = \frac{CI}{RandomCI}$. The random consistency ratio can be found in table 4.

Number of Criteria	**CI Random Matrix**
3	0.58
4	0.9
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49
11	1.51
12	1.53
13	1.56
14	1.57
15	1.59

Table 4. Consistency index, random matrices, based on number of criteria.

The process continues with pairwise comparisons for each of the alternatives, of which there are three in the example, for each criteria to obtain the preference weights. For the five criteria there will be three more pairwise comparisons; each alternative being compared to each of the five criteria. In addition, the calculation of preference weights would be done the same as the calculation of criteria weights previously, along with the consistency ratio (Figure 9.)



Suitability Score Pairwise	Land Option 1	Land Option 2	Land Option 3	Row Product	nth root	Option Weights	Eigenvector	Eigenvector/Criteria Weights		
Land Option 1	1.00	2.00	1.00	2.00	1.26	0.40	1.20	3.00	**CR**	0
Land Option 2	0.50	1.00	0.50	0.25	0.63	0.20	0.60	3.00	**Consistent?**	Yes
Land Option 3	1.00	2.00	1.00	2.00	1.26	0.40	1.20	3.00		
					3.15	**1.00**		**3.00**		

Cost-Benefit Pairwise	Land Option 1	Land Option 2	Land Option 3	Row Product	nth root	Option Weights	Eigenvector	Eigenvector/Criteria Weights		
Land Option 1	1.00	3.00	1.00	3.00	1.44	0.44	1.34	3.03	**CI**	0
Land Option 2	0.33	1.00	0.52	0.17	0.56	0.17	0.52	3.04	**Consistent?**	Yes
Land Option 3	1.00	2.00	1.00	2.00	1.26	0.39	1.17	3.03		
					3.26	**1.00**		**3.03**		

Social Pairwise	Land Option 1	Land Option 2	Land Option 3	Row Product	nth root	Option Weights	Eigenvector	Eigenvector/Criteria Weights		
Land Option 1	1.00	0.50	0.33	0.17	0.55	0.16	0.49	3.01	**CI**	0
Land Option 2	2.00	1.00	0.50	1.00	1.00	0.30	0.89	3.01	**Consistent?**	Yes
Land Option 3	3.00	2.00	1.00	6.00	1.82	0.54	1.62	3.01		
					3.37	**1.00**		**3.01**		

Environmental Pairwise	Land Option 1	Land Option 2	Land Option 3	Row Product	nth root	Option Weights	Eigenvector	Eigenvector/Criteria Weights		
Land Option 1	1.00	4.00	3.00	12.00	2.29	0.63	1.96	3.11	**CI**	0.1
Land Option 2	0.25	1.00	2.00	0.50	0.79	0.22	0.68	3.10	**Consistent?**	Yes
Land Option 3	0.33	0.50	1.00	0.17	0.55	0.15	0.47	3.10		
					3.63	**1.00**		**3.10**		

Technical Feasibility	Land Option 1	Land Option 2	Land Option 3	Row Product	nth root	Option Weights	Eigenvector	Eigenvector/Criteria Weights		
Land Option 1	1.00	1.00	0.50	0.50	0.79	0.25	0.75	3.00	**CI**	0
Land Option 2	1.00	1.00	0.50	0.50	0.79	0.25	0.75	3.00	**Consistent?**	Yes
Land Option 3	2.00	2.00	1.00	4.00	1.59	0.50	1.50	3.00		
					3.1748	**1**		**3**		

Figure 9. Alternative weights, completed with consistency checking.

The calculation of the multi-criteria score is the last step. In order to calculate the score of the first land use, the criteria weight that was calculated will be multiplied by each of the first alternatives preference weights that were calculated. The same will be done to determine the second land uses multi-criteria score except with the second alternatives preference weights for each criteria (Figure 10.). In the example, since the land option one and two are so close, a sensitivity analysis can be performed to see which criteria weights were most influential, however, this is outside the scope of this paper. This will continue for every alternative. In the end the highest multi-criteria score is the most appropriate choice for that parcel of land (Figure 11.).

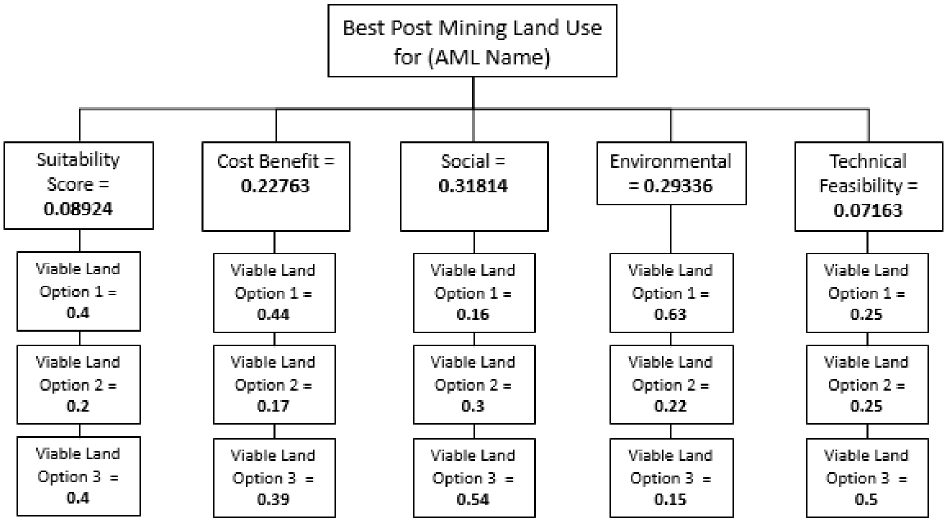


Figure 10. Completed hierarchal tree with filled in criteria and attribute weights.

	Suitability Score	Cost-Benefit	Social	Environmental	Technical Feasibility	Multi-Criteria Score
Importance Weights	0.089	0.228	0.318	0.293	0.072	
Land Option 1	0.400	0.443	0.163	0.630	0.250	0.391
Land Option 2	0.200	0.171	0.297	0.219	0.250	0.233
Land Option 3	0.400	0.387	0.540	0.151	0.500	0.376

Figure 11. Multi Criteria Score, chosen land option is highlighted.

Step 2.1. SMART

Using SMART, rankings will be determined by the stakeholders at the state level to determine importance of criteria for the linear and integer programming step, which will be used to identify which lands can be chosen based on budgetary constraints. The first step of SMART is to rank the criteria based on importance, followed by creating ratios of importance for adjacent criteria. After that, cascading values for each criteria must be calculated. From this the criteria importance weight can be calculated by dividing the cascading values by their total sum (Figure 12.).

	Criteria Ranked (Least to Most)	Example r(#,#)	Importance Ratios	Formula for Calculating Cascading Values	Cascading Values	Criteria Importance Weight
1	**Technical Feasibility**			1=	1	0.017
		r(1,2)	2			
2	**Suitability**			1*r(1,2)	2	0.034
		r(2,3)	4			
3	**Social**			1*r(1,2)*r(2,3)	8	0.136
		r(3,4)	2			
4	**Cost-Benefit**			1*r(1,2)*r(2,3)*r(3,4)	16	0.271
		r(4,5)	2			
5	**Environmental**			1*r(1,2)*r(2,3)*r(3,4)*r(4,5)	32	0.542
					59	

Figure 12. SMART table for identifying criteria importance weights for the objectives in the linear programming step.

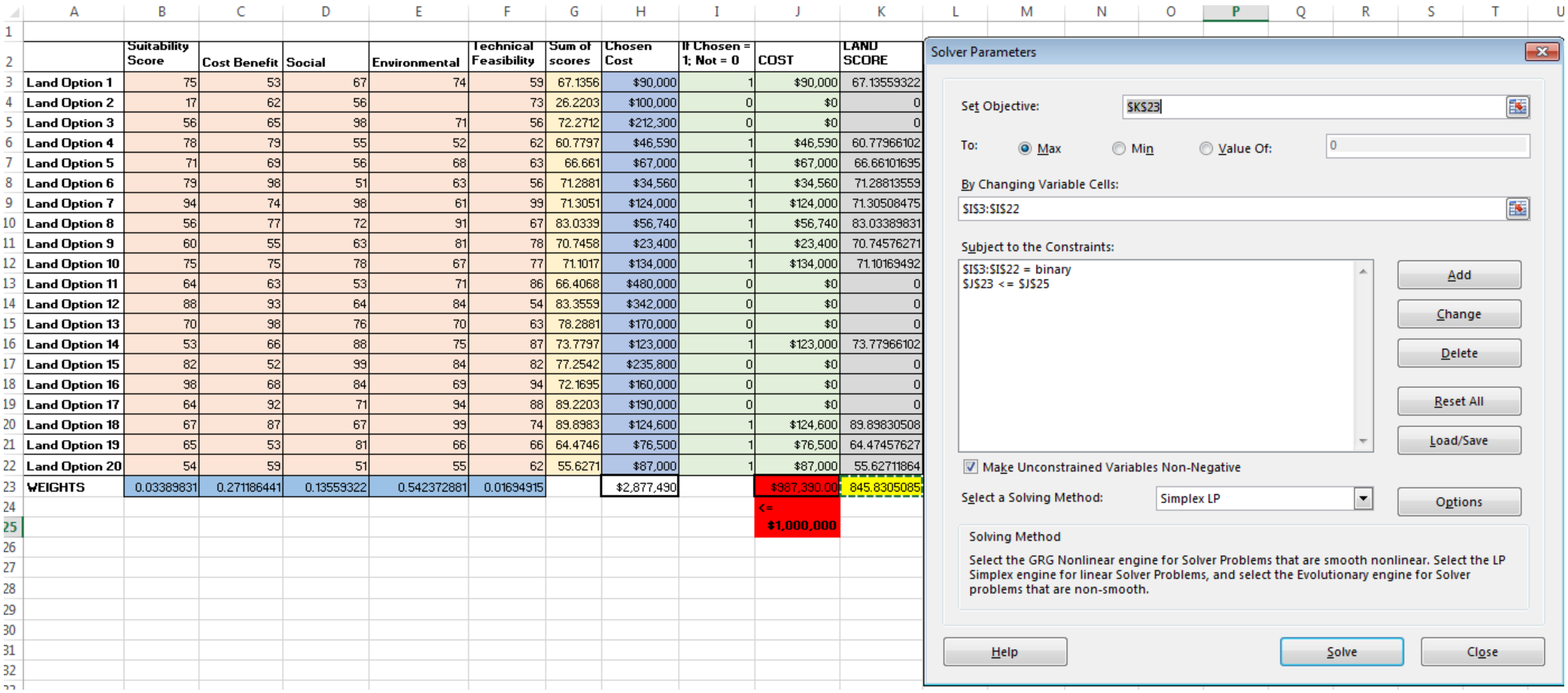
Step 2.2. Linear and Integer Programming

Once a decision maker has gone through step one and identified PMLU for however many AML's they deem necessary or have chosen for further analysis, the next step is to establish priority and to determine how many can be reclaimed when constrained financially by a fixed budget. Using linear programming, the state can identify which sites they should prioritize. The method setup in excel using the Solver Add-in would have the objective function be to maximize the land suitability score value, see below for description. The constraint would be the budget that was allotted, and the decision variable for the chosen land set to binary to ensure no lands are chosen more than once. In addition the weights, created using SMART, can be added to the suitability to allow for assigning more importance on issues that state may want to concentrate on. This makes it a multi-objective optimization (Cohon, 1978).

$$Objective\ Function\colon to\ Maximize\ Land\ Suitability\ Score\ Value\ (MLSSV),$$
$$MLSSV = Sum\ Product\ of\ Criteria * Weights\ of\ Criteria,$$

$$Subject\ to\ Constraints\colon (1) Land\ can\ only\ be\ chosen\ once\ and$$
$$(2) sum\ of\ land\ saved\ cost\ has\ to\ be\ less\ than\ the\ budget$$

Figure 13 shows the setup in Excel, and the corresponding Solver add-in. In addition to identifying lands based on budget constraints, a trade-off curve may be created by altering the budget constraint through a range of possible budget values. The trade-off curve would be able to show how much of an increase in the sum of the combined suitability scores, what can be called the Land Score, could be obtained if the budget was to increase (Figure 14.).



	Suitability Score	Cost Benefit	Social	Environmental	Technical Feasibility	Sum of scores	Chosen Cost	If Chosen = 1; Not = 0	COST	LAND SCORE
Land Option 1	75	53	67	74	59	67.1356	$90,000	1	$90,000	67.13559322
Land Option 2	17	62	56		73	26.2203	$100,000	0	$0	0
Land Option 3	56	65	98	71	56	72.2712	$212,300	0	$0	0
Land Option 4	78	79	55	52	62	60.7797	$46,590	1	$46,590	60.77966102
Land Option 5	71	69	56	68	63	66.661	$67,000	1	$67,000	66.66101695
Land Option 6	79	98	51	63	56	71.2881	$34,560	1	$34,560	71.28813559
Land Option 7	94	74	98	61	99	71.3051	$124,000	1	$124,000	71.30508475
Land Option 8	56	77	72	91	67	83.0339	$56,740	1	$56,740	83.03389831
Land Option 9	60	55	63	81	78	70.7458	$23,400	1	$23,400	70.74576271
Land Option 10	75	75	78	67	77	71.1017	$134,000	1	$134,000	71.10169492
Land Option 11	64	63	53	71	86	66.4068	$480,000	0	$0	0
Land Option 12	88	93	64	84	54	83.3559	$342,000	0	$0	0
Land Option 13	70	98	76	70	63	78.2881	$170,000	0	$0	0
Land Option 14	53	66	88	75	87	73.7797	$123,000	1	$123,000	73.77966102
Land Option 15	82	52	99	84	82	77.2542	$235,800	0	$0	0
Land Option 16	98	68	84	69	94	72.1695	$160,000	0	$0	0
Land Option 17	64	92	71	94	88	89.2203	$190,000	0	$0	0
Land Option 18	67	87	67	99	74	89.8983	$124,600	1	$124,600	89.89830508
Land Option 19	65	53	81	66	66	64.4746	$76,500	1	$76,500	64.47457627
Land Option 20	54	59	51	55	62	55.6271	$87,000	1	$87,000	55.62711864
WEIGHTS	0.03389831	0.271186441	0.13559322	0.542372881	0.01694915		$2,877,490		$987,390.00	845.8305085
									<= $1,000,000	

Solver Parameters

Set Objective: $K$23

To: ● Max ○ Min ○ Value Of: 0

By Changing Variable Cells: $I$3:$I$22

Subject to the Constraints:
$I$3:$I$22 = binary
$J$23 <= $J$25

☑ Make Unconstrained Variables Non-Negative

Select a Solving Method: Simplex LP

Solving Method

Select the GRG Nonlinear engine for Solver Problems that are smooth nonlinear. Select the LP Simplex engine for linear Solver Problems, and select the Evolutionary engine for Solver problems that are non-smooth.

Figure 13. Excel setup of hypothetical land options for a state. The objective function in the yellow box and the constraint for budget in the bright red boxes.

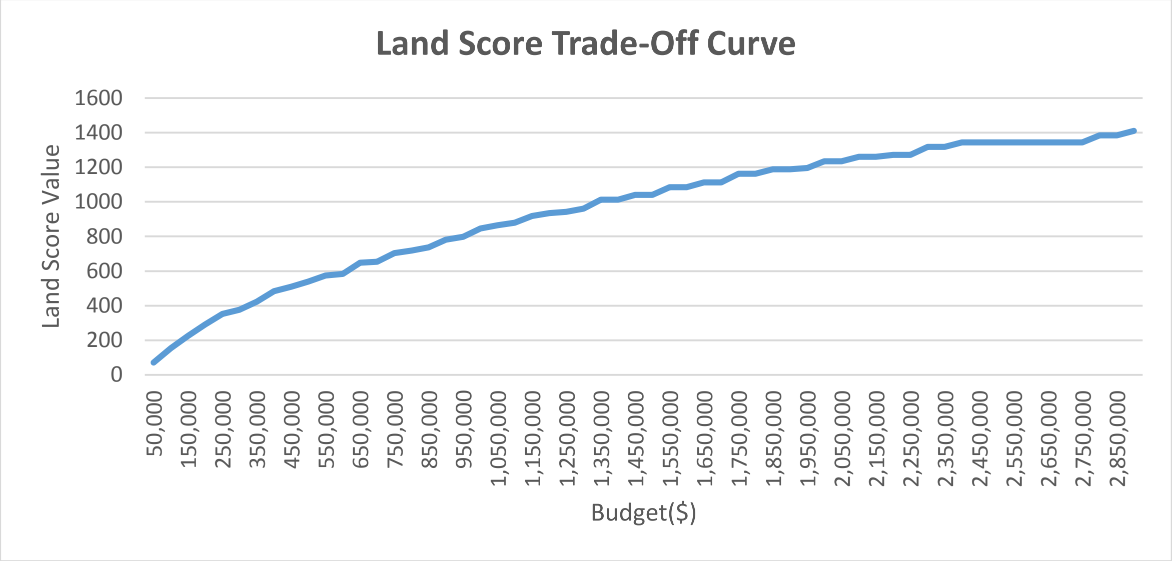


Figure 14. Land Score Trade-Off curve. The curve shows the amount of Land Score gain by budgetary increases to show amount of value that can be added by increasing the budget.

Output

The final output is a prioritized list of AMLs that the state should pursue in reclamation. In addition the PMLU has been identified, and a cost-benefit analysis is included in the decision support system to allow for economic analysis and budgeting. The trade-off curve that can be created from changing the budgetary constraint will also allow the stakeholders to determine if the increase in land value score is worth the additional increase in the budget. The attributes weights can be adjusted each time to allow for stakeholder preferences on the issues.

Discussion:

Private vs Public Use

The structure of this system allows for the incorporation of input and decision from stakeholders. The stakeholders for part one, can be both private and public, such as residents living around the proposed land or government officials that have jurisdiction of the area. At part one, it is extremely valuable to have community and grass roots groups input for the choice of PMLU. The community may be directly affected by the choice and thus should have a say, if the land is public. However, if the land is privately owned the stakeholders become the state and the immediate land owner, because the privately held land only has to follow laws and regulations set and the interests of the land owner. In this case, the state should act in the public's best interest.

Part two of the system relies less on the lowest level of stakeholder or the community level but more on the values and goals of the states that have jurisdiction of the funds for the land. Since the states receive the money from the federal government, the prioritizing of land needs to be based on the current initiatives of the state and federal governments. Part two will require very little community involvement in the system. However, this does not mean they are excluded from the thought process. The criteria will allow representation of the communities but on a larger regional scale.

Advantages and Limitations

The system has advantages and limitations at this point of the design. The advantages of the system are: multiple stakeholder involvement, a logical based system for PMLU determination, multiple land use determination and prioritization, and an economic analysis for budgetary increases. Additionally the system can be used for other land planning scenarios. The limitations are: the complexity of mathematical computations, the creation of value ranges for the frameworks, and expert driven approach to decision making systems.

With the multiple stakeholder involvement, opinions and values for the criteria and attributes can be seen and followed through the process, thus making it transparent. The stakeholders won’t always have consensus about the values that are being used to obtain the allocation of land uses to available parcels, but will have transparency of the process. This will allow for more meaningful and effective discussion and compromise. The involvement of stakeholders also enhances the equity of the solutions of the many stakeholders. With the proposed system unnecessary pairwise comparisons are eliminated with the Boolean statements, ensuring only alternatives suitable for the land are compared, and the solutions allow for more in-depth analysis, with the ability to transfer over to other programs and situations. The proposed system has a huge advantage of being used for multiple land use determination scenarios.

The limitations are mostly the same limitations as with other decision support systems. The systems are expert driven and require more than just standard knowledge. AHP uses a complex, non-layman approach, also the knowledge that is required to use many of these programs and techniques takes time to learn and understand. This system in particular uses multiple tools, GIS, Excel, and the Solver Add In. At this time the limitations aren’t easily overcome but with time and further research, many of these issues can be fixed.

Conclusion and Directions for Further Research

The need for AML reclamation in the Appalachian is clear. With the vulnerability of society, the economy, and the environment to the factors involved in mine reclamation, a logical decision support system was needed. The proposed system works in conjuncture with stakeholders of all levels and fulfills the requirements of the law to present criteria and rankings for PMLU for AML's.

The expansion of previous decision support systems has sound logic and allows for the involvement of stakeholders at multiple levels. In addition, it accounts for more than just the environmental and land suitability analysis. The system can be used as a standalone analysis for private users, used by land owners looking for investment funds to support their projects by utilizing the first part of the system, or used by government when incorporating linear and integer programming for optimization. Not only can this system be used for AML's, it has applications for conservation and land development in general. With some minor changes in aspects like the initial MSLA framework and criteria throughout, this can become a versatile tool for budget assessment in land planning and decision making for land use.

The next step in the progression of this system is to continually update the frameworks and scales for the evaluation of new criteria and attributes. This would also include programming or creating an application for practical use. This is in contrast to what is seen in the paper, of using the multiple tools to complete the decision support system. In addition, the testing of the system at a state level, with actual identified land and stakeholder involvement should be followed up on to receive feedback on the usability of the system.

Acronyms and Abbreviations:

AHP	Analytical Hierarchy Process
AMD	Acid Mine Drainage
AML	Abandoned Mining Land
ARC	Appalachian Regional Commission
ARRI	Appalachian Regional Reforestation Initiative
FAHP	Fuzzy Analytical Hierarchy Process
GIS	Geographic Information Systems
MADM	Multi-Attribute Decision Making
MTM	Mountaintop Mining
MLSA	Mine Suitability Land Analysis
OSM	Office of Surface Mining
OSMRE	Office of Surface Mining and Reclamation Enforcement
PMLU	Post Mining Land Use
SMART	Simple Multi-Attribute Ranking Technique
SMCRA	Surface Mining Control and Reclamation Act

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