Landscape Ecology and Reclamation Success

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Abstract

To all landscapes, including reclaimed ones, there is a spatial diversity with both horizontal and vertical boundaries. Understanding of this spatial diversity and the reasons for it can be enhanced by the application of synecological principles, remote sensing techniques, geographic information systems (GIS), and multivariate analysis procedures resulting in improved long-term management of reclaimed or rehabilitated landscapes.

Introduction

Mines have been developed on almost every conceivable landscape. These include agroecosystems and wetlands as well as forest and range ecosystems. The spatial distribution of these landscapes can be considered from a landscape ecology perspective. Landscape ecology is the study of landscapes, their spatial patterns, and how such patterns develop. Landscape pattern is organized in special ways: the component events and patches occur at characteristic scales that are positively correlated in time and space (Urban et al. 1987).

Landscape ecology considers ecosystem functions at a landscape scale. The various definitions include a particular interest in space (Golley 1987). Forman and Godron (1981) defined a landscape as a distinct, measurable unit with several interesting ecological characteristics. Within the landscape is a recognizable and repeated cluster of ecosystems and disturbance regimes. Elements of energy distribution, flow of water, mineral nutrient cycling, species distribution, landform, soil development, ecosystem change, and human impact come into play. Landscape ecology is an integrative science. Its value as a discipline is the viewpoint it affords. The interrelationships between human society and its living space and its perception is a holistic one. If knowledge about a landscape can be organized and put to use, we can think in terms of accomplishing reclamation or rehabilitation of a landscape.

Landscape ecology provides a "new" framework upon which to base land management research and ultimately decisionmaking. Each ecosystem has developed under a different set of external variables and, therefore, each ecosystem has different capacities to resist or recover from stresses (Risser 1985). Landscape structure is a complex arrangement of patches, corridors, and matrices. The levels of homogeneity and heterogeneity and the complexity of such structure are studied to provide information for land managers, including restoration ecologists.

From a biological standpoint, landscape ecology requires understanding of both autecological and synecological principles. Synecology tends to be emphasized within landscape ecology, although ecophysiological and genetic principles must not be ignored. This chapter reviews some aspects of synecology, landscape ecology, remote sensing, and multivariate analysis of ecosystem parameters. The landscape perspective has been used for many years by foresters, range managers, and wildlife managers. The focus has been on forest and range ecosystems and their productivity, and on the edge effect and its importance for wildlife habitat.

Spatial Diversity

Each landscape that we work on has both vertical and horizontal dimensions. The horizontal dimensions are the polygons that we describe when we map the various ecosystems. The vertical dimensions are the geology, soil, soil chemistry, ground water systems, lake and river depths, and other variables encountered in the earthward dimension. The structure of the vegetation and its various layers constitutes another vertical dimension as does the atmosphere. These vertical dimensions must be examined along with the polygons.

Landscape patterns are the consequence of numerous disturbances or perturbations creating patches. Patch implies a relatively discrete spatial pattern, but does not establish any constraint on patch size, internal homogeneity, or discreteness (Pickett and White 1985). Patch implies a relationship of one patch to another in space and to the surrounding, unaffected or less affected matrix. Patch dynamics refers to patch change. Perturbation activities including logging, grazing, croping, and other land uses. In addition, other perturbations can influence these landscapes either pre- or postmining such as fire, flooding, insect infestation, and plant disease.

Clearcutting in forests is one example. Franklin and Forman (1987) used a checkerboard model and five other models to evaluate the probability of disturbance with regard to wildfire, windthrow, and species diversity. Fortunately, ecological restoration (based on restoration ecology principles) can allow for strategies to restore and conserve biological diversity (Jordan et al. 1988).

Patch dynamics as exemplified by changes in patch bodies must be understood as we examine landscapes. Johnston and Naiman (1987) described how patch bodies are either created or modified by beaver impoundments. They further discussed impoundment geographic constraints associated with energy and material transfer in aquatic ecosystems impacted by the beaver. Beaver create patch bodies through browsing pressure, an ability which they share with many other large animals. Like other animals, beaver affect the spatial distribution of landscape resources by transporting materials across patch body boundaries, thus creating patches with new characteristics.

Patches can influence the distribution and abundance of animal species. Influences include the size of the woodland or habitat unit, interpatch distance, and density of similar habitat patches in the surrounding landscape. For example, bird abundance is strongly regulated by such patch dynamics in woodlands. This is the result of a smaller number of individuals that can be maintained in a smaller patch. If the patch becomes too small, no birds can be maintained (VanDorp and Opdam 1987). Another term used to describe both landscape patterns and patch dynamics relative to wildlife is habitat fragmentation. Perry (1988) discussed how various forest pests influence landscape pattern.

Plant synecology deals with the classification and/or ordination of vegetation and the relationships of plant communities to environments (West 1988). West suggests that "it is the ecosystem that responds to management action or inaction, not just vegetation, soils and micro-climate. The land manager would thus like to recognize where one ecosystems stops and another begins and how similar or different an ecosystem is from other areas where he has observed success or failure of a particular management approach."

An important part of the landscape ecology perspective is the question of vegetation/soil relationships as considered from a synecological perspective. First there is no 1:1 relationship between soil and vegetation classification units. However, since many soil boundaries are based on landform boundaries, a better correlation often exists between soil and vegetation map units than with the classification units themselves (Leonard et al. 1988). Certain correlations have been developed between vegetation, soils, and landform. The success or failure of past management can be determined. New management trials and new research results can be extrapolated to new areas with greater confidence based on these relationships.

Reclamation Landscapes Premining: Planning for Reclamation

Mining protocol suggests that a mine will not be developed unless a prudent man can make a profit from the enterprise. Ecologists can suggest an analogy that would state that a mine should not be developed unless prudent men can agree that the environment can retain its ecological integrity and be ecologically restored over the long term as landscapes are mined and managed. However, it is often very difficult to determine if a mine can be restored and maintained after product extraction. This requires a knowledge of landscape ecology, the identification of ecological equivalency among the various ecosystems, and a review of empirical results. Then evaluations can be made of the success of land restoration procedures. (Fig. 1).

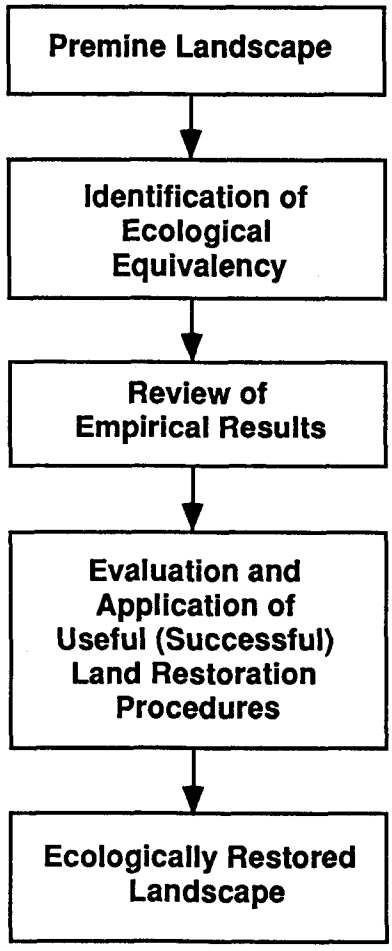

Figure 1.—An often used approach for evaluating information that can be applied to assure ecological restoration of landscapes.

How would we go about doing this? First, the prudent man would recommend that an inventory of landscape resources be developed. Ideally this would include all aspects of the ecosystem. The inventory should include geology, soils,

vegetation, wildlife (including fishes, reptiles, and invertebrates), water (including water quality and ground water), air quality, visual resources, and all other important resources both within the landscape to be mined and in the surrounding region since cumulative impacts are important and must be considered. My purpose is to explore how landscape ecology can provide perspective and insight into how best to manage mined landscapes both pre and post mining based on a knowledge of landscape ecology.

The inventory must be followed by a reclamation plan. Within the reclamation plan, consideration must be given to numerous aspects of ecological land restoration. Among these would be such things as surface soil stockpiling, waste rock disposal, tailing disposal, erosion control practices, species selection, recommended species mixtures, supplemental irrigation for vegetation establishment, fertilization, the possible use of container-grown plant materials, seedbed preparation, recommended mulches where thought necessary, maintenance of roads and fences, and a host of other questions and recommendations.

Multivariate Analysis Procedures

In this paper I am emphasizing natural vegetation. There are new alternative procedures for looking at vegetation distribution and vegetation patterns. These involve numerical classification of vegetation and ordination of these vegetation attributes (Gauch 1982). Several ordination approaches are available including reciprocal averaging (RA) and detrended correspondence analysis (DCA). Both of these methods locate samples along ordination axes representing one or more environmental gradients by eigenvector ordination techniques. (Gauch 1982; Whittaker 1967, 1987). Non-metric multidimensional scaling (NMDS) is another ordination technique that is thought to be useful in successfully discovering or documenting gradients of high beta diversity (species changes) (Minchin 1987). These techniques integrate the vegetation data into a form that portrays distribution of species and stands along environmental gradients.

A rotational correlation analysis can be used to determine if various relationships fit along an ordination axis or at some significant rotation at an angle away form the axis. In several desert studies we have developed rotational correlation matrices to examine the relationship of the following factors to vegetation distribution along the axes: (1) a radiation index (based on elevation, slope, and aspect), (2) elevation, (3) total species, (4) shrub cover, (5), grass cover, (6), forb cover, (7) slope, (8) number of shrub species, (9) total cover, (10) total biomass, (11) shrub biomass, (12) grass biomass, (13) forb biomass (Tueller et al. 1991). Numerous other factors can be added to such a matrix, quickly evaluated via the computer, and interpretations made relative to changes on various landscapes. This, of course, depends upon the availability of data and the reasonableness of gathering certain kinds of data. For example, even though biomass information and or ecosystem productivity information is often of great interest, the cost of acquisition tends to be prohibitive.

These multivariate approaches have been designed to evaluate the individual distribution of species in space and time, to identify unique successional trajectories driven by a variety of life history features, and to uncover or discover many possible unique biotic interactions only intermittently operative. There is often a large element of chance especially in the initial floristic composition (West 1988). Also, the multivariate approach can lead to the determination of subtle relationships that may or may not be related to the dominant species on a site (Tueller and Eckert 1987).

The multivariate approach can lead to a better understanding of landscape processes. The predictability of vegetation assessment can be improved. Sites with similar ecological characteristics can be defined and empirical results of ecological restoration procedures can be better extrapolated to those sites (polygons) where high success can be assured.

Landscape Awareness Principles: A Remote Sensing Viewpoint

Remote sensing information useful for landscape management is derived from measurements of electromagnetic radiation by air- or satellite-borne cameras and scanners, video cameras, infrared detection appartus, and by radar and radio frequency receivers. Spatial, temporal, and spectral characteristics of these various systems provide data in various formats. Applications tend heavy toward inventory, evaluation, and monitoring of land resources and the incorporation of remote sensing data to support and improve the decision processes related to wise land use.

With remote sensing we have a view of resources and input to the management of resources that is unique. This view is a synoptic one giving a single-glance intergrative, interpretive impression of large land areas. Such a view has not been previously available prior to the development of remote sensing technology. Remote sensing data, data analysis, and interpretation, along with the synoptic view, given greater understanding of land-based resources such as forests, rangelands, terrestrial and aquatic wildlife habitats, riparian zones, wetlands, watershed and water resources, outdoor recreation, and uses of landscapes for mining.

If we accept the thesis that remote sensing can play an important part in the process of restoration ecology, then it is necessary to describe how this can come about. Remote sensing includes many forms, many kinds of data, numerous scales, numerous spectral bands, and a variety of data gathering and interpretation paradigms. We should further consider how this new knowledge of the ecosystem, alluded to above, and derived from remote sensing might come about.

Numerous authors have described procedures for mapping landscape polygons. For rangelands the procedures have been reviewed by McGraw and Tueller (1983) and Tueller (1989) utilizing remote sensing techniques. These studies need not be reviewed here. One can use remote sensing procedures, using either photo interpretation techniques or digital image processing techniques, to map real landscape differences.

What is not always known without considerable reliable field experience is the exact nature and status of the landscape resource represented by each polygon. Remote sensing technique provides the mapping and can provide some of the actual resource data if the spectral characteristics of the landscape are known (Tueller 1987, 1989). Pixel modeling and vegetation indices and various kinds of resource spectral signatures can provide data sets helpful in allowing understanding of the landscape resources. The coupling of the various data sets, both ground and remotely sensed, can lead to an understanding beneficial to the ecologist charged with the requirement of restoring a given landscape.

Several examples can be given which relate to the distribution of resources in a spatial sense over a landscape. The relationship of drainage, landform, and waterpoints to forage utilization on rangelands constitutes one example. Another example is to examine the levels of productivity of range or forest vegetation as related to landform, soil, insolation, and other factors. A third example would be to consider how landscape diversity provides edge effect and habitats suitable for a variety of wildlife species. Also, numerous algorithms have been developed to determine resource changes and can be used as part of the monitoring process (Jensen 1981).

Recently, my student Norbert Schweyen and I have been able to predict vegetation cover in desert shrublands with Landsat Thematic Mapper data. A high correlation ($r = 0.923$) has been found between desert shrub plant cover and the Perpendicular Vegetation Index (PVI). The PVI is a vegetation index that has the capability of providing information relative to vegetation quantity and quality on arid landscapes. The ability to measure and predict vegetation attributes using satellite digital data can be very valuable for studying pre- and postmined landscapes.

Presently much consideration is being given to the development and application of Geographic Information Systems (GIS). A simple and workable definition of a GIS has been given by Parker (1987) — information technology systems which store, analyze, and display both spatial and non-spatial data. Points, lines, and polygons or areas can all be depicted, overlayed, stored, and retrieved and then changed as land management problems are resolved.

A review of recent papers on GIS suggests to me that this sparkling new technology is doing some very simple things, but doing them rather quickly and efficiently (Johnston 1987; Nellis and Lulla 1990; Moran 1990; Astroth et al 1990). GIS interest, as currently viewed, is thought of as a "final solution" to many resource management problems. This quick fix is unfortunately not provided by GIS and is dependent upon a well-trained cadre of professional applied ecologists and resource managers. A GIS system does nothing new but it does old things fast. It places landscape features and data concerning landscape features together rapidly and in ways that we have not been able to do before. A colleague of mine refers to GIS as simply a different kind of filing cabinet, one with a screen and printer/plotter.

The real value of GIS is in the process of interpreting adjacent/competing land uses and showing quickly where these various uses occur in relation to one another. Probably the greatest potential benefit from GIS techniques is the ability to couple data base information directly to various polygons.

Armed with information accumulated concerning plant synecology, vegetation/soil relationships, and other landscape variables, we are then prepared to evaluate these landscapes using principles of landscape ecology, multivariate analysis techniques, and remote sensing/GIS. This allows the mapping and organization of landscape knowlege resulting in recommendations for ecological restoration (Fig. 2).

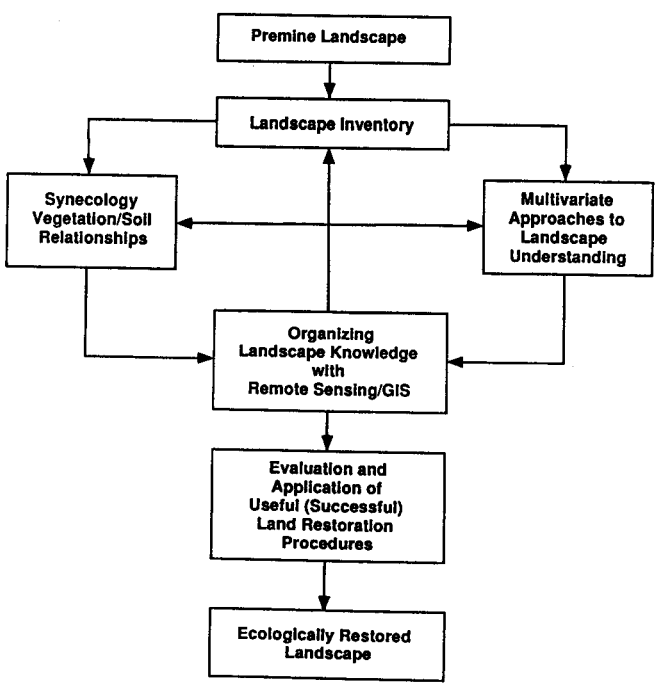

Figure 2.—Four-part diagrammatic model directing information to the ecological restoration of mined landscapes. Product extraction is the objective of a prudent man mine. Land restoration procedures can result in an ecologically restored and productive postmined landscape.

Reclamation Landscapes Postmining: Consequences of Mining

Environmental Effects

Every mine, because of its very nature, results in a variety of land perturbations. These include exploration roads, assessment work, access roads, haul roads, open pits, adits, overburden dumps, waste dumps, tailings ponds, and administrative areas. Each of these land use requirements during the mining process impacts the land. The land is fragmented. Ecosystems are often altered completely. Secondary successions are set into motion and management strategies based on a reclamation plan are invoked to ameliorate the impacts. Landscape ecology provides a holistic view of this process. This leads to understanding which in turn leads to good management and the recreation of landscape usefulness.

Long-Term Management of Reclaimed Landscapes

According to Bradshaw (1988), the endpoint in all reclamation must be a robust self-sustaining ecosystem which, if not achieved for any reason, negates the entire reclamation process. If the best known methods are used and if all underlying problems associated with the site are solved along with repeat and concurrent reclamation, we can reasonably expect success. In some cases the cost may tend to become prohibitive and perhaps the cost will have to be borne by the public interested in environmental integrity rather than the land owner.

The barriers to effective ecosystem exploitation and rehabilitation are often both ecological and sociopolitical (Maguire 1988). I am not sure why Maguire used the term exploitation since that term has a negative connotation. We must think positively and agree that to extract precious products from our landscapes, as demanded by society, is a positive management oriented endeavor and should be viewed in a positive light. This becomes a social, political, legal, and ethical problem and has little to do with a prudent mining human. Either the mining company or one or more public agencies acting in behalf of the environment will have to evaluate, manage, and monitor these lands into the future. The landscape ecology perspective can assist various interested persons and institutions to understand the reclamation process, the necessity for such action, and the probabilities for success.

Economic, sociological, and ecological concerns must be considered in any analysis of a land use system (Franklin and Forman 1987). Great importance must be attached to the evaluation of spatial and long-term consequences of human-imposed landscape patterns. These include such questions as patch configuration and size, edge lengths, and their configuration and disturbance susceptibility, as influenced by the mining process.

Long-term management can be prescribed with greater confidence as suitable landscape ecology data are obtained and insight from remote sensing and multivariate data analysis procedures is used. The long-term management, in most cases, will require only the typical management that would normally be used to manage the various resources found on the site postmining. However, the prudent land owner, whether the mine owner or a subsequent land owner, should be concerned enough about the landscape to see that the land and its vegetation and other resources are monitored. There are many good monitoring methods and scenarios to assist in the determination of ecological resource integrity. Monitoring should include periodic evaluations of several resources: vegetation (timber, wood, pasture, and range), soil (erosion), water (ground and surface), wildlife, and other important resources. Landscape ecology principles coupled with remote sensing/GIS can assist with the monitoring process.

Cumulative Effects

Whereas cumulative impacts have always been specified in the National Environmental Protection Act (NEPA) process, only recently have impact studies begun to emphasize cumulative impacts. The Council on Environmental Quality (CEQ) defines cumulative impacts as "the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (federal or non-federal) or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time." Cumulative impacts are judged as to type—piecemeal, slow degradation, off-site, homotypic, heterotypic—and as to the way they occur—additive, synergistic, multiplicative, or threshold. Cumulative impact assessment takes a broader view than conventional impact assessment: the boundaries, the number of disturbances, the geographic area, and the time frame considered all tend to be larger (Preston and Bedford 1988). The restoration ecology/landscape ecology approach suggested here, particularly referencing remote sensing/GIS, can enhance the cumulative assessment process on mined land and relate the mining activity to the totality of other landscape impacts in a predefined region.

Conclusions

The outcome of the approach that I have outlined here is a holistic assessment of the reclamation process. This assessment includes premining resource inventory, the development of a reclamation plan, the accumulation of appropriate multivariate data sets, and interpretation of the data via remote sensing/GIS. In particular GIS provides the opportunity to combine data base information with polygons quickly and efficiently. These are analyzed in order to understand the polygons of the landscape and their relationship to one another. The principles of landscape ecology, reclamation planning, multivariate data anlaysis,

and remote sensing/GIS combined in appropriate ways to improve the probability of successful restoration of impacted ecosystems.

I was intrigued by Cairns' (1988) fear that some scientists feel that even partial effectiveness in restoration will be viewed as a license for further ecological destruction in the name of progress and growth. They further fear that some of the wilderness areas, national parks, and other ecosystems that now have exceptional protection will have this protection reduced as a consequence of the feasibility of repairing damage following exploitation of various resources in these systems. Cairns further asserts that some attempts will almost certainly be made to intrude on previously protected areas on the grounds that the restoration process is now sufficiently advanced to make this possible. Being naturally optimistic, I have less concern. However, I will concede that we have much yet to learn to maintain the integrity of our landscapes. Landscape ecology and each of the subjects of this symposium offers hope in the process of landscape restoration.

We are looking toward new levels of landscape understanding. Landscape ecology, remote sensing, synecology, vegetation/soil relationships, GIS, and multivariate statistical approaches to vegetation analysis can lead to improved management models based on new and innovative methods. An improved approach to landscape understanding is the result of these integrated activities.

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Cumulative Effects of Mining on Hydrology, Water Quality, and Vegetation

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Abstract

Evaluating the cumulative effects of mining and other land disturbances at the watershed-scale poses a challenge to researchers and practitioners. Offsite cumulative effects may arise as a result of multiple mining disturbances occurring simultaneously within a watershed or from the interaction of mining activities and of adjacent land uses (grazing, residential development, recreation, timber harvest). Progressive surface and underground mining may generate onsite cumulative effects by modifying soil and vegetation composition, slope stability, and surface erosion potential. In addition, this temporal sequence, typical of many coal mining operations in the East and gold mining operations in the West, can affect offsite resources such as water chemistry, channel sedimentation, riparian vegetation, aquatic habitat, and peak flows. To address these important issues of cumulative effects, we need to consider the physical, chemical, and ecological processes within the time and space in which these activities occur.

Introduction

The concept of cumulative effects involves the interaction of natural ecosystem processes with the effects of land use distributed through time or space, or both. At the watershed scale, mining activities often occur in combination with other land use such as road construction, residential development, agriculture, timber harvesting, grazing, and recreation. Interaction among these activities can result in effects on offsite resources (water quality, aquatic habitat) that are cumulative through time or that are not accurately predictable when evaluating each land use separately. Onsite cumulative affects can result from sequential mining activites and may affect soil development, vegetation composition, and erosion potential.

Concerns regarding cumulative effects related to mining vary by region. For instance, in Appalachia, coal mining may occur in the same watershed along with grazing, agriculture, or woodlot management. All of these activities can accelerate soil loss and the delivery of sediment to streams as influenced by their spatial and temporal distribution. In the Northeastern and Lake States there are concerns over effects of various types of mining along with concurrent impacts from atmospheric deposition, insect epidemics, and the increasing level of forest harvest. These activities may lead to depletion of nutrients from forest soils and changes in chemistry of streams, lakes, and groundwater. In the West the recent increase in gold mining has encroached upon wilderness areas and land uses such as grazing and timber harvest. The major concerns about effects relate to erosion, fish habitat, and riparian ecosystems.

Progressive Underground Mining

Underground mining operations have the potential to generate both on- and offsite cumulative effects. An important example of an onsite effect is in the progressive underground mining of coal seams. When only minimal structural pillars are left in place, land subsidence may occur. This is exacerbated in seismically active areas. Subsidence is common around underground coal mines in the following regions: agricultural lands in the Midwest (Darmody and others 1988); rangelands in Colorado, Utah, and Wyoming (Dunrud 1976; Degraff and Romesburg 1981); and anthracite mine communities in northeastern Pennsylvania.

Subsidence not only destroys property and alters topography and surface drainage, but also influences outlets for acid mine drainage, and may create areas of future instability by oversteepening of slopes and redirecting of subsurface flow. The generating of acid drainage by opening new pyritic deposits to oxidation and allowing redirected subsurface flow to contact these deposits is a major offsite cumulative effect. Acid mine drainage can be a problem in areas where no subsidence has occurred. However, the additional flow pathways created by subsidence would complicate the problem as well as any ameliorative solutions.

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Surface Mining

Surface mining creates the greatest environmental disturbances of any mining technique because of the vast land areas disturbed, the volume of spoil material generated, and the changes in the properties of the disturbed matrix. Typically, strip mining of coal proceeds in a progressive manner whether the operation involves overburden removal or relatively flat terrain, contour mining along coal outcrops in relatively steep terrain, or mountaintop removal. Temporal cumulative effects from these mining practices can arise because of the lag time in reclamation and changes in the hydrologic function, erodibility, and nutrient status of the reclaimed spoils.

Traditionally, hardrock mining employed underground techniques and the laws governing reclamation of hardrock mining were tailored to these early extraction methods. Recently, surface mining methods have been adapted for removal of lower grade ores of precious metals. Most notably, the cyanide-heap leach process has made profitable the extraction of gold from very low-grade ore bodies. The process has opened up large land areas in the Intermountain West for goal exploration and mining. Cumulative effects related to these activities may occur because of both the vast spoil deposits that must be reclaimed and the open pit mine sites that are not required to be filled under current laws.

The exploration phase of precious-metal mining operations can cause considerable disturbance. Core drillings normally are taken in a grid matrix to determine the location of the high-grade ore body. When a high level of precious metal is assayed, a more detailed grid system is overlayed in the immediate vicinity to map the ore body more accurately. This exploration procedure requires a vast network of low-grade roads to facilitate movement of drilling rigs from point to point. Many times steep and unstable slopes must be accessed. In relatively steep watersheds, exploration roads crisscross mountainsides and potentially concentrate surface and subsurface runoff, increase the hazard of slope failure, accelerate surface erosion, and detract from the esthetic quality of the natural landscape. Since the exploration phase of precious-metal mining requires more intensive road networks than during the extraction phase, the temporary roads must be considered in a cumulative effects analysis. Similar problems exist in the exploration of oil and natural gas, especially in mountainous terrain.

Long-Term Weathering of Spoil Material

Soils are a product of climate, vegetation, topography, parent material, and time (Jenny 1941). Soil development of mined areas is unusual because vegetation, topography, and even parent material to a limited extent can be controlled. In the eastern coal region the climate is humid, precipitation is well distributed throughout the year, and vegetation growth is good. These conditions probably would encourage soil development on disturbed areas such as mines. However, some geologic strata in this region have experienced accumulation of solutes or formation of sulfides in reducing environments during past depositional periods (Evangelou and Karathanasis 1984). The effects of these depositional minerals on soil and water acidity can be predicted by physiochemical relationships. Soil development does appear to be quite rapid in the eastern coal areas. Wade and Halverson (1988) found recognizable O, A, and B soil horizons had developed after 22 years under both hardwood and conifer plantations. The majo. difference among vegetation types was in the 0 horizon. The organic layer was thicker under a mixed pine than under hardwood plantations.

Comparisons also were made with the undisturbed soil adjacent to the mine. Soils were less developed when the A horizon was approximately 3 cm on the mine and 10 cm in the surrounding forest. However, when the soil chemistry on and off the mine was compared there were few significant differences between mined and unmined sites. Thirty-one soil variables, including both nutrients and toxic materials, were measured and only K, Mn, Cu, Cr, and A horizon thickness were found to differ significantly from adjacent unmined soils (Wade and Halverson 1989). This site appears to be returning rapidly to original conditions.

Davidson and others (1988) studied the progression of soil pH in several eastern coal areas over many years and found a significant pH shift toward premining conditions. These results also suggest soil development over short periods.

In a study of 70- to 130-year-old shaly iron ore spoils in northern West Virginia, Smith and others (1971) found that rooting depth was greater in mine spoils than in nearby native forest soil in spite of the higher bulk density and better structural development in forest soil. Forest site quality, pH, and mineralogy were not greatly different between natural soils and mine soils.

Mine spoil development in southeastern Kansas was evaluated one year after reclamation of a coal mine (Welch and Humbleton 1982). The only visible pedogenic development was the physical weathering of shale fragments, due largely to freeze-thaw activity. The chemistry of the mine soil was similar to that of native soil in the area, except the pH was approximately one unit lower in mine spoil samples.

Multiple Land Uses

Road construction is a common companion of mining because there may be no existing roads or only an inadequate network. The impact of roads has been mixed. Earlier mined, recently mined, and unmined watersheds in Tennessee were instrumented in the early 1980's to evaluate the effect of roads (Woods and others 1986). The combined effect of road construction and mining was not uniform. Total dissolved solids (TDS) were greatest on newly mined watersheds where levels approached 1,000

ppm. On earlier minded watersheds, TDS levels were in the hundreds and unmined watersheds had values ranging from 10 to the low hundreds.

In general, magnesium and sulfate levels were lowest in undisturbed watersheds and watersheds with old mines. Conversely, sodium levels were high on undisturbed watersheds and newly mined watersheds. These results were further confounded by physiographic regions with Cumberland Mountain watersheds responding differently from Cumberland Plateau streams.

The cumulative effects of road constructed and mining are not simply additive. Rather, effects appear to be a complex function of road and mine location in the watershed, road construction and mining technique, geologic substrate, and reclamation efforts on both old roads and mine surfaces.

In the West, grazing often occurs within the same watershed as mining. The effects of grazing have been cumulative through this century and have resulted in catastrophic channel incision and drastic changes in riparian vegetation in many areas. Recent mining activities in these watersheds may exacerbate fine sediment inputs to streams, but the long-term effects of mining activities on channel morphology are uncertain (Sidle 1989). In Appalachia, conventional or limited-till agricultural practices often occur near active coal mines. The effects of these agricultural practices on sediment and nutrient transport must be evaluated along with those from mining.

Large strip mining operations in forested settings require extensive clearcutting before exploration and earthmoving. Depending on lag time between timber harvest and actual mining disturbance, harvesting may affect sediment production. Additionally, harvest activities may occur in the same watershed independent of, and concurrent with, mining operations. This poses additional concerns regarding cumulative effects, depending on harvesting techniques and silvicultural methods.

In certain areas of the East, residential and industrial development occurs in the same drainage as mining. In addition, reclaimed mine sites sometimes become sites for housing tracts or businesses. This is especially true in Appalachia where flat, accessible land is limited. Variations from approximate original contour reclamation of coal strip mines permit such development to occur (Zipper and others 1989). Thus, the evaluation of potential cumulative effects on such resources as water quality must address not only the effects of reclamation, including revegetation and changes in spoil chemistry, but also the influence of the new land uses.

Strip mining and associated road construction in steep terrain increase the potential for landslides (Sidle and others 1985). These mass failures, together with erosion caused by other types of land use and sources, contribute to the overall cumulative effects on basin sedimentation. Mining activities in steep terrain generate massive quantities of spoil material that require placement of spoil material at sites that already may be unstable. Most reclamation efforts primarily are concerned with revegetation of spoil material with little emphasis on long-term stability. Factors affecting the amount of regrading needed on hillsides include depth of overburden removed, thickness of the extractable resource, and slope gradient. Recommendations have been made to regrade and compact spoil material to approximately 34° on outslopes (Allen 1973); however, this may be difficult or undesirable in steep terrain.

The Surface Mining Control and Reclamation Act of 1977 requires mine operators to regrade mine spoils to approximate original contour. This concept may have shortcomings when applied in steep terrain because regraded spoil material may have significantly different hydrologic and geotechnical properties from native soil (Sidle and others 1985). The natural slope-regraded spoil interface may provide an area for positive-pore water pressure to develop, and this may initiate shallow landslides. Research on coal mines of Appalachia reclaimed by approximate original contour methods indicates potential instability in many of the highwall backfills (Bell and Daniels 1985; Bell and others 1989). Alternatives to original contour reclamation at steep sites may need to be considered to afford better protection for slope stability (Zipper and others 1989).

Only a few detailed inventories are available that assess the degree of landsliding associated with mining. A study by Lessing and Erwin (1977) indicated that 8 percent of the landslides in seven greater urban areas of West Virginia (3,367 km^2 total area) were attributable to mine spoil banks. The major causes of these slides in coal spoils were overloading slopes with poorly consolidated spoils, inhibiting subsurface drainage, and oversteepening slopes. A study of abandoned tailings from silver, lead, and zinc mines in northern Idaho indicated that there was a low potential for mass failure in more than 80 percent of the sites surveyed (including both reclaimed and unreclaimed spoils) (Gross and others 1979).

Surface Erosion

Accelerated erosion frequently follows any form of land disturbance. Land disturbance due to mining is a particular concern because large areas and steep terrain often are involved. The absence of a protective vegetative cover during and immediately after mining also contributes to erosion.

Erosion studies in the eastern coal region in Tennessee and Kentucky showed greatly accelerated erosion after slopes had been restored. Some of the slopes were steep, exceeding 50 percent. The site in Tennessee lost 33.9 mm of soil material while the steep slopes in Kentucky lost 23.8 mm, and gentle slopes had no loss (Curtis and Superfesky 1977). However, the erosion was not uniform in time or space. The bulk of the erosion occurred early, before vegetation was established, and at a point about 100 feet below the top of the slope. Rills and gullies also tended to

form on long, uninterrupted slopes. Davidson (1981) concluded that vegetation was the most effective erosion control measure although terraces, mulches, and chemical stabilizers can be helpful (Plass 1987).

Mines in western coal regions showed similar wide variation in soil loss, with erosion removing 2.5 to 50 mm per year from an Idaho mine (Morris and Taylor 1987). Erosion rates on an Idaho phosphate mine were measured during simulated rain storms. Again, erosion rates were variable but not related to slope position as had been found in eastern studies (Hart and Whitson 1988). The conclusions of the phosphate mine studies suggested the incorporation of coarse material into the surface layer as an effective erosion control measure, but the subsequent development of a vegetation cover was necessary for long term protection. Toy (1989) evaluated geologic and accelerated erosion rates and found natural erosion rates of 2.7 mm and erosion on reclaimed slopes averaged 4.1 mm. These values were not considered significantly different. The slopes were modest, less than 15 percent, and the results suggest erosion is not greatly accelerated by mining on gentle slopes.

In-Stream Sedimentation

The stream channel provides an important focal point for cumulative watershed effects because it integrates the offsite effects of many land uses and natural events that occur throughout the drainage. In particular, channels respond to changes in sediment load—as sediment load increases, channels become more shallow and wide. Also, the size and distribution of pools, and important habitat feature for fish, can change with increasing sediment loads. Increasing of the fines in streambed gravels that result from accelerated sediment load can restrict oxygenation of incubating fish eggs and impede fry emergence (Cordone and Kelly 1961; Crouse and others 1981).

A central Nevada study on a watershed that has experienced long-term grazing and more recent mining showed that pools were less frequent and the channel wider in the most heavily grazed reach (Sidle 1989; Coffman and others 1989). While mining had no immediate effect on channel morphology, the fine sediment in streambed gravel was higher near a large mine dump than in the rest of the channel (Sidle and Amacher 1990).

Peak Flows

The effects of mining on peak flows and floods has long been a controversial subject. Flooding has been attributed to any form of land disturbance, including mining. Disturbances such as timber harvests are generally recognized as mechanisms to increase water yield. The impacts of mining, since they extend into geologic formations beneath the surface, have been more difficult to define.

In the eastern coal region, hydrologic records from smaller watersheds have been analyzed to isolate the effects of mining (Bryan and Hewlett 1981). The results showed that storm runoff volumes were unaffected by mining but the hydrograph was altered. Small peaks were increased in the summer, but the effect on the peak flow declined as the peak increased. The largest peaks were less than anticipated on mined watersheds. The decrease was attributed to the disruption of impervious geologic strata in the watershed followed by development of a greater water storage capacity in the material (Curtis 1978). Additional evidence supporting the concept of reduced peaks from major storms over mined watersheds was derived from impoundment studies. In a study of major storms, 41 percent of the precipitation flowed from a mined area into an included pond while 76 percent of the precipitation appeared as flow from a control watershed (Curtis 1984). The mining operations in these areas had a mixed impact with some increases in peaks from minor storms but also some reductions of peak flow, especially during large storms. At least three other studies in Appalachia (Collier and others 1979; Curtis 1972; Sidle and Menser 1980) report increases in peak flows related to mining activities in watersheds. Increased peak flows were in part attributed to concentrated areas of soil compaction and disturbance near stream channels (Sidle and Menser 1980).

Some of these results must be interpreted carefully because not all include the impact of current reclamation practices. Areas that were permitted, mined, and reclaimed under the new regulations have not been instrumented for a sufficient period to draw conclusions.

Water Quality

The effects of mining on water quality are varied and depend in part on factors such as the mining technique, overburden properties, and regional climate and hydrology. Two general types of water chemistry problems can be identified. The first case involves chemistry changes directly attributable to current or recent mines. The second situation involves acid mine drainage from old or abandoned mines. Mine drainage often appears after mining, and even reclamation, is completed.

Mining operations may produce elevated levels of sediment and dissolved minerals in surface waters, especially during active mining and before reclamation efforts become effective. In general, water quality tends to improve with time since mining with water quality variables approaching premining levles (Becker and others 1986). About 15 to 20 years are required for water quality in the eastern coal areas to approach premining conditions. Effective reclamation presumably would reduce the time needed for recovery.

Acid mine drainage in the eastern coal region is a major environmental problem. In southern Kentucky, seep waters have been measured where pH is less than 3, and sulfate and iron concentrations are in thousands of ppm (Halverson and Wade 1988). Even small flows of such contaminated water can have significant impacts on surface

water quality. Both chemical and biological treatment schemes are used to treat acid mine drainage, but costs are high.

Summary

The cumulative effects of multiple land use remain undefined and are further confounded when mining occurs on the watershed. Mining, due to the subsurface disturbance, can be a major contributor to changing the ecology and hydrology of an area. However, research results have shown that the impacts of mining have great variation. Mining can have minor and temporary impacts or the changes can be major and present over long periods.

The effects of mining on hydrology depend on original watershed characteristics and reclamation techniques. Hydrology may be altered to favor greater flows and peaks in some watersheds. However, proper use of wetlands, ponds, and other impoundment techniques as well as the production of deeper soils can mitigate some of the effects.

Water quality generally declines during and immediately after a mining operation. However, the effect is temporary and water quality tends to return to pre-mining conditions after the area is reclaimed. Other reclamation procedures, such as spoil placement, offer the promise of further reducing the time required for water quality to recover.

Mining can be disruptive to the vegetation, soils, and hydrology of a watershed. We should view the potential changes as an opportunity and not simply as the source of problems. While much information remains to be developed, completed research suggests that careful planning and implementation of reclamation can yield a site and ecosystem to meet future needs. For example, water yield can be increased by creating long slopes protected with coarse fragments. Conversely, water yield could be decreased through the use of impoundments or terraces and by taking advantage of increased soil moisture storage. Planning, including clear objectives for the ultimate use of the area, is key to developing the ecosystem needed to meet future objectives.

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