14--OIL SHALE MINING AND SPENT SHALE DISPOSAL

By Robert V. Steele

A. Introduction

An important aspect of the recovery of oil from the oil shale resources of the western United States is the large amount of material that must be mined, processed and ultimately disposed of if a large-scale oil shale industry is developed. Many of the adverse environmental consequences likely to result from oil shale development are directly related to the large volumes of material that are involved, as well as the nature of the material itself. This chapter presents the techniques and problem areas of oil shale mining and spent shale disposal, and provides background for the discussion of more specific environmental impacts in Chapter 15.

It has been estimated that 1.5 trillion barrels (240 billion m^3) of oil are contained in the oil shale deposits of the Green River Formation in Colorado, Utah, and Wyoming, although a much smaller quantity is practicably recoverable. The amount of recoverable oil contained in 25-gal/ton (0.1 m^3/1000 kg) grade or higher shale (suitable for above ground retorting) is estimated to be 240 billion barrels (38 billion m^3), of which 83 percent is located in the Piceance Basin of Colorado.[1] A 1 million B/D (160,000 m^3/D) industry operating for 20 years would only recover about 3 percent of this amount, however.

The physical form of the resource is not liquid oil but a solid organic material called kerogen, which is imbedded in a marlstone matrix. Only about 15 percent by weight of the oil shale is kerogen (for 30-gal/ton or 0.13 m^3/1000 kg shale). The remaining marlstone component of oil shale is a relatively useless material, which must be disposed of after the kerogen has been converted to liquid form and recovered. The fact that the organic portion of the shale constitutes such a small portion of the resource has important implications for the future of oil shale development. The recovery of even a small portion of the oil shale of the Green River Formation would bring about the largest mining operation in the history of mankind.

A mature oil shale industry of 1 million B/D (160,000 m^3/D) would involve the mining of 1.4 million tons of oil shale per day, and the disposal of 1.2 million tons (1.1×10^9 kg) of spent shale per day. The mining operation to support a single 100,000-B/D (16,000 m^3/D) retorting and upgrading plant (140,000 tons/day or 1.3×10^8 kg/D) would be larger than the largest mine now in operation in the United States--the 110,000 ton/day (1.0×10^8 kg/D) Bingham Canyon open pit copper mine in Utah.[3]

The disposal of spent shale is in itself an enormous problem. If the spent shale is disposed away from the mine, a 1-million B/D industry would fill the equivalent of a box canyon one-mile long (1.6 km), 1000-ft wide (0.3 km), and 250-ft deep (76 m) every 1.5 months. The enormity of this problem indicates that the methods chosen to deal with it will be crucial to the future of the oil shale industry.

B. Oil Shale Mining

1. Underground Mining

Mining the oil shale from the thick deposits characteristic of Colorado's Piceance Basin presents no special technical problems. The most suitable underground mining method is the "room and pillar" technique, which has been widely used in coal mining and has been established as a reliable method for oil shale mining in prototype operations by the Bureau of Mines. The numerous outcroppings of the kerogen-rich Mahogany

Zone along the canyons of the Piceance Basin provide ready access to deep-lying oil shale deposits.

The first step in the development of a room-and-pillar mine is to excavate the entrances, or adits, through which mining equipment is transported. The nature of the oil shale deposits will permit horizontal adits to be used generally, which will allow easy passage of equipment and the use of trucks to haul out the mined shale. Vertical adits may also be used, however, when horizontal adits are impractical.

Once the adits have been established, the development of the mine proceeds as follows. First, horizontal holes 30-ft (9 m) deep are drilled along the width of a "room" to be excavated. The holes are filled with an ammonium nitrate-fuel oil (ANFO) mixture, which is then detonated. The shale rubble is loaded onto large ore trucks with front end loaders for delivery to the primary crushers outside the mine. Next, a hydraulic backhoe scrapes away the remaining shale, which was fractured but did not fall away. After all the shale is removed from the room, roof bolts are installed to strengthen the roof against failure. Mining proceeds from room to room, with pillars of solid shale rock left in place to support the roof of the mine. Prototype mine experience has indicated that the optimum room size for an oil shale mine is 60 × 60-ft (18 × 18-m) with rooms separated by 60 × 60-ft (18 × 18-m) pillars.

Since the oil shale zone varies in quality, a 60- to 80-ft (18- to 24-m) thickness has to be mined to yield an average grade of shale (about 30 gal/ton) suitable for retorting. Generally, this width of deposit will be mined in two steps. First the "upper bench," 30- to 40-ft (9- to 12-m) high, will be developed as described above. Then the "lower bench" will be developed in a similar manner, with the exception that the blast holes will be drilled vertically instead of horizontally.

Figure 14-1 shows the room-and-pillar mining plan envisioned by Colony Development Operation.[3] Using 60 × 60-ft (18 × 18-m) rooms and pillars, and developing two 30-ft (9-m) benches of 35/gal/ton (0.13 m/1000 kg) average oil shale grade, Colony anticipates that 60 percent of the in-place resource can be extracted. To supply a 50,000-B/D (8000-m^3/D) plant for 20 years the mine would eventually occupy an area of 4100 acres (6.4 sq miles or 17 km^2) underground.[3]

2. Surface Mining

Surface mining of oil shale deposits that lie close to the surface will be an economical alternative to underground mining. The economy of surface mining is determined by the stripping ratio, which is a measure of the amount of overburden that must be removed relative to the amount of resource recovered. On the basis of a ratio of the thicknesses of overburden and resource, oil shale deposits may be economically surface mined up to a stripping ratio of about 2.5.[4] Thus, even some areas of the Piceance Basin, which have 1000 ft (300 m) of overburden, are amenable to surface mining due to thickness of the recoverable resource (up to 2000 ft or 600 m).

There are two kinds of surface mining--strip and open pit. For the very lowest stripping ratios (less than about 0.5), strip mining is the appropriate method of resource recovery. In this type of surface mining, which is commonly used to extract coal in the west, explosives are used to loosen the overburden and large draglines are used to remove it. Power shovels are used to excavate the exposed resource seam and load the shale onto trucks (see Chapter 13). The overburden is stored at a nearby site until a large enough area is mined to allow backfilling operations to begin.

Strip mining will probably be suitable only for oil shale deposits lying considerably nearer the surface than 1000 ft (300 m) because

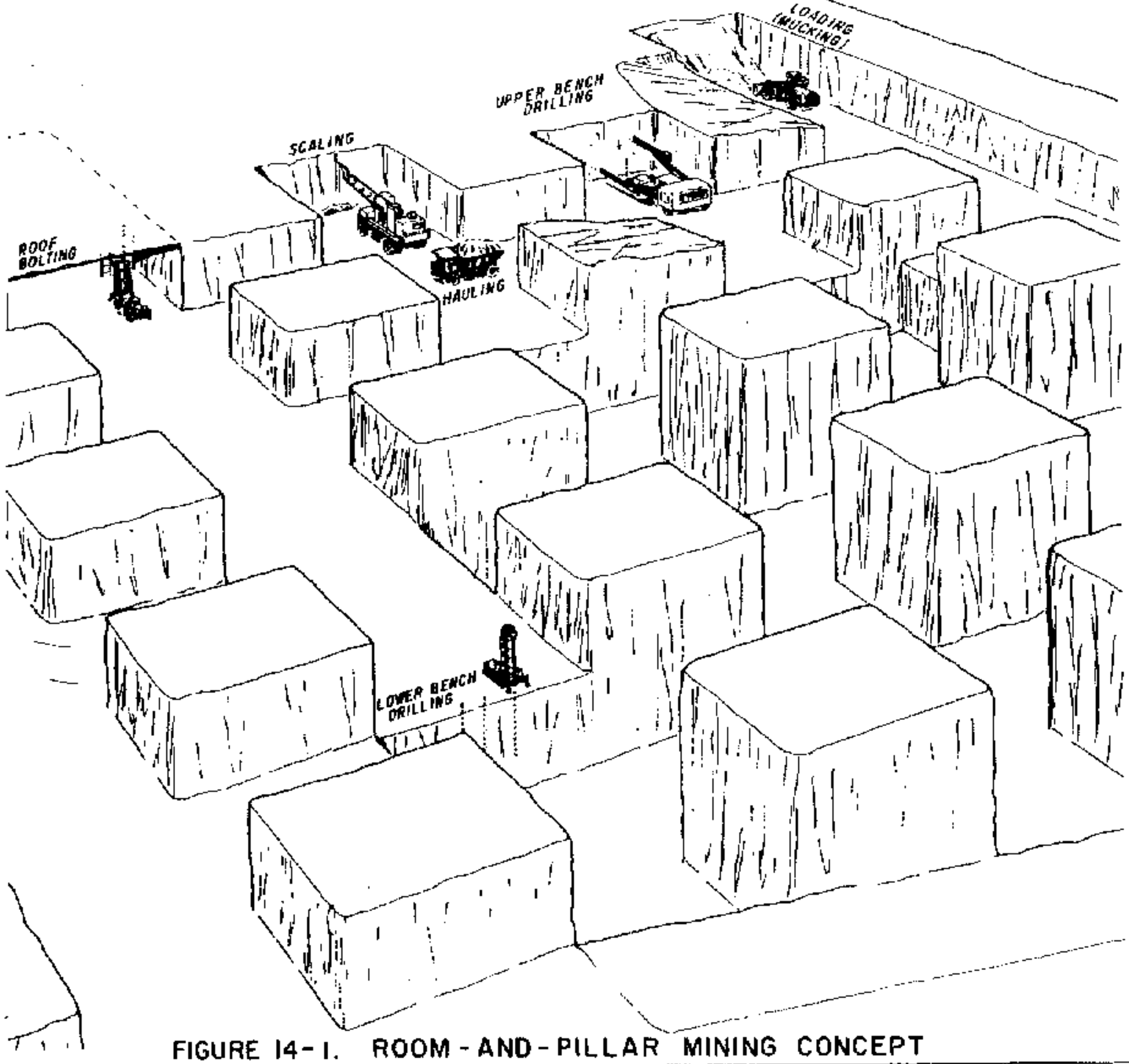


FIGURE 14-1. ROOM-AND-PILLAR MINING CONCEPT

Source: Reference 3

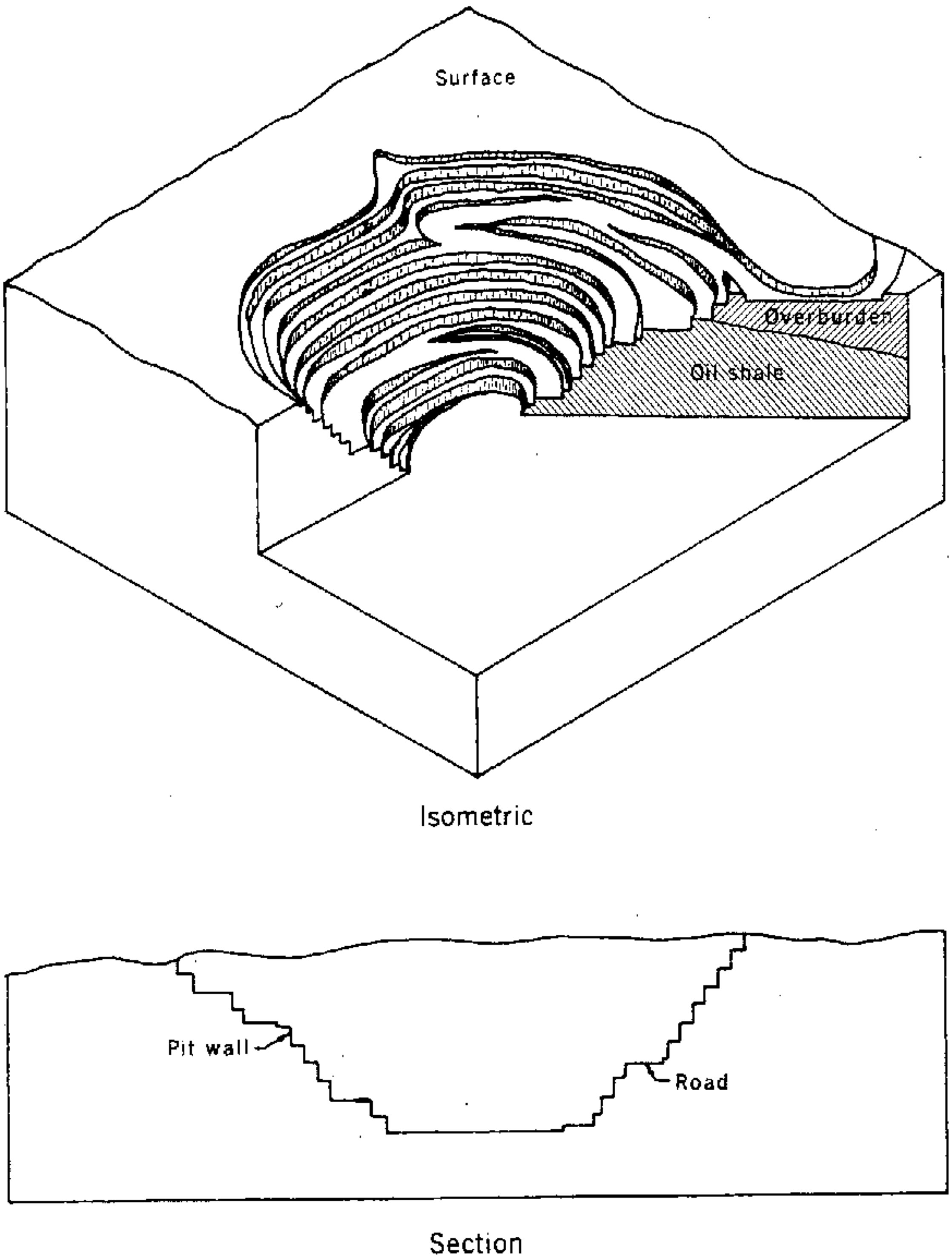
of the difficulty of excavating such a large depth of overburden with draglines. Open pit mining can be used for deeper deposits, and deposits with stripping ratios of 0.5 to 2.5 can be extracted economically.[4] In open pit mining, the overburden is also loosened by blasting; however, the ore is removed by power shovels and trucks rather than by draglines. As the pit is deepened, a series of benches are established, which provide stability for the sides of the mine. When the desired shale deposit is reached, it is loosened by blasting, loaded onto trucks, and conveyed to the crusher. Figure 14-2 illustrates the characteristics of an open-pit mine.

In open pit mining, as in strip mining, large amounts of overburden are generated, and a suitable site for storage must be found. Eventually, all the overburden can be returned to the mine and reclamation can take place.

C. Spent Shale Disposal

After the oil shale has been mined, crushed, and retorted, approximately 85 percent of the original shale mass remains for disposal. The consistency of the spent shale may be of a fine granular form covered by carbonaceous residue if TOSCO II retorting is used, or a chunky material similar to agglomerated ash if the Paraho or another gas-combustion-type retort is used.[5] In either case, the spent shale is a relatively uselesss material, the disposition of which poses a major problem in oil shale development.

Most plans for oil shale development call for the disposition of the spent shale in canyons near the retorting operation. The plan is to spray the hot shale with water as it exits the retorts to cool it and control the dust, and then to transport the waste by conveyor belt to the disposal site.[3] There it will be graded, compacted, contoured



Source: Reference 5

FIGURE 14-2. SCHEMATIC OPEN PIT DEVELOPMENT and eventually revegetated, once the pile has reached its final height. Compaction will be required to minimize erosion and leaching of the pile, and to prevent the collapse of the pile's leading edge. In addition, the slope of the sides of the pile can be no greater than a three- or four-to-one grade if sliding is to be prevented.[5]

Runoff from the pile due to melting snow and rain will be highly saline due to the high concentration of salts in the spent shale. Therefore, a catchment dam must be constructed at the foot of the pile to collect runoff so that local streams are not contaminated.

Some of the spent shale can be returned to the mine. This is most readily accomplished if surface mining is employed, since it can be done in conjunction with the return of overburden to the mined-out areas. Spent shale can also be returned to the mine if underground mining is employed, but it will be more difficult because it will interfere with mining operations. In addition, the return of spent shale prohibits future recovery of shale contained in the pillars or in lower grade deposits.

In either case, disposal problems will remain since the volume of shale expands under retorting (10 to 30 percent, depending on the retorting process used) and not all the spent shale can be returned to the mine. Furthermore, temporary disposal sites will still be required since several years of mine development are needed before backfill operations can begin.

D. Environmental Problems

1. Mining

The environmental disruption associated with oil shale mining is typical of that of any large surface or underground mining operation, except that the sheer size of the operation will mean that the scale of the disruption will be much greater than any previously encountered.

Clearly, underground mining will cause the least ecosystem disruption. The major surface disturbance is the construction of roads for mine access. Surface subsidence should not be severe if pillars are properly placed within the mine.

Potentially serious is the contamination of aquifers in the mine area. The Mahogany Zone in which the richest shale occurs, forms an impermeable layer between the relatively pure aquifers that lie above this zone and the saline aquifers that lie beneath it in the Leached Zone. Shale mining will disturb this layer, permitting the saline aquifers to contaminate the upper aquifers, which recharge the streams of the region.[6] Furthermore, groundwater will seep into the mine from this highly saline zone, and dewatering the mine will produce large quantities of saline wastewater for disposal. To avoid the contamination of nearby streams, this wastewater must be eliminated through deep well injection or evaporation from lined ponds.[5]

Surface mining will cause similar disturbances of aquifers and saline water contamination problems. However, the major environmental disruption will be the disturbance of the area being mined and the resulting need to dispose of large quantities of overburden. Although the overburden will eventually be returned to the mined-out area for reclamation, a total of 2000 acres (8×10^6 m^3) could be disturbed per 100,000-B/D (16,000 m^3/D) operation before any reclamation would take place.[5]

2. Spent Shale Reclamation

Even under the best reclamation strategies, the naturally occurring ecosystems of the canyons in which the spent shale may be deposited will be completely covered and destroyed. The goal of reclamation is to establish a new ecosystem on the spent shale piles, which can be self-sustaining long after human involvement has ended. This goal involves stabilization of the pile against erosion and sliding, establishment of a suitable plant cover, and ultimately the generation of a plant succession system similar to other systems in the area.

Stabilization of spent shale from TOSCO II retorting appears to be possible with the appropriate amount of compaction and careful grading of the pile. After one or two years of natural weathering, the surface layers may be leached enough to reduce the salt concentration to a point where plant life can exist.

Research carried out by Colony Development Operation, and others, has indicated that a wide variety of plants can be grown if the spent shale pile is carefully fertilized and watered. However, only a few types of wheat-grass will survive on unattended spent shale.[7] Revegetation of the type of spent shale created by other types of retorts may be more difficult due to its clinker-like quality.

In general, the prospects for achieving a long-term stable ecosystem on massive spent shale piles have still not been fully assessed and it remains one of the major problems of oil shale development. Additional discussion of spent shale revegetation problems can be found in Chapter 15.

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15--REGION SPECIFIC BIOLOGICAL IMPACTS OF RESOURCE DEVELOPMENT

By Buford R. Holt

A. Powder River Basin

1. Introduction

Three significant classes of biological impacts can be important in the Powder River Basin of Wyoming:

- Retardation of revegetation by drought, erosion, heavy grazing, and spreading of toxic spoils.
- Adverse behavioral modification of big game and small game predators by mining and coal transport activities.
- Destruction of locally rare habitats.

The sections that follow focus on the environmental setting, major sources of impacts, and the potential for mitigation. Accounts of lesser impacts and additional biological detail can be found in the Final Environmental Impact Statement for the Eastern Powder River Coal Basin of Wyoming.[1]

2. Environmental Setting

The Powder River Basin is a broad, shallow topographic depression superimposed on a structural basin. The landscape consists of low, gently rolling hills, interrupted by broad flood plains containing shallow braided streams. Buttes, mesas, and rough, hummocky terrain add minor but significant diversity to the generally featureless terrain.

The climate is typically arid with frequent, unpredictable droughts. Most of the precipitation is derived from summer thunderstorms.

The winter snows are light and the snowmelt usually runs off before the ground thaws. Soil moisture is sufficient in the wettest years to support dryland farming, and lands near the Powder River Basin were plowed after the First World War, contributing to the subsequent dust bowls of the thirties. Comparable abuse by overgrazing has also been fostered by a tendency to be misled by the relatively high forage yields of the wettest years, resulting in substantial overstocking in the drier years. Consequently, the range in the basin has been severely degraded by decades of overgrazing.

The soils are generally clayey, with slow to moderate internal drainage. Contrary to experience in humid regions, these clayey soils have less available water than sandy soils and are dominated by the more drought-tolerant species of the short grass prairie and elements of the cold deserts to the west. Water infiltrates more slowly into the fine textured soils and is more readily lost since even the fraction which penetrates below the first few inches can move to the surface by capillary action and is subsequently lost. On sandy soils water penetrates quickly and deeply, with loss only of that fraction in the surface layers. Correspondingly, the soils with the best moisture relations are the coarse textured soils of the scoria (baked shale) outcrops and the fine textured soils along stream courses. However, although they are deep and moist, the latter are generally either saline or alkaline and could be troublesome to rehabilitate if the underlying coal is strip-mined.

The vegetation of the basin is chiefly stunted plants of big sagebrush and sparse stands of blue grama, a drought-tolerant grass. Desert shrubs and arid grassland species dominate the overgrazed uplands and gentle slopes that prevail in the Basin, but pine forests cover the hills bordering the basin, and tall shrub communities line the larger, intermittent streams. Within the shrub and grassland communities, these conspicuous patterns are paralleled by significant variations in species composition even though the local variation in elevation is generally less than 100 ft as shown in Figure 15-1. The scoria outcrops are covered mainly by bluebunch wheatgrass and blue grama but contain several of the grasses characteristic of the wetter prairies to the east, including little bluesteam, prairie sandreed, and Indian ricegrass. Some of these more demanding grasses such as needle and thread are also found on the loamy upland soils where relatively good infiltration and storage of water can be expected. The big sagebrush-blue grama mixture predominates on the drier, clayey soils on the prevailing sideslope terrain (Figure 15-1a, 1b). Western wheatgrass and other salt-tolerant species dominate the relatively moist and productive alluvial lands. The dominant grasses within each vegetation type consistently include both cool and warm season grasses, designations based on the periods of maximum growth. However, these differences in the seasonality of growth are also correlated with differences in water loss during photosynthesis and may make the warm season grasses slightly more suitable for initial reclamation efforts. The establishment of both groups of grasses is necessary to maximize productivity over the entire growing season and to maximize the availability of the nutritionally superior new foliage throughout the calving period.

The dominant vertebrate land animals are small mammals and birds, with a conspicuous lack of large predators. Coyotes, badgers, foxes, and bobcats are the largest native predators in the Basin, but smaller ones also occur, including weasels, raccoons, and the black-footed ferret (an endangered species).[1] The big game species are limited to elk, mule deer, antelope, and white-tail deer. Small game species include sage grouse, wild turkey, sharp-tailed grouse, ring-necked pheasant, and cottontail rabbit.

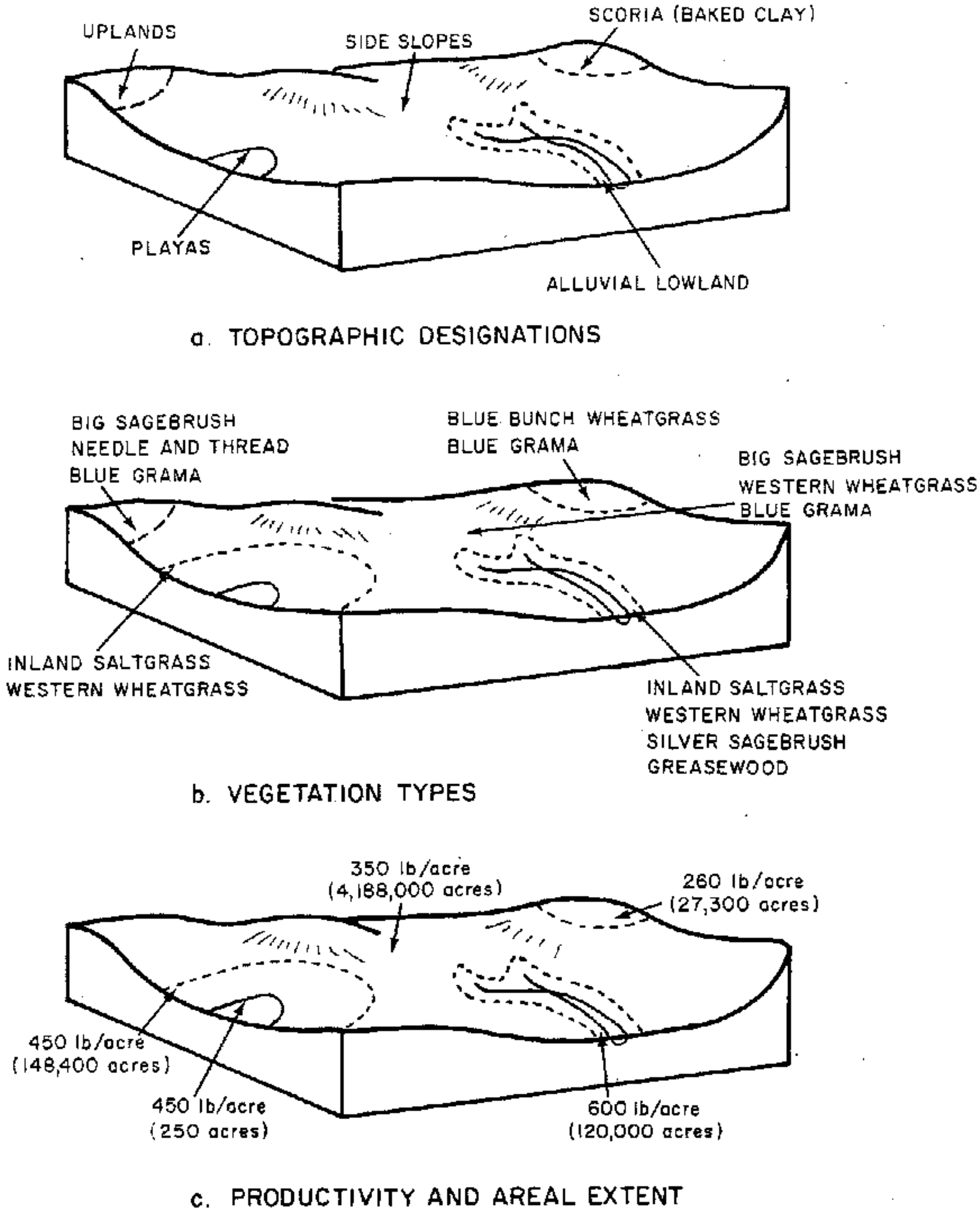


FIGURE 15-1. NATURAL LAND UNITS OF THE POWDER RIVER BASIN

Invertebrate animals (insects, spiders, snails, etc.) have been little studied in the Basin, apart from surveys of species important to game fishes. Even so, these data on aquatic invertebrates should be useful as indicators of changes in water quality, and the available baseline data should be augmented.

The aquatic vertebrates are mostly warm-water fishes, reflecting the shallowness of the sparsely shaded streams and the consequent high summer temperatures and the fluctuations in water level and turbidity, which result from irrigation use. Most of the fish species are small, nongame species, but game species include large and small mouth bass, bluegills, and catfish, and, where water quality permits, various species of trout.

3. Immediate Impacts

It is unlikely that adverse effects on the animal population will be significant early in the exploitation of the Powder River Basin, but those that do occur will probably result from changes in the movement and distribution of game species or their predators.

The causal mechanisms are likely to arise from seemingly innoculous barriers such as sheeptight fencing, which antelope can leap over but frequently do not.[1] (Paradoxically, the antelope typically crawls under fencing rather than jumping it even though it is a conspicuously good jumper.)[2] Similarly, erection of utility poles may significantly increase the intensity of predation on small mammals or breeding grouse by providing perches for predatory birds, although large raptors are frequently killed when over-extended nests get wet, droop, and cause shorts. An analogous impact of fencing on songbird distributions, however, probably will not be important since shrubs provide an abundance of perches for songbirds. Conversely, some of the more conspicuous landscape changes, such as the fragmentation of shrubland corridors by mining activity, may not affect game movements in the Powder River Basin because the big game species are either highly local in their movements, such as the white-tail deer, or exceptionally wide ranging, such as the mule deer and elk, species which readily travel across grassland.

4. Cumulative Impacts

The most extensive impacts will derive from the destruction of habitats during mining and the subsequent replacement of the present shrub-grass mixtures with predominantly herbaceous vegetations of potentially lower productivity, thereby removing deer and antelope winter browse plants.

The magnitude of the potential productivity changes of these mined landscapes is the subject of dispute.[1] It is unlikely that the productivity of the reestablished vegetation will be much larger than the overgrazed range which they replace, without routine irrigation and reductions in the grazing intensity. The upper limit of productivity on these lands, even if well managed, probably will be less than the current maximum of 600 pounds of forage per acre characteristic of the wettest sites and may, as the Powder River Environmental Impact Statement (EIS) suggests, be as low as 200-500 pounds per acre, approximately the present productivity of scoria lands. This lower estimate is markedly below the present productivity of 350 pounds of cattle forage per acre of the dominant sagebrush vegetations and if the estimate is accurate it represents a long-term reduction in productivity of 25-50 percent.

Impacts attributable to modifications of productivity and the species composition of the vegetation will be greatest for the deer populations and least for the elk, which inhabit the pine forests just to the east of the strip-mine areas. The elk, however, are expected to be heavily affected by the increased human activity in the vicinity of the mines with a consequent reduction in the acceptability of an otherwise usable habitat.[1] Impacts of increased human activity should be minor for most small game; this may possibly cause declines in rabbit populations, and possibly long-term increases in prairie dog abundance. If the latter is true, the vegetation changes set forth in the EIS might enhance the survival probabilities of the black-footed ferret, an endangered predator of prairie dogs.

However, impacts on wildlife should be greater than productivity reductions alone would indicate since shifts in the species composition of the vegetation are probable and may be drastic. Deer and antelope depend on shrub forage much of the year, and elk utilize shrubs seasonally.[1,3] Correspondingly, deer and antelope utilize little grass, mostly in the spring when the carotene, digestible protein, and phosphorous contents are adequate. However, the magnitude of the effect of shrub removal will depend partially on the species removed and their location, for the shrublands comprising the winter range are the most critical, and their removal would most heavily affect the big game populations.[1]

The greatest long-term impacts on rare and upland game species will probably derive from the destruction of winter ranges, mating grounds, or tall shrub-woodland habitat. With the exception of the tall shrub and woodland habitats, which are essential for white-tail deer and elk throughout the year, these impacts involve the destruction of environments needed during restricted, but crucial portions of the organism's life cycle. For example, it is not clear that man can reproduce the environmental conditions necessary for the formation of a grouse dancing or strutting ground. However, it is probable that winter range for deer and antelope can be recreated by replanting shrubs,[4] although economic pressures may preclude this in private lands.

Restoration of stream habitats to their original mix of meanders, pools, and riffles, is improbable and certainly the thin shade provided by greasewood will not be quickly restored. Consequently, it is probable that mining activities in the Powder River Basin will severely affect local fish populations, may seriously impact local upland game species, and may reduce or eliminate at least the elk herd in the hills immediately to the east of the mines. The latter impact is perhaps the most serious, for the other species are widespread. The elk is largely confined to the western mountains and portions of the Canadian wilderness, even though it was once widespread throughout the North American woodlands east of the Rockies.[2]

5. Mitigation

Presently anticipated mitigation of the impacts of fencing, stream diversions, mining, and urbanization is largely limited to restoration of the original gently rolling topography and the reestablishment of vegetation in the mined areas.[1] No mention is made in the EIS of any plans to rehabilitate streams, possibly reflecting their minor economic importance of the wildlife which they contain.[1]

The probability of successful rehabilitation of terrestrial vegetation is moderate if the mine spoils are carefully layered and appropriate steps are taken to facilitate vegetation establishment.[5] Rehabilitation efforts have been moderately successful in areas receiving at least 10 inches of rain, even in the absence of irrigation.[5]

However, the rehabilitation programs are still young, and it is too early to appraise their success in the face of the recurrent droughts characteristic of the western plains. Moreover, appraisals to date have focused on the mass of plant material produced to the exclusion of their nutritional value. Since the species used typically provide good forage, the implicit assumption of high nutritional quality is probably sound, but the possibility remains that deficiencies of biologically essential elements in the new soils, and hence in the forage, may necessitate the addition to the soil of trace elements such as cobalt or copper. However, the data base on rehabilitation covers a broad enough range of sites to permit eventual refinement of appraisals of rehabilitation steps that will be necessary on the most difficult sites.[5]

The preliminary data from these rehabilitation experiments are sufficient to rank the rehabilitation probabilities of various sites within the West. The most difficult sites to rehabilitate are really the least extensive but most are in the Powder River Basin.[5]

The principal, universal constraints on rehabilitation in the West appear to be drought, inadequate seed sources, excess salinity, premature grazing, and the necessity for reshaping and appropriately layering the spoils.[5] In some areas instability of the soil surface must be added to the list,[5] as must frost-heaving on clay-rich soils during the relatively wet winter months.[6] Mitigation of all these constraints is feasible for small areas, but the prospect of mitigation of drought and grazing constraints over the large areas that would be involved over the 5-25 years variously estimated as the minimum duration of "post rehabilitation" is questionable. Indeed, the magnitude of the rehabilitation, irrigation, and fencing operations under those conditions probably would warrant an environmental appraisal in themselves.

Availability of suitable seed stock is considered to be a significant constraint for floodplain and badlands (severely eroded) sites,[5] but it should not be an unsolvable problem since cottonwood and willow are easily propagated by cuttings in the East, and research with mechanized planting techniques for upland shrubs is well advanced in the West.[4] Similarly, the greater availability of seeds of tall and mid-grass prairie species[5] probably owes more to the development of commercial markets for them in recent years than it does to any inate superiority over western grasses for successful seed production.

The salinity problems cannot be easily avoided in all cases, but they can be minimized by reliance on sandy soils as top-dressings. Use of sandy top-soils would have the subsidiary benefit of good soil-moisture relations, for in arid regions sandy, not clay-rich soils contain the maximum amount of water that is available for plant growth. In arid regions, clay soils are seldom wetted deeply and the deeper bodies of water are readily lost through capillary movement and subsequent envaporation. In contrast, water infiltrates fairly deeply into the sandier soils, and is retained in all but the upper two to three centimeters due to the absence of capillary movement.[7] The moderately sandy soils also tend to be less erosion-prone than the salinized clay-rich soils[5] and should minimize the probability of frost-heaving of young plants.[6]

Protection of young plants during the establishment phase will be consistently difficult because new tissues are typically the most nutritious and most highly favored by grazers.[3] Erection of sheeptight fencing around the newly revegetated areas should reduce this hazard, but it will be at best an expensive, partial solution. To the extent that it is effective, however, it reduces the winter range of antelope in the short run.

In all cases, however, the addition of top soil as surface coating (top-dressing) enhances success of vegetation establishment.[8] In the absence of irrigation and fertilization, native species can be expected to yield 2-3 times as much forage as introduced species. If ample fertilization and irrigation are available, the introduced species yield perhaps 10-20 percent more than the native species.[8]

In summary, successful rehabilitation appears to be feasible in wet years on sites recovered with the regional soils, but the success of rehabilitation programs in drought years is yet to be appraised.

B. Piceance Basin

1. Introduction

Environmental impacts in the Piceance Basin are dominated by three factors.

- Unsuitability of shale residues for plant growth without intensive supplemental management.
- Chronic drought and meager supplies of water for supplemental irrigation.
- Instability of many of the ungullied riverbottoms, causing substantial risks of heavy erosional damage and downstream sedimentation.

On balance, reclamation costs are likely to be higher in the Piceance than in any of the western or eastern coal fields because acid wastes and acid drainage excepted, the factors that most strongly limit reclamation in the coal fields are present. In addition, there is an immense problem of saline drainage.

The sections that follow focus on the environmental setting, the major sources of impacts, and the potential for mitigation. Additional detail can be obtained from the Environmental Impact Statement for the Colony Development Operation[9] and the Colorado State University report on surface rehabilitation potential.[10]

2. Environmental Setting

The Piceance Basin is a tectonic feature in arid, northwestern Colorado, which is overlain by a topographically diverse landscape. The "basin" is divisable into a rugged southern section, cut by thousand-foot canyons, and a more subdued northern plateau. The southern portion is characterized by dendtritic drainage patterns with deeply incised streams and marginally stable valley bottoms.[10] Although these streams apparently are not transporting significant sediment loads out of the basin now, any action that significantly increases runoff would trigger massive and rapid erosion with consequent sedimentation downstream, which would cause biological impacts well outside the oil shale region itself.

The soils in the Piceance Basin are typically shallow, weakly developed, and stony. The surface horizons are thin and lack conspicuous organic layers except in the forested regions. The subsurface temperatures are quite low, reflecting the low mean annual temperature. The soils are typically dry during all or most of the warm season, when growth would otherwise be most favorable.[10] A fairly broad spectrum of soils occurs within the region, but the more fertile ones are rare and typically restricted to the canyon bottoms and the floodplains of the major streams.

The climate is characterized by cold winters, warm summers, and chronic drought. Annual precipitation ranges from 12-15 inches with approximately two-thirds occurring as snow, and the rest as thunderstorms.[10] The frost-free season ranges from 90-120 days.[10] Snowmelt occurs as late as June[11] and initiates the period of highest runoff. Minimum stream flows occur in February when the soils are frozen and the snowmelt is mimimal.

Surface runoff averages less than an inch per year,[11] but is strongly pulsed, such that the erosion and flash flood hazards are great throughout the region. The dissolved solids content of the surface waters is moderate, as is water hardness.[11] The ground waters are meager and saline at shallow depths.[11]

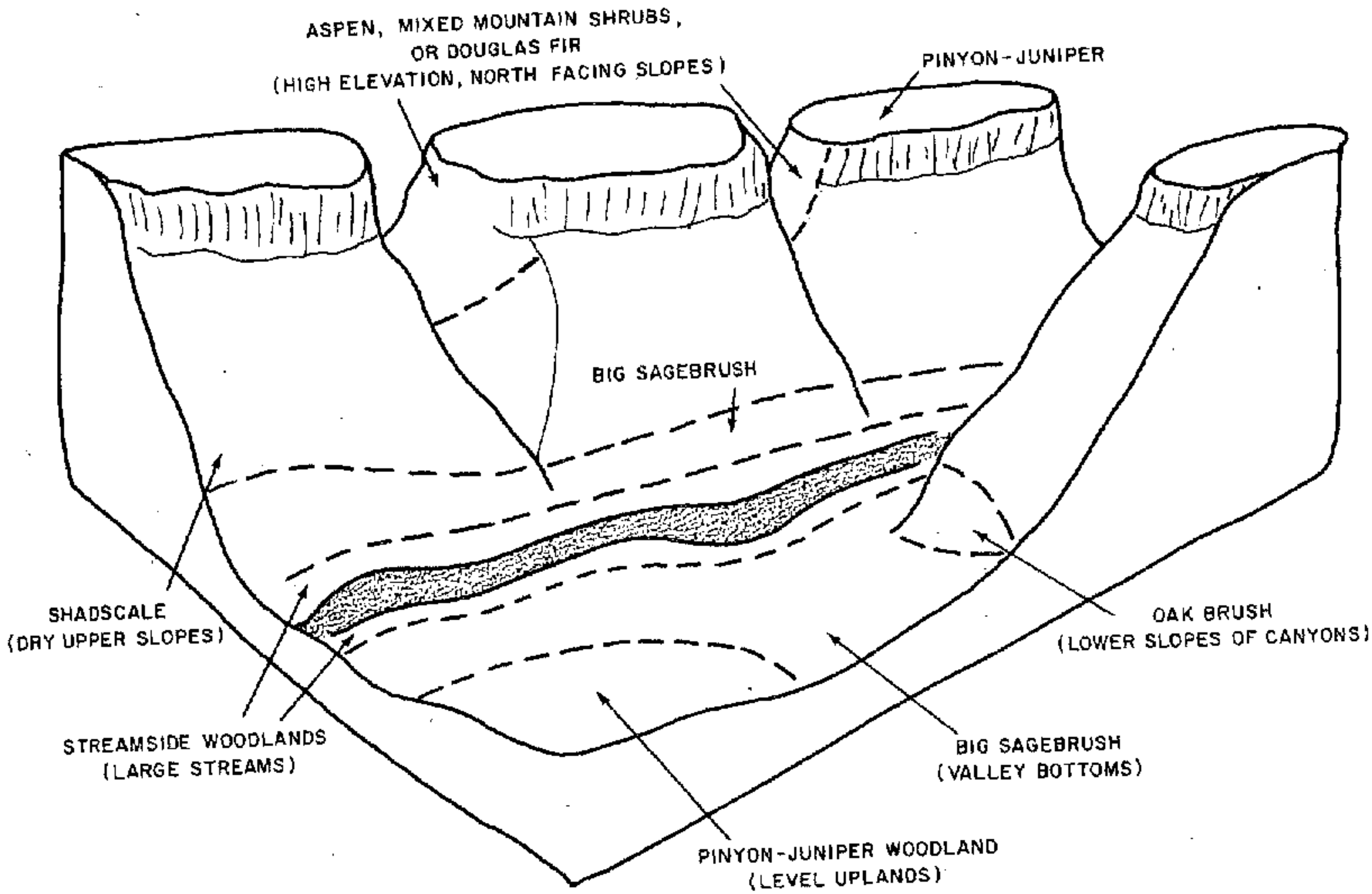
The vegetation of the basin is dominated by pinyon-juniper woodlands on the plateaus, tall shrub communities in the highly dissected southern region, and sagebrush communities on the fine textured, seasonally moist stream bottom soils in both regions. Riparian or gallery forest occurs along the larger streams in the south where water is available throughout the warmer months.[10] These gross characterizations are explicable in terms of the seasonality of water availability and the amount of water that is available during the respective growing seasons. The region as a whole is arid, but the lower temperature prevailing at the higher elevations lowers the loss rates from both plant and soil surfaces, rendering the higher elevations effectively wetter. The dominant plants are pine, juniper, and sagebrush. There are shallow-rooted species, which are metabolically active at the relatively low temperature prevailing in the spring and can effectively utilize the relatively abundant water supplies available just after the snowmelt. In contrast, the tall shrub communities of the lower elevation southern region are tap-rooted species that are metabolically active slightly later in the spring but that are able to utilize the deeper subsurface reservoirs of water that occur on the coarse textured soils of the lower valley slopes. The sagebrush species dominate the seasonally wet, fine textured alluvium in both regions, due to their tolerance of the extreme dryness of these soils during the summer months and their ability to utilize the moisture available in the late spring. On sites where the water supplies are dependable in the warm summer months, relatively rapidly growing deciduous trees such as cottonwood, boxelder, and chokecherry become dominant. Small areas of Douglas fir and aspen occur on the cooler, moister north facing slopes in the canyons at high elevations and shadscale, a desert shrub, covers the driest, steeper slopes as shown in Figure 15-2.

The terrestrial fauna of the area has received little attention to date, but as many as 100 mammalian species might be expected in the region, including 15 species of bats.[12] However, mule deer, coyotes, rabbit, and rock squirrels are the most conspicuous segment of this diverse fauna, although a number of familiar but rare species such as cougar and wild horses are to be expected in the region.[13] The reptilian fauna should be similarly diverse, with an abundance of lizards and snakes, but the amphibians are probably poorly represented. At least 62 species of birds are known to frequent the area,[14] but the total is probably at least twice that number.[15] Among these are a number of rare and endangered species such as the golden eagle, the bald eagle, the peregrine falcon, the Yuma Clapper rail, and the prairie falcon, most of which are favored targets of unthinking hunters.

The aquatic fauna is very poorly known,[13] but does include several rare species including one of potential interest as breeding stock for game fish hatcheries, the Colorado cutthroat trout.

3. Immediate Impacts

The immediate impacts of development will probably be felt most strongly in the aquatic ecosystems of the basin itself, with lesser impact on the biota of the Colorado River, and minor impacts on the upland communities. The principal hazards in the short run will probably be those associated with routine construction, particularly erosion and sedimentation.



SOURCE: ADAPTED FROM REFERENCE 10

FIGURE 15-2. VEGETATION OF THE PICEANCE BASIN

4. Cumulative Impacts

The principal long-term impacts will be associated with the mining and oil extraction processes themselves and will derive largely from the alternations in runoff, water quality, and the deposition of waste materials. An additional effect may be felt in lease tract C-a where strip mining is feasible since this tract stretches across the migration route of the White River mule deer herd, a group of possibly several thousand animals, which, unlike most deer populations, is migratory.[13] Extensive mining operations potentially could disrupt this normal pattern of movement, leading to overgrazing of portions of the herd's range and consequent long-term decreases in the herd size.

At full production (as the maximum credible implementation scenario), with approximately 20 retorting plants in operation, there is a possibility that the water flowing through the major streams in the area, Piceance, Parachute, Roan, and Yellow Creeks, may be significantly increased from runoff derived from disposal of spent shale.* However, the relative importance of evaporative losses and surface drainage are very sensitive to the disposal practices used. Losses are only likely when the spent shale deposits are watered with more water than needed simply to keep the surface wetted, which in this water-deficient region is most likely to occur during efforts to reestablish vegetative cover. If a water surplus is not added, or steps taken to provide a barrier to upward movement of capillary water, salt will accumulate to toxic concentrations in the surface soils. If these soils are rich in clays,

*The estimated 8000 acre-ft per year of water that will be needed to wet down the spent shale and reestablish vegetation for a single oil shale processing plant represents the runoff from a square area approximately 14 miles on a side; for the basin as a whole with 20 plants operating, the water needed would be about twice the runoff occurring naturally.

salinization will cause dispersion of the soil particles, making the soil impervious and causing substantial increases in runoff. If simple overwatering is used as an inhibitor of salinization of the surface soils, substantial leaching of the underlying deposits of spent shale can be expected. Either method of water manipulation alone may consequently destabilize the stream bed deposits and cause massive erosion.[10] If this occurs rapidly, the biota of these streams will probably be decimated, although eventual recovery should follow the development of enlarged channels.

Impacts on stream biota can also be expected if local streams are used as water sources for dust control programs on roads and waste dumps. Removal of substantial fractions of water would tend to cause replacement of the biota of permanent streams by organisms characteristic of intermittent streams. Particularly strong reductions in the larger sized classes of those species that are most susceptible to human or avian predation due to restriction to isolated pools, lead to reductions in their breeding stocks.

Changes in salinity or in the suspended sediment concentrations will significantly affect the biota of the streams within the "basin," and, if sufficiently large, also within the Colorado River. Moreover, the latter impact is more difficult to appraise because the salinity and sediment concentrations are both high now and the percentage change expected is small.[16] Nonetheless, small increments have enormous biological and economic significance when the baseline values are near the limits of tolerance of the species at risk. One must also factor this into evaluations of the economic utility of energy extraction when the increased salinity requires that an energy intensive desalinization be undertaken downstream to meet international treaty obligations.

The prognosis for the probable impacts on terrestrial biota is less ambiguous but equally grim. The overburden in strippable areas consists of mixtures of limestone, siltstone, shale, and sandstone that yield rather coarse particles under the handling conditions that appear economically feasible.[1c] While sand-sized particles enhance moisture availability for plants in arid regions by allowing rapid, deep penetration of the water, the larger particle sizes to be expected in the overburden spoils will retain too little water to sustain early growth. The spent shales, on the other hand, are almost wholly comprised of small particles, ranging in size from that of sand (< 2mm diameters) down to silt and clay (< 0.002 mm). As a substrate for plant growth, they are particularly unfavorable due to the previously mentioned aridity of the region, their dark coloration, and the lethally high temperatures that occur at the surface of spent shale piles. Moreover, spent shale is highly resistant to wetting, a property of some arid soils in the West, soils which are notably slowly revegetated following disturbances.

5. Mitigation

The basic mitigation steps for reclamation of spoil heaps and spent shale dumps broadly parallel those described for the western coal fields. It is essential that care be given to the stockpiling of soils and weathered rock, in strip-mined areas, for use as top dressings on the spoil heaps; that care be taken in the selection of the plants used for revegetation; that operations be planned whenever possible to capitalize on the relative moistness of north facing slopes; and that reclamation proceed closely behind the stripping or dumping operations. Spent shale will probably require additional steps to prevent wind erosion during the disposal process and to prevent subsequent salinization of the upper layers of the reclaimed waste piles. The former objective can be achieved by continual wetting of the surface, although at enormous costs in water consumption, but it might also be achieved by spreading a layer of gravel on the surface to form an artificial desert pavement at the end of any given dumping program. The second problem might be solved by laying a sufficiently thick layer of gravel on the spent shale before adding the top dressing of soil to prevent upward movement of salt-laden water by capillary processes. Such a coarse layer would prevent salinization of the surface soil and, by reducing the volume of water needed for revegetation, should reduce the impact of leached salt on the surface waters of the region. Soil for the reclamation of the spoils resulting from underground mining could be obtained from the meta-stable deposits of the streambeds with the side-benefit of reduced hazard of mass erosion, but these soil and weathered rock supplies may be grossly inadequate. If so, dredging in the Colorado River may be environmentally and economically acceptable as an alternative.

Impacts on streams within the "basin" can best be mitigated by pacing development to preclude abrupt changes in water quality and quantity but some impact seems unavoidable.

C. North Dakota Coal Fields

1. Introduction

The principal impacts in the North Dakota lignite fields should resemble those of the Powder River Basin but should be much less intensive. The principal differences are:

- Rehabilitation potential in North Dakota is higher due to greater water availability and soil fertility.
- Less disruption of wildlife habitat will occur in North Dakota due to prior conversion of substantial acreage to cultivation.

Destruction of regionally rare aquatic and streamside habitats remains a potential impact, although these mining impacts are dwarfed by the impacts of the dams constructed by the Corps of Engineers on the adjacent Missouri River.

The sections that follow focus on the environmental setting, the major impacts, and the probability of successful rehabilitation of the land assuming appropriate layering and reshaping of the soils.[1]

2. Environmental Setting

Broad, level uplands and gentle slopes dominate the topography although occasional hills and broad river valleys provide some diversity. To the east and north, the region is bounded by the bluffs and broad floodplains bordering the Missouri River, and to the west, by the badlands of the Little Missouri. Southward, the gentle terrain of the coal fields continues to South Dakota without interruption. Wetlands are rare southwest of the Missouri, but the regions eastward and downwind of the mining and industrial region are dotted with small ponds that are heavily utilized by migrant and breeding waterfowl.[11,17]

The climate in the coal fields is characterized by extremes of temperature and precipitation similar to those in the Powder River Basin, although the temperature range in North Dakota is larger and the moisture range is generally less than in the Powder River Basin. Precipitation is more strongly concentrated in the summer in North Dakota than in the other western coal fields, which, combined with the slightly lower summer temperatures, makes the effectiveness of precipitation in North Dakota greater than in the Powder River Basin.[18]

The soils of the region are loamy, slightly alkaline, moderately deep (up to 2 ft), with relatively high sodium concentrations.[5,19] As a consequence of the relatively high sodium and clay contents, formation of large soil particles (aggregates) is impeded in these soils and they are consequently readily eroded, particularly following repeated freezing and thawing.[1,5]

The vegetation of the Dakota fields is a mosaic of rangeland and small grain fields, with rare strips of woodlands along the major streams. The western border contains a small forest of ponderosa pine and the Little Missouri National Grasslands, which consists of farms that were abandoned during the dust bowl years of the 1930s. The woodlands along the Missouri, the Knife, the Little Missouri, and the Spring rivers consist of cottonwoods, elms, green ash, and boxelder, with small amounts of bur oak on the better drained river terraces.[20] These are rapidly being cleared for cultivation, now that the flood frequency has been greatly reduced by the construction of major dams on the Missouri, but they still provide extensive deer habitat.[20] The rangeland vegetation resembles that of the Powder River Basin with the exception of the greatly reduced incidence of shrubs[20,21] and the significantly higher productivity of even the poorest of the North Dakota sites. The range of forage production in the North Dakota is 980-1600 lb/acre,[21] roughly three times the productivity of the Powder River grasslands where approximately 50 acres are needed to support one cow.[1] The uplands are typically characterized by silty soils covered by stands of buffalo grass and needle and thread, while needle grass and little bluestem cover the relatively moist slopes of the steep-sided ravines that occur at the ends of the local drainage systems. Prairie dropseed and needlegrass dominate the sandiest ravine bottom soils.[21]

The vertebrate fauna of the fringes of the lignite fields are quite diverse due to the diversity of habitats provided by the mixture of urban, riverine, agricultural, and range environments. Approximately 150 species of birds are reported for the Missour Valley Region of North Dakota, including substantial numbers of woodland and aquatic species.[20]

Although censuses do not appear to be readily available, the number of species actually occurring in the lignite fields should be substantially smaller, due to the rarity of wetlands and forest. The major wetlands, and consequently the major waterfowl breeding areas are to the north and east of the Missouri River,[17] but there are four wildlife refuges within the lignite region.[22] Similar but less pronounced declines in species diversity with distance from the Missouri River may occur among the mammals and will surely occur within the amphibians, while reptiles may increase in diversity. In general, diversity among North American mammals increases with aridity, and particularly with increased variability in rainfall; extrapolating from these general patterns, it would appear that the mammalian fauna reported for the region do not reveal their true diversity.[23] Mule deer are the largest common mammals although cougar and black bear have been sighted in recent years.[20] The fish fauna is fairly well known, with preponderance of warm or turbid water species (i.e., species tolerant of low oxygen levels during the hottest months). As a whole, vertebrate fauna are dominated by small, geographically widely dispersed species, apparently lacking notable populations of rare or endangered species.

Invertebrate fauna have received exceptionally little attention apart from the grasshoppers which are economically important pests regionally.[20]

3. Immediate Impacts

Significant impacts are unlikely in the short run except in the highly localized areas of activity. Certainly, immediate impacts associated with road construction and mining should be less than in the Powder River Basin where the existing network of roads and fencing is less dense. Nor is significant restriction of the movement of game likely since the species present are either small or readily jump fences.[20]

4. Cumulative Impacts

The most significant impacts in the North Dakota coal fields are likely to be the destruction of the less common habitats such as steep slopes, which would be extremely difficult to reestablish. Such sites are characterized by locally unique combinations of microclimate and water availability, and consequently maintain distinctive plant communities. Apart from the eradication of these western representatives of the eastern prairies, the ultimate impact of mining should be modest if reclamation proceeds closely behind the stripping operations and is conducted with care. The soils are somewhat saline and become increasingly so with increasing depth, and spoils from the deeper layers rapidly become impermeable to water. Raw spoils particularly from the deeper layers are consequently exceedingly difficult to reclaim, but sites treated to a topdressing of material from within 10 ft of the surface typically have the highest reclamation potential of any within the Great Plains coal fields, due to the relatively favorable water balance prevailing in the region.[5] Disruption of lands along the river fringes due to coal development is likely to be minor relative to the changes already occurring in species composition in the floodplain forest in response to changes in the flooding regime caused by the major dams on the Missouri.[24]

5. Mitigation

Mitigation measures applicable in North Dakota are the same as those described in the appraisal of the Powder River mining operations. Their application in North Dakota is facilitated, however, by the greater availability of suitable seeds and water, and an academic base of experience in prairie reestablishment. However, care must be taken in those portions of both regions that have stony soils not to create gravel layers too close to the soil surface since they form an effective barrier to root penetration in arid regions.[25]

D. Illinois Coal Fields

1. Introduction

Three impacts dominate the Illinois coal region:

- Destruction of prime agricultural land.
- Production of acid drainage.
- Potential destruction of the floodplain forests of the Wabash River.

Impairment of wildlife habitat and destruction of natural ecosystems are generally not problems in Illinois due to the prior impacts of agricultural land uses, which have left only rudimentary fragments of the original prairies in cemetaries and along railroad rights of way. The dominant wildlife species are typified by Virginia deer and ring neck pheasant, both of which depend on the habitat fostered by man, and consequently tend to increase with increased human activity in humid regions.

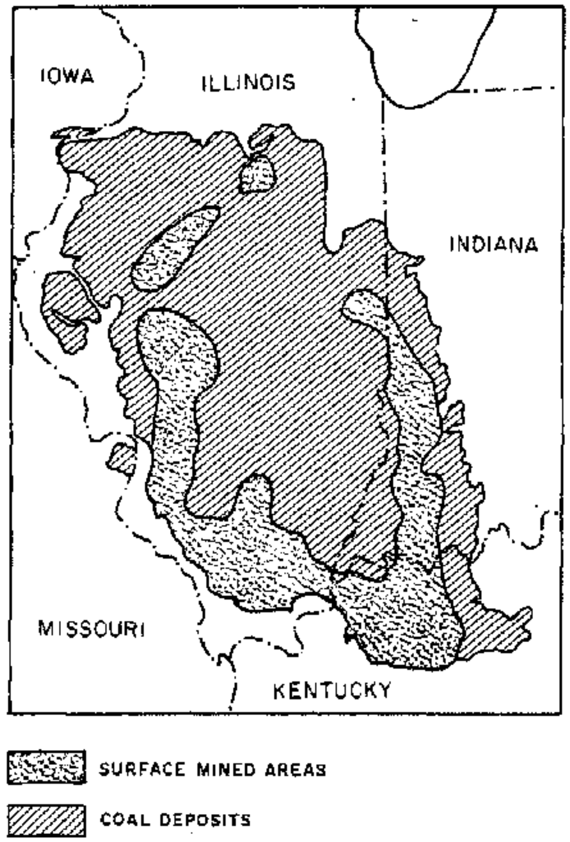
Rare or endangered species are unlikely to be threatened throughout northern and central Illinois, but do warrant consideration along the extreme southern fringe of the Illinois coal basin where the unglaciated terrain is characterized by usually rugged topography and underlain by extensive cave systems. This combination of topographic diversity and absence of glaciation have permitted the persistence of a number of endemic plant species as well as a number of broadly distributed species, which reach their northern distributional limits in southern Illinois. The vegetation of the southern fringe of the coal basin is consequently distinctive and rich.[26] The Wabash floodplain represents a special case of this general pattern, and, while heavily logged, still represents a unique extension of the rapidly disappearing southern floodplain forests of the Mississippi River.[27]

The sections that follow focus on the environmental setting, the major impacts, and the probable potential for rehabilitation. Additional biological detail and extensive bibliographies of pertinent literature are available in the Missouri Botanical Garden's report on the biota of the St. Louis region.[28]

2. Environmental Setting

The Illinois coal basin straddles the eastern extension of the tallgrass prairies and shares the climatic variability characteristic of the great plains but in a much milder form. Minimum monthly rainfall in Illinois is roughly equivalent to the maximum rainfall of the Powder River Basin and the average annual rainfall in Illinois is three times that of the Powder River Basin.[29] Approximately half of the precipitation in Illinois occurs during the growing season as a consequence of thunderstorm activity, and the remainder is precipitated as either rain or snow during winter storms associated with larger atmospheric movements (frontal storms). Floods occur primarily in the winter when the soil is frozen and in the early spring as the seasonal rainfall within the region is augmented by snowmelt.[30]

The topography of the midwestern coal fields is essentially featureless except for the gentle hills and low cliffs of their southern fringe. The major portion of the Illinois coal region is a level plain of glacial debris overlain by windborne sediments, which is transected by a few small rivers that meander through broad floodplains.[30] As shown in Figure 15-3 the southern boundary of the region is comprised of low, unglaciated hills underlain by an extensive cave system. The drainage system is well developed and lakes are consequently rare throughout the region.[30]



SOURCE: ADAPTED FROM REFERENCE 31

FIGURE 15-3. ILLINOIS COAL REGION

Streams in the region are typically alkaline but generally less so than in the western coal fields.[11] Hardness expressed as ppm of $CaCO_3$ ranges from 120-240 ppm in the Illinois basin, while it is at least 180 ppm in the Powder River Basin and typically over 240 ppm. Similarly both regions have exceeding hard groundwater, with concentrations in excess of 240 ppm except in the southern portions of the Illinois coal fields where a steep gradient in water hardness marks a transition to soft waters south of the Ohio River.[11] Sediment concentrations in the western and midwestern fields are similar, reflecting the easily eroded nature of the Illinois soil and the heavy use of row cropping in the Midwest. The water pollution potential from commercial fertilizers and domestic sewage is considerably greater in the midwestern region where fertilizer use is the heaviest in the nation.[31] Groundwater aquifers are absent in the central Illinois coal region, except for narrow aquifers along river courses. Moreover, since groundwater use is generally small, groundwater depletion is a problem only in the northern portion of the coal region.[30]

The soils of the region are generally 4 to 5 ft deep and exceptionally fertile, although soils in the southern portion of the region are characterized by impervious clay layers, which impede drainage.[30,32]

The structure and to some degree the fertility of the soils still reflect the nature of the original plant cover, the more strongly leached soils being those that developed under forest cover, which occurred in patches throughout the region. The soils are easily eroded and erosion to date has been characterized by the USDA as moderate to severe.[30]

The current vegetation of the northern and central portions of the Illinois coal basin is essentially a matrix of corn interspersed by roadside weeds such as giant ragweed, sunflowers, goldenrods, asters, marijuana, and assorted grasses. Remnants of the original prairies are found only in older cemetaries and along railway rights of way and presently consist of major prairie grasses such as little and big bluestem, Indian grass, and switchgrass, along with a number of broad leaved herbs which superficially resemble the weeds of abandoned croplands. The original woodlands are likewise rare, since the woodlands were settled before the prairies.[33] Woodland species are consequently found predominantly within the vicinity of homesites and along streams. In virtually all cases, woodland must be regarded as second growth, heavily disturbed stands.

The vegetation of the southern portions of the coal region is predominantly oak-hickory forest, a forest type widely distributed throughout the eastern United States.[34] The principal exceptions to this are the extensive floodplain forests of the Wabash River along the eastern edge of the coal field, which represents the northernmost extension of the rapidly disappearing floodplain forests of the alluvial plains of the Mississippi River. These forests have been logged, but still represent a unique resource even though the mammoth trees recorded in early photographs, including bald cypress, swamp gum, and sweet gum[35] are gone. A number of locally rare variants of these lowland forest vegetations have been described[36] for areas lying along the southern fringe of the coal area, many of which will be disturbed by mining if acid drainage is uncontrolled. The upland forest of oak and hickory have been repeatedly logged and burned, and most postdate the heavy logging of the 1890s and endured a second wave of logging during the 1920s.[36] It is of interest that the oaks of these forests fall into two groups reminiscent of the cool season-warm season distinction of the grassland dominants. Unpublished data from Brookhaven National Laboratory suggest that these groups, the red and the white oaks, are differentiated with respect to elemental composition and it is intuitively plausible that the distinctions between the two groups extend to other physiological properties. While significance of these distinctions is not clear, it is probable that they enhance the productivity of mixed forests and may have nutritional significance for browsers such as deer.

The flora and the vertebrate and invertebrate faunas of the major portion of the coal region probably contain few rare or endangered species given the extensive prior manipulation by man. However, the areas bordering the southern mining region contain a number of endemic and locally rare plant species such as French's Shooting Star in the unglaciated uplands bordering the Ohio River, and large numbers of rare animals are to be expected in the cave ecosystems underlying this region. While these probably will not be extensively impacted by mining, it is possible that they will be damaged by drainage waters from the strip-mined regions if adequate care is not taken to bury the toxic spoils to retard oxidation of sulfur containing overburden. The impact of mining warrants appraisal, but the greatest hazard to rare species in the region probably is associated with a proposed waterway development project on the Wabash.

The vertebrate animals of the uplands are typical of species found in the fringes of woodland, abandoned fields, and roadsides throughout the eastern half of the United States. Deer are the largest of the wild game, which includes the usual mixture of small game such as rabbit, raccoon, possum, squirrel, pheasant, quail, and dove. The total vertebrate fauna in the uplands consist of perhaps 40 species of reptiles, 10 species of amphibians, and 80 species of mammals,[32] and 115 species of birds.[15] The region borders the Mississippi flyway and a modest number of transient species pass through the area.

The vertebrate fauna of streams contain several additional species of reptiles and amphibians, as well as a large number of fish, including such game species as largemouth and smallmouth bass, crappie, bluegill, and catfish.[28,33] Individual streams draining the study area may have as many as 30 species of fish.[28]

Enormous numbers of invertebrates such as insects, leeches, snails, sowbugs, and crayfish are present in both upland and aquatic habitats, and they have been relatively well studied by the Illinois Natural History Survey. Indeed, as a consequence of the long continued efforts of the Natural History Survey and the state and federal soil conservation services, the biota and soils of Illinois are exceptionally well known, and the appraisals of impacts for this region can be defined with greater precision than for any other coal region.

The productivity of the region is high and diverse cropping is biologically feasible, although corn production dominates. In contrast to the Powder River Basin where as many as 50 acres may be needed per cow, approximately one acre per cow is sufficient in Illinois.[30]

3. Immediate Impacts

The immediate impacts of substantial expansion of the present mining activities should be much less than in the Powder River Basin or the North Dakota coal fields. The road and fencing networks are already substantial, and the game species involved are less strongly affected by fencing, both negating the impact of additional fencing. All impacts in the short term will be the consequence of increases in the areal extent of active mining itself.

4. Cumulative Impacts

The long-term impacts of strip mining will be relatively minor if reasonable care is taken to restore the land surface by layering and grading the spoils as outlined in the Environmental Impact Statements for the Powder River Basin.[1] Indeed, the restoration process is easiest here due to the presence of adequate rainfall during the growing season in all but the most exceptional years, the presence of deep layers of topsoil throughout much of the strippable region (up to 4 ft in thickness),[38] and the ready availability of seeds for both native and commercial plant species.[5] It is unlikely that destruction of shrub cover at any one time will be sufficient to substantially affect the game populations, and the rates of recovery of shrub cover should be high if reclamation is attempted.[39] Slow but uneven recovery can be expected even without reclamation,[39,40] although the erosion hazard is enormous in the western portion of the coal field where the loess deposits are deep.[11]

Indeed, the greatest impacts will probably be seen in the aquatic environments in response to increased turbidity and acidity of surface waters and the silting of spawning beds. However, with care, these impacts can be kept to relatively low levels, and the probability of exposure of sulfur rich deposits appears to be fairly low in much of the basin.[38] The principal problems with acid mine drainage can be expected in the southern fringe of the strip-mineable area.

5. Mitigation

The necessary mitigation measures are the same as those described for the Powder River Basin but are much easier to implement. Indeed, rehabilitation should be easier in Illinois than in any other coal field in the United States.

E. Appalachian Coal Fields

1. Introduction

The Appalachian coal fields are characterized by four environmentally significant features:

- Acid mine drainage is frequent from both surface and underground mines.
- Surface disruption of strip mining is exceptionally severe due to the rugged topography.
- Restoration of the land surface to the original contours is rarely feasible, although partial restoration is practical.
- Erosion is severe on sites which are not reclaimed.

These problems are not unique but are exceptionally frequent and severe in Appalachia.

The sections that follow focus on the environmental setting, the potential for mitigation, and the probable range of responses to attempted rehabilitation.

2. Environmental Setting

The Appalachian coal field occupies a southwest-northeast trending series of ridges and valleys and adjacent plateaus. The region as a whole is an intricate network of deeply incised streams, most of which empty into the Ohio River or its tributaries.[30] Topographically, the plateau consists of broad tableland, which grades into dendritically dissected hill land on both the northern and southern extremities and is underlain by horizontal or gently warped strata. The ridge and valley region is characterized by ridges up to 1500 ft high and tens to hundreds of miles in length, underlaid by strongly folded and faulted strata;[41]

The soils are thin to moderately deep, well drained, and easily eroded. Throughout much of the region, the uplands are too steep to farm, and the narrow floodplains are often plagued with poor drainage or frequent flood damage. The dominant land use is consequently forestry, with mixtures of pasture and cropland on the gentler terrain. As is generally true in the nation as a whole, the best agricultural soils are also the best soils for construction and are preferentially occupied by roads and urban areas.[41]

The climate is continental, with cold winters and hot, humid summers. The rainfall varies from 38 to 66 inches per year. The frost-free season averages 165 days and ranges from 150-200 days.[41] Precipitation is evenly spread throughout the year but varies in form from the cloudbursts of summer to the gentle, steady rains or snows of winter. Snowfall ranges from 2 to 60 inches, with between 10 and 40 inches being typical of most of the region. Soils in the northern portions regularly remain frozen throughout the winter but are subjected to sporadic freezes and thaws in the south. Frost penetration ranges from 3 to 20 inches and generally extends through the most densely rooted portions of the soil (the upper 6 inches).[11]

Surface water runoff is high, varying from 10 to 20 inches per year. Minimum stream flow occurs in late summer and early fall, and maxima occur in late winter or early spring when the soils are frozen or saturated and the transpiration losses are low. Groundwater supplies are typically marginal and are unimportant water sources throughout the region as a whole. Dissolved solids and salinity values are typically low, and the water quality in unmodified waterways is the best of the four coal regions considered. Surface waters are soft and, consequently, weakly buffered relative to those of the other regions--roughly half the hardness of water in Illinois--a factor that makes them particularly susceptible to change in response to acid mine drainage. Pollution from agricultural sources is low due to the topographic restrictions on mechanized agriculture, but urban pollution is locally severe.[11]

Streams in the region are generally shallow with frequent alternation of pools and riffles and a variety of bottom types. Typically, they are densely shaded during the warmer months and exhibit peaks of phytoplankton productivity in early spring and late fall when sunlight at the stream surface is maximal. Reproduction of both invertebrate and vertebrate fauna typically occurs in the spring when the decomposition of the accumulated tree litter accelerates and the phytoplankton production peaks. Most of the fishes migrate upstream to spawn, rendering the head waters critical to the maintenance of diversity in the larger streams.

The terrestrial vegetations are predominantly forests and include the most diverse forests of the continent in the highly dissected rim of the Cumberland Plateau and the Smoky Mountains. These forests frequently contain as many as 20 commercial species and several species of understory trees such as redbud, serviceberry, and hawthorn. This rich assemblage of sugar maple, white and red oak, hickories, ash, basswood, birches, magnolias, elms, beech, cherry, buckeye, and tulip-popular grades into less diverse stands of oak and hickory on the drier sites, and ultimately into stands of red cedar on dry limestone outcrops. On the shale barrens of Pennsylvania and the more acid, nitrogen-deficient mine spoils, black locust, which possesses a nitrogen fixing symbionic, becomes dominant. The wetter sites are dominated by sycamore, willows, red maple, elms, hackberry, black walnut, and assorted shrubs. The undisturbed forests on most, well-drained sites characteristically have relatively few shrubs but possess an exceptionally diverse herbaceous flora, which is metabolically most active before closure of the tree canopy in the late spring. As sites become either wetter or drier, and the tree canopy more open, the understory vegetations become more dense with a shift towards shrubs and ultimately drought-tolerant herbs on the drier sites such as ridge top and rock outcrops and a shift towards tall shrubs on the wetter, more poorly drained sites.[42]

Terrestrial vertebrates of recreational interest include gray squirrel, turkey, bear, deer, grouse, raccoon, possum, woodcock, and rabbit, but in general the fauna parallel the diversity of the vegetation, and the number of organisms of biological interest is large.[41] The southern Appalachians are a center of diversity for salamanders and other amphibians, while the region as a whole is moderately rich in mammalian species, with roughly 50 species of quadrupedal mammals and 10-15 species of bats.[23] Birds are likewise well represented, with perhaps 115 species in the region as a whole.[15]

Aquatic vertebrates include the species to be expected in Illinois but also include assorted cold-water species, although the trout populations are significantly augmented yearly with hatchery stock in all but the most remote cold-water streams. Smallmouth, stripe, spotted, rock, white, and largemouth bass; walleye, catfish, crappie, and bluegill constitute the major warm-water game fishes of the region[41] but a rather small portion of the total fish population, which includes minnows, suckers, and other nongame species.

Invertebrate fauna, both aquatic and terrestrial, are very diverse but as usual are unlikely to be endangered, with the possible exception of cave dwellers along the fringes of the mining regions.

3. Immediate Impacts

The immediate impacts of strip mining and the associated dirt roads are severe and, without considerable care, are both persistent and widespread. The coal seams are thin and the amount of overburden is extremely high. The spoils typically include substantial amounts of large rock fragments. As this overburden is first blasted and then shoved away from the seam, large rocks frequently roll down the adjacent hillsides, creating a swath of disruption somewhat larger than that caused by simple excavation and displacement of soils and other loose material. The resulting scars are often 50 to 100 ft high, including the terrain buried by displaced fill, and may stretch for miles. Severe as these impacts of the mining cut are, however, they may have only slightly more local impact on terrestrial biota than the less controversial interstate highway system, which has left equally permanent, if less vivid, scars on the landscape.

The immediate impacts of underground mining are modest, but the eventual impacts through waste disposal or acid drainage are often severe, even if less extensive than stripping.

In contrast to the impacts on land animals, the immediate- to long-term impacts of both strip and deep mining activity on aquatic organisms are persistent and often more severe than routine earth-moving activities such as highway construction. The increments to the silt load of streams is often severe in both mining and construction, but the mine wastes have the additional impact of significantly altering the acidity of streams by the continual release of extremely acid waters. In effect, acid mine drainage preempts the headwaters spawning grounds for many fishes, leading to inadvertent changes in the species composition of the biota downstream of the areas of immediate kill and this means a replacement of species that spawn in headwaters by those that spawn in the shallows of large streams, which in turn implies displacement of cold-water species, such as trout, by warm-water species, such as bass, catfish, or carp.

4. Cumulative Impacts

The long-term impacts scarcely differ qualitatively from those characteristic of the short term. The biological productivity of the land is lowered, life is often excluded from small streams, and more subtle changes in the biota of the intermediate-to-large streams are probable.

5. Mitigation

The mitigation steps applicable to Appalachia are similar to those of the midwestern and western coal fields but are far more difficult to implement. The thinness of the layers of weathered bedrock and soil combined intensify the need for careful analysis and handling of the overburden, while the steepness of the topography makes such painstaking work exceedingly difficult and expensive. Even in the best of circumstances, it is improbable that it will be economically feasible to restore the land to its approximate original contours, although it should generally be possible to greatly lessen the incidence of acid drainage and to speed the reestablishment of vegetation. The methodology is basically in hand to reclaim spoils[43,44] and, given adequate incentives for implementation, should be effective.

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