EVALUATING REVEGETATION SUCCESS

Criteria for evaluating success of revegetation include ground cover, production, and stocking as appropriate for the approved postmining land use (Table 9). Other criteria, such as species diversity, approved in the PAP can be used to judge the effectiveness of revegetation.

Revegetation success may be compared against either reference areas or technical (performance) standards. With the reference-area approach, crop or herbage production and environmental protection (cover) on the reclaimed site is compared with the same parameters on a similarly managed and vegetated unmined site nearby that serves as the reference or standard for comparison. The technical-standards method of evaluating success consists of comparing production, cover, or stocking on the reclaimed area with an accepted performance standard appropriate for the postmining land use.

Reference Area Selection

Reference areas are unmined land units maintained under appropriate management to measure vegetation ground cover, productivity, and other parameters, such as plant species diversity, that are approved in the PAP. The selection of reference areas depends on the approved land use for the revegetated area. In many cases, postmining vegetation and land uses differ from premining vegetation and land uses. An example of this would be converting oak savanna grazing land to improved pasture of fescue or bermudagrass. In this case, the reference area would be an improved pasture of fescue or bermudagrass.

Reference areas represent the climate, geology, soil, slope, and vegetation in the permit area. Essential criteria for comparing revegetated and reference areas include:

- Individual site factors, including elevation, precipitation, slope, and aspect, are similar on both areas.
- Both areas are composed of the same plant life-forms and seasonal varieties of vegetation. A wooded area would not be a reference for pasture land.
- Management of the reference area during the revegetation phase is consistent with that proposed for the revegetated area. The condition class of the reference area (when dealing with rangeland) is the same as that desired in the management plan for the revegetated area, and indicates a stable trend.
- Certain edaphic characteristics are similar, though it is unlikely that the revegetated area will have exactly the same soils as the reference area.
- A revegetated area that is realistically comparable to the reference area, i.e., it can produce a similar kind and amount of vegetation.

It is not essential that the reference area be immediately adjacent to the revegetated area so long as these criteria are met. However, where the two areas are separated by too much distance (preferably not outside a radius of 20 miles), differences in rainfall distribution patterns, elevation, and other environmental factors could result in statistically different production, cover, and diversity values.

The size of reference areas may differ because of the many site variables involved. A recommended minimum size for hay and croplands is 1 acre, but larger areas (2 to 5 acres) are preferable because they better represent the variation in production and cover due to differences in nutrient availability, topography, drainage, and other site-related criteria. Reference areas suggested for grazing land are 5 to 10 acres in humid regions and from 20 to 100 acres or larger in semi-arid and arid range areas. Larger reference areas tend to better represent the variation and species diversity of an inventory unit simply because more space is available for more of the potential species to occur.

Several reference areas may be desirable. The number selected may correspond with the number of inventory units selected for each permit. However, each inventory unit that exhibits a wide variation in vegetation cover or production may need to be represented by more than one reference area. The number of reference areas chosen is more dependent on the variability of the premining vegetation than the size of the permit area. In most cases, at least one reference area per type of inventory unit (i.e., vegetation type, range site, or ecological response unit) is desired. The risk involved with using only one reference area is that the cover, production, and diversity values used to determine bond release may not represent the inventory unit adequately. Poorly selected reference areas, abnormal climatic conditions, fire, nontypical soil or topographic conditions, or biotic influences can contribute to the misrepresentation of an inventory unit. Thus, more than one reference area per major inventory unit is desirable.

Table 9. Criteria for evaluating revegetation success for postmining land uses.

Postmining Land Use	*Parameter*
Grazing land, pasture land, land occasionally cut for hay	Ground cover and productivity
Cropland	Crop production
Fish and wildlife habitat, recreation, shelterbelts, or forest products	Tree and shrub stocking and ground cover
Industrial or residential use	Ground cover
Areas previously mined and not reclaimed (orphan lands)	Ground cover

Technical Standards

This evaluation approach involves the comparison of technical standards of production, cover, or stocking with the same parameters measured on the reclaimed area. Resource agencies, such as the Soil Conservation Service (SCS) and the State Agricultural Extension Service, are

sources of guidance in establishing standards. Primary sources on which to base production criteria are published yields for counties and/or soil- and range-site mapping units. Recent county soil survey reports published by SCS contain expected yields for forage and other crops by soil type. State crop reporting services publish average yields per acre by county (see examples in Tables 10 and 11). Unpublished crop-yield data from State Agricultural Experiment Stations often are available to extension agents.

Expected forage production and the important plant species on native rangelands are described in Range Site Descriptions available from SCS. Tree and shrub stocking (number of stems per acre) and ground-cover standards for nonagricultural areas are primarily based on recommendation of State and Federal agencies responsible for administering forestry and wildlife programs. Since orchards normally do not become productive within the 5-year responsibility period (above 26-inch precipitation areas), the use of reference areas or establishment of production standards is not appropriate for them. Orchard evaluation should be based on ground-cover requirements, appropriate stocking, and approved management of live trees (as recommended by State horticultural extension agent).

Table 10. Example of crop yield information available in soil survey reports.*

Soil Series and Mapping Units	Crop Yields†								Pasture (forage)	
	Corn		Wheat		Soybeans		Alfalfa			
	A	B	A	B	A	B	A	B	A	B
	Bu						Tons		Lbs	
Allen:										
AeC	48	75	34	51	23	35	2.1	3.3	2700	3900‡
AeD	46	68	30	46	—	—	2.1	3.1	2700	3600
AeE	—	—	—	—	—	—	—	—	2500	3400
AnD3	32	50	24	36	—	—	1.7	2.4	1800	3000
Atkins: At	35	50	—	—	22	30	—	—	1600	2700
Bewleyville:										
BeB	58	92	36	54	27	40	2.3	3.4	2300	3900
BeC	55	85	34	52	21	36	2.2	3.3	2300	3900
Bodine: BdF	—	—	—	—	—	—	—	—	1100	1800
Bonair: Bn	42	68	—	—	20	33	—	—	2100	3600
Bouldin: BoF	—	—	—	—	—	—	—	—	—	—
Christian:										
ChC2	42	60	32	47	17	21	2.0	2.9	2400	3300
ChD2	40	55	30	44	—	—	1.9	2.6	2200	3300
CnC2	40	56	32	44	16	20	2.0	2.5	2500	3300
CnD2	32	52	28	41	—	—	1.8	2.4	2100	3000
CnE2	—	—	—	—	—	—	—	—	1900	2700
CsD3	—	—	20	33	—	—	1.4	1.9	1500	2200
Curtistown:										
CuB	75	115	38	54	28	43	2.6	3.8	3000	4500

* Adapted from USDA Soil Conservation Service, 1981.

† Yields in column A are those obtained under common management; those in column B are to be expected under a high level of management. Absence of yield indicates crop is not suited to the soil or is not commonly grown on it. Production units are per 1 acre.

‡ These values were converted from cow days/acre by assuming 20 pounds of air-dry forage is required for one cow for one day.

Table 11. Examples of yield data from State crop reporting services (Alabama counties, 1977-78).

County	Yields			
	Corn	Soybeans	Wheat	Hay
	Bushels/acre			Tons/acre
Bibb	26	22	26	2
Blount	37	24	34	2
Cherokee	34	23	28	2
Choctaw	31	25	17	2
Cullman	27	24	31	2
DeKalb	36	23	29	2
Etowah	40	25	36	1
Fayette	30	21	29	2
Franklin	35	21	26	1
Jackson	35	22	27	1
Jefferson	23	24	33	2
Marion	36	22	24	2
Marshall	43	20	24	2
Morgan	35	19	25	2
Shelby	22	21	33	1
St.Clair	36	21	27	2
Tuscaloosa	19	20	27	2
Walker	21	26	28	2
Winston	30	19	29	2

Mapping

A map is a basic tool for delineating areas of similar vegetation (inventory units) on permit areas (both before mining, where required, and after revegetation) and on reference areas and for locating and laying out sampling points or sites on the inventory units. On permits where revegetation success is judged by technical standards, mapping is needed primarily to delineate the areas of different postmining land uses. Where reference areas are used, vegetation near the mined area may need to be mapped to delineate vegetation types similar to those that were on the permit area before mining. Mapping is best accomplished by on-the-ground investigation with the aid of aerial photos; soil survey maps; topographic maps; and other resource maps, such as those that show range sites, pasture, and woodland suitability groupings appropriate to the vegetation communities involved.

Vegetation Sampling

In most situations, some method of sampling is needed to measure the required vegetation parameters on reclaimed areas and, where necessary, on reference areas. Exceptions are where production is determined by harvesting hay, ensilage, or other crops or where stocking is measured by counting woody plants on an entire inventory unit. In such cases, calculating a statistical confidence interval

is not appropriate because no sampling technique is used. Sampling also may be unnecessary on areas where it is obvious that ground cover and stocking of woody plant stems exceed approved success standards.

Principles of Sampling

Vegetation sampling is a means for making inferences or conclusions about a plant community based on information obtained from examination of a small proportion (sample) of that community. Ideal sampling techniques are repeatable, accurate (i.e., capable of revealing the true characteristics of the plant community), efficient, and convenient and easy to use (i.e., provide accurate information with minimal expenditure of labor and time in devising and executing).

Table 12. A set of random numbers.

Column 1	Column 2	Column 3	Column 4
6327	0983	3798	4679
2167	6484	9467	9058
5939	0407	1804	8827
4672	3865	5689	9878
8071	5185	5514	5308
9509	0603	7461	8850
6615	2588	3558	3349
4833	2422	9790	1183
5594	1809	6931	6571
9441	1699	3947	7702
7922	9812	7229	5252
9419	6494	8179	8065
6178	3556	2466	2495
2647	3961	7546	4799
0474	1839	6926	6534
9814	1577	8293	0301
0104	4579	0627	8667
1608	9470	4131	5345
9722	1557	0471	5498
4189	3582	3675	9461
9855	8088	9006	6897
5791	8234	1472	3421
0872	3310	0510	9046
8953	9809	8037	8376
2895	4319	6544	8953
0609	5248	8734	2498
9795	2464	6170	1063
1572	7371	7936	2841
4307	0294	6060	5194
4857	0197	2401	7005
1632	7189	6463	9830
0745	8034	7882	7152
0736	5110	5165	6571
8168	7924	5876	1407
7468	5313	2736	9010
6044	5420	3077	9070
6716	0059	3001	8871
9342	0169	6880	7986
5809	6048	9051	1151
1532	9715	7081	0109
5506	5812	5917	4415
4045	1751	2817	9958
5966	9930	6437	7279
6062	3296	5093	2503
4097	8379	5670	0614
6793	3999	4645	5143
7960	4853	0583	1920
1321	4067	8503	1604

Statistically sound vegetation sampling procedures incorporate the concept of randomization. The basic purpose of random sampling is to allow each observation or data collection unit an equal chance of being included in the sample. This is needed to provide an unbiased estimate of the mean and variance (indicator of variability) of the vegetation characteristics for making statistical comparisons. The purest form of random sampling is called simple or completely random sampling. Theoretically, simple random sampling is the most unbiased and statistically clean, but it is seldom used as a self-sufficient sampling design because it usually is less efficient and less practical than other sampling designs, especially in terms of time needed to devise and execute in the field.

Systematic (nonrandom) data collection designs, on the other hand, usually are more time and cost efficient but cannot be used to obtain unbiased data unless stratification or other procedure of random selection is incorporated at some stage of sampling. Thus, most designs for sampling vegetation integrate some degree of systematic sampling or stratification with random sampling. Such designs are called stratified sampling or stratified random sampling.

There is a wealth of literature that discusses the relative merits of simple random sampling and stratified random sampling designs. Most of these designs are considered valid for making statistically unbiased estimates of the population. Regardless of the type of design, the basic and most important consideration in sampling is that the sample points are selected objectively and without bias by the investigator. In addition, sample points should be distributed throughout the sampling units and not just within a small portion of the sampling units. They also should be located far enough within the sampling unit to avoid transition zones and edge effects created by highways, rivers, etc.

Selecting random sample points objectively is best accomplished by using a table of random numbers (Table 12). To use a list of random numbers, select an arbitrary, objective starting point anywhere on the table. Select subsequent numbers by progressing in order down the column.

Each digit within a random numbers table is a random number, though random numbers commonly are given as four digits. If the bottom of column 2 were selected as a starting point, 4067, 406, 40, or 4 could be used as the first random number. The units of measure used for locating the sample points (spaces, meters, feet, and so forth) will determine the size (number of digits) of the number selected. The same sequence of numbers always should be selected, and zeros should be counted as one of the digits.

Sampling Designs

It is not the intent of this handbook to recommend a universal sampling design or the statistical manipulations that go with it. Many references are available that provide guidance and details on sampling systems and the statistics needed to handle the data. Examples of several

sampling designs are in the section that follows. These designs—simple random, stratified or restricted random, and systematic sampling with multiple random starts—allow the calculation of a valid estimate of the variance of the mean and can be adapted to most of the techniques used for sampling cover, production, and stocking. The specific design chosen depends somewhat on the parameter under investigation and on the sampling method used.

Random Location of Sample Points

The location of random sample points is depicted in Figure 22. The procedures for selecting random sample points are:

1. Select two random numbers as described previously. The first number chosen is used as the distance along the x axis and the second as the distance along the y axis.
2. Locate the x coordinate by pacing or measuring the random number distance along the x axis from the point of origin. From the x coordinate, pace or measure a line perpendicular from the x axis and equal to the random number distance along the y axis. The point at the end of the line is the random sampling point. A perpendicular line from the y axis to the random sampling point is equal to the distance that was paced along the x axis. A sample point that falls outside of the sampling unit is not used.
3. Return to the point of origin, select the next two random numbers, and repeat the process described. Continue this process until all sample points have been taken.

The preceding method suggests that the sampling points will be located directly in the field at the time that the vegetation is sampled. This method also can be used by first locating the sample points on an aerial photograph or map. Location of the axes along cardinal compass points will facilitate the rest of the procedure. Once all of the sample points are located on the map, the most convenient itinerary or travel path to all points is determined and shown on the map (Figure 23). Directions for locating the sample points in the field are then written on the map. These directions include the compass bearing and distance from one point to the next, beginning from the origin of the reference axes. The person(s) doing the field sampling will need a compass and measuring tape (pacing may suffice) to locate each point per directions on the map.

As seen here, a simple random design can be tedious and time consuming to devise and execute. Designs incorporating both systematic and random sampling procedures often are more time and cost efficient than simple random sampling. They also provide an unbiased estimate of the population mean and a valid basis for computing sampling variance.

Stratified Random Design Using a Baseline

The procedure for locating random sampling points using a baseline is shown in Figure 24. The following describes this procedure:

1. Locate a baseline either through the middle or along one edge of the inventory unit. Points along this line are spaced a predetermined and equal distance apart,

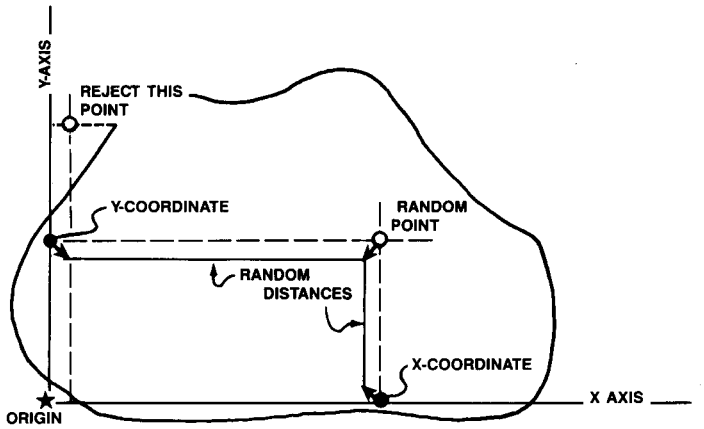

Figure 22. Random location of sample points on map or in field (from Knight 1978).

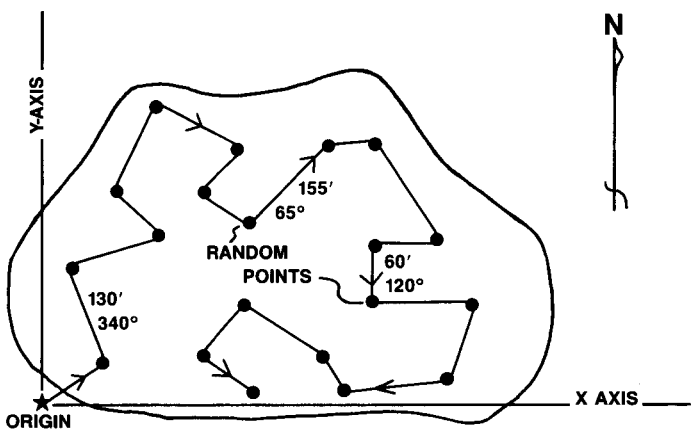

Figure 23. Sample points can be located in field by compass directions and distances from coordinates randomly selected on a map. Connected points show least-effort travel path. (Adapted from Raelson and McKee 1982).

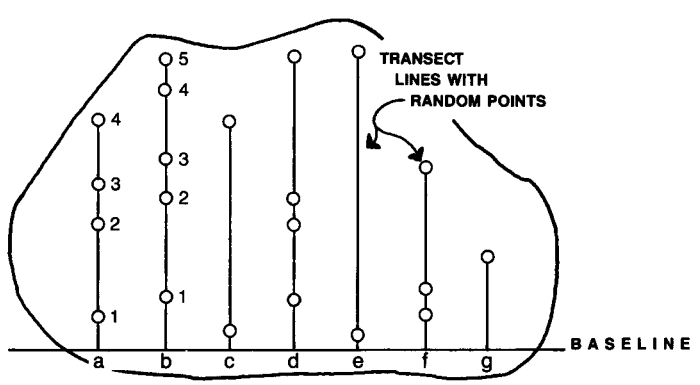

Figure 24. Stratified random design using a baseline (from Knight 1978).

such as 100 feet.

2. Proceed to the first point (a) on the baseline and select a random number. This number is the distance to the first sample point (1) on a line running perpendicular to the baseline. Where the baseline is located in the middle of the area and the random number is even, the sample point is located to the right of the baseline; if it is odd, the sample is located to the left. The second sample point is obtained by choosing a second random number that is the distance to point 2 from point 1 along the same perpendicular line. Additional points are located in the same manner until the perimeter of the inventory unit is approached. The investigator then returns to the baseline and proceeds to the second predetermined point (b). Sample points are then located along a line perpendicular to this point as described. The procedure is repeated until an adequate sample has been collected.

Random numbers that result in the overlap of sample plots should be disregarded in most sampling situations.

Systematic Sampling with Multiple Random Starts

Systematic sampling with multiple random starts is an efficient method of locating sample points that still allows a valid calculation of the variance of the mean of the measured vegetational characteristics, even though it utilizes systematic sampling (Shiue 1960). This method can be implemented using a baseline and is similar to the stratified random method shown in Figure 24. The procedures for establishing sample points using this method include the following:

1. Locate a baseline either through the middle or along one edge of the sampling unit. Points along this line will be spaced a predetermined and equal distance apart.
2. Proceed to the first point on the baseline and select a random number. The random number is the distance to the first sample point along a line running perpendicular to the baseline (transect line).
3. Locate subsequent points a predetermined and equal distance apart along the transect line. Discontinue sampling along the transect line when the perimeter of the sample unit is approached.
4. Return to the baseline and proceed to the second predetermined point. Sample points are located along a transect line perpendicular to this point as described. The distance to the first sample point is once again determined by the selection of a random number. Continue in this manner until an adequate sample has been taken and the entire sample unit has been sampled.

Where the baseline is placed in the middle of the sample unit, transects are placed on both sides of the baseline by the procedure described for the stratified random design. A minimum number of random starts is six, but more are preferred.

Modifications can be inserted in the preceding designs to add randomness, but each addition increases the time required to devise and use the design. For example, points along the baseline could be selected by using a restricted random procedure where one of several (suggest 3) equidistant points within each 100-foot segment is chosen randomly as the beginning point for the transect line. Similarly, each sample point on the transect line could be chosen randomly from several equidistant points within segments of a prescribed equal length.

Measuring Ground Cover

Concepts

A definition of ground cover appropriate to mined-land revegetation is "the area of ground covered by the combined aerial parts of vegetation and the litter that is produced naturally on site, expressed as a percentage of the total area of measurement." In a strict sense, cover by aerial parts can be viewed as the vertical projection of all aboveground standing plant material or vegetation onto the ground surface (Figure 25). Obviously, at any given time, this may include some standing dead plant material. Litter, the dead fallen organic material, is included in ground cover because it, like living and dead standing vegetation, also protects the ground surface from raindrop impact and erosion.

According to the strict definition of vegetative cover given, the many small openings that are not actually overlain by plant parts within a canopy are not counted as cover. Aggregated over a large area with many plants, these small uncovered interstices can account for a sizeable percentage of the total ground area. On the other hand, where a loose definition of cover is used, all of the area within the vertical projection of the perimeter of the canopy of a plant or group of plants is included as cover and a larger estimate of cover is obtained than where the strict definition is applied (Figure 26). One important function of vegetation cover is to reduce splash erosion by intercepting and dissipating the energy of raindrops. Openings within a canopy may allow raindrops to reach bare soil and affect the amount of splash erosion or control of it. As discussed later, techniques that measure cover as defined by the loose concept of cover usually are more sub-

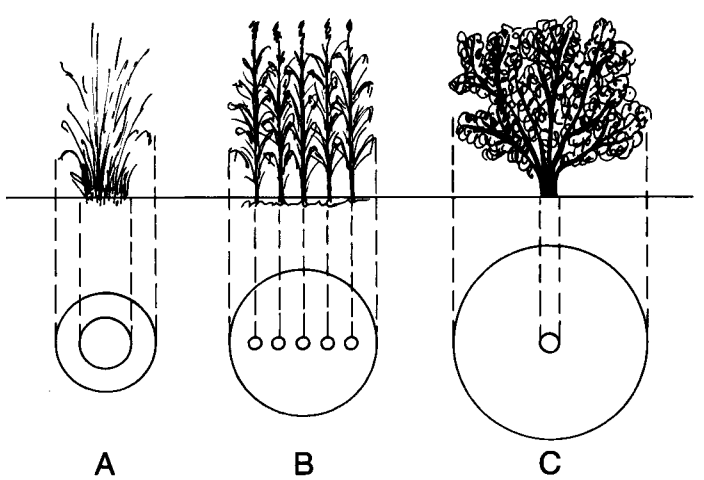

Figure 25. Difference between maximum spread of foliage (aerial cover) and basal area for (A) bunchgrass, (B) sod-forming grass or stand of single stem plants, and (C) forb, shrub, or tree.

jective than techniques that measure it by the strict definition.

Comparing ground cover on a revegetated area to an approved standard requires that the revegetated area be sampled with the same methods and units of measure that were used to establish the standard. Cover data can be collected by species, by life forms (grasses, forbs, shrubs), or for all vegetation as a whole. Rocks on the surface, though not included as ground cover by definition, do contribute to protecting the surface from raindrop impact and other erosional processes.

Where reference areas are used, cover is a valid comparative measure only where both the reference and the revegetated areas have received equal levels of utilization or none at all. For example, it is conceivable—even though livestock grazing is not part of the management plan—that one area or other could be browsed or grazed selectively by deer because of a difference in species composition or nutrient content of the forage. In such situations, valid comparisons cannot be made between the two areas.

The distribution or evenness of vegetational cover also is an important consideration in assessing revegetation success. In fact, distribution of cover may be more important than the average overall cover. Control of erosion is more likely to be effective and complete where revegetation is distributed uniformly over an entire area than where patches or small areas with substandard cover or no cover are present. A potential hazard is that erosion, especially gullies, may begin in the unvegetated patches and spread or cut into adjoining vegetated areas. It is probable that erosion and siltation will be greater from one or two sparsely vegetated or unvegetated ¼-acre patches, for example, within an otherwise adequately vegetated area than from an uniformly vegetated site that has less average cover overall. An unvegetated or poorly vegetated area 50 by 200 feet (about ¼ acre) lying lengthwise up and down a steep slope could potentially transform into an expanding gully that would require considerable effort to repair and stop. The maximum size that could be allowed for any one patch of substandard cover should vary according to soil, slope, and other sites conditions. An unvegetated strip running lengthwise up and down a steep slope is more likely to severely erode than a similar-size strip running contour on a gentle slope or on level ground.

Estimating Cover Visually

Normally, the simplest and fastest way to evaluate ground cover is by visual or "eyeball" estimation of the entire area in question. It also is the most subjective, least accurate, and least repeatable of any estimation method used. Even among trained observers, estimates of cover on a given area may differ by 25 percent or more. Cover estimates by a single observer may be inconsistent from day to day or even throughout the day. Visual estimates of ground cover by most observers become more accurate as the cover approaches 0 or 100 percent and less accurate as the cover approaches 50 percent. Usually, it is with ground covers near this mid range that an accurate measure will be most needed for determining eligibility for bond release.

The accuracy of visually estimating cover on large areas can be increased by sampling with randomly or systematically placed small plots known as quadrats. The quadrat usually is delineated by a frame placed carefully on the ground so that the natural position of the vegetation is disturbed as little as possible (Figure 27). Sample plots or quadrats 1 m² in area often are used, but the size and shape can be varied to suit the structure of the vegetation being

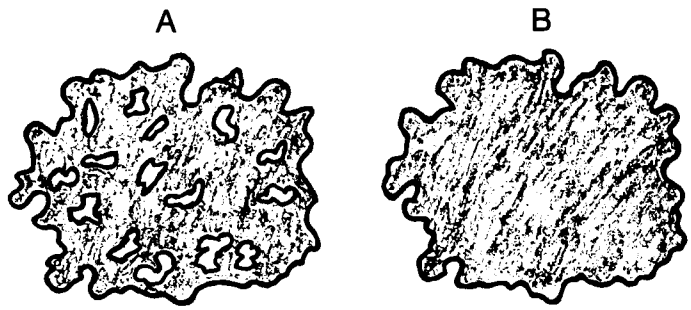

Figure 26. An illustration of (A) the strict definition of vegetative cover (the white areas inside the plant or plant community canopy are not covered) and (B) the loose definition of cover.

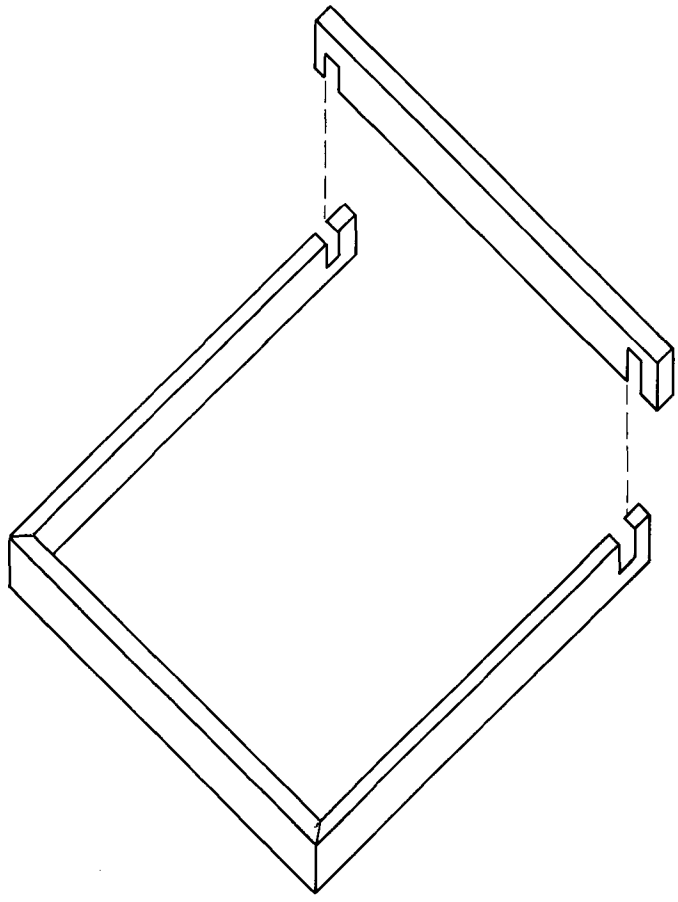

Figure 27. Quadrat frame with removable side to facilitate placement in vegetation. The frame can be constructed from 1/8- × 1-inch strap metal.

evaluated and the convenience of the observer. Where production is to be measured, the same quadrat may be used for sampling both cover and production. Quadrats are located within inventory units by one of the sampling designs discussed.

Accuracy is gained by using quadrats because it is easier to see and estimate ground cover in small defined plots than in large areas. Sampling with quadrats also provides the opportunity for statistical analysis. The final cover value is a mean of the quadrat estimates, and an estimate of error and statistical confidence can be determined. Some ecologists have shown that quadrat size or shape does not significantly influence the visual estimate of cover, and that sampling adequacy is achieved more easily by increasing the number of observations rather than increasing quadrat size. Accuracy in estimating cover with quadrats can be improved somewhat by placing marks equidistant along each side of the quadrat frame to delineate the outside points of an imaginary grid (Figure 28). The observer then envisions the number of grid units that are covered or filled by vegetation and litter. This can also help the observer by providing a reference for the smallest unit of estimation (e.g., 5 percent). Even with these aids, observers still tend to overestimate ground cover because it is difficult to accurately account for the openings within and among the foliage of an individual plant or closely spaced groups of plants.

Training is required for an observer to become proficient at estimating cover visually. For training purposes, cover estimated by the use of quadrats can be compared with cover measured by a number of points (as described for the point-quadrat method) placed randomly within the quadrat.

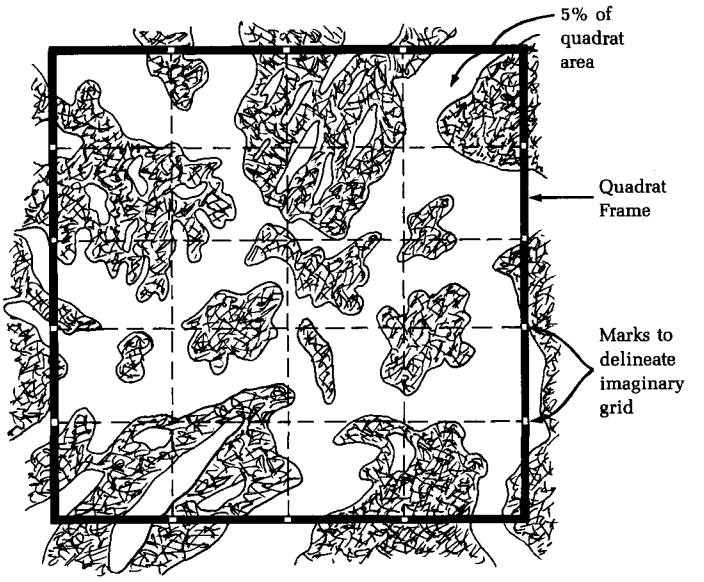

Figure 28. A small plot or quadrat can be used to aid in the visual estimation of ground cover. Marks on the frame can help the observer envision an imaginary grid and provide a reference for the smallest unit of area estimated (5 percent).

Point-Quadrat Method

This method for measuring cover also is called point-intercept, point-hit, point-frequency, point analysis, point drop, or point. The point-quadrat method reflects the concept of reducing the size of a quadrat to a point, e.g., a quadrat virtually without area or, at most, a very tiny area. The method involves the recording of a "hit" or "miss" on vegetation or litter at a point defined by the sharpened tip of a rod or pin that is lowered vertically through the vegetation canopy. The contact point also can be defined by sighting through an optical device such as a sighting tube equipped with crosshairs. One inconvenience with using either a sharpened pin or sighting tube is that a supporting frame is needed in the field to hold and steady them and provide vertical alignment.

The point-quadrat is an accurate, repeatable, and reasonably objective method for measuring aerial and basal cover, but it has several limitations. With the measuring techniques and gadgetry normally used, the method is limited to measuring relatively low-growing herbaceous and dwarf-shrub vegetation. Thirty inches is about the maximum height that can be measured effectively or conveniently. To overcome this problem, an optical instrument has been developed that allows point-hit measurements to be taken in vegetation of any height (Vierts 1985). Point readings made with any device can be difficult to obtain when vegetation is moving in the wind.

In practice, a frame designed to hold several pins or one designed to use a single pin to make several readings has been used most often (Figure 29). The frame must hold or guide the pins at two places so that a stable, nearly vertical alignment of the pins is maintained as they are lowered to the ground. Any change from a fixed angle of vegetation interception can alter results, so it is important that all readings be done with the frame in the same position.

To measure cover, only the first contact by the point of the pin on vegetation or litter need be recorded. If the point contacts both vegetation and litter, there is only one recording made. Similarly, only one "hit" is recorded even where several contacts with vegetation are made by the point of the pin as it is lowered to the ground. However, where additional information is desired about the plant community, such as composition, structure, basal area, and ground surface cover, all contacts of the point with aerial vegetation and whatever is encountered at ground level can be recorded. Recording hits on the basal area of plants may be desired because basal area is considered a better indicator than aerial cover for determining trend or changes in the condition of rangeland. Recording all hits by species or life forms (grasses, forbs, half shrubs) can provide information about the composition and diversity of the plant community.

The optical-point bar is a recently developed instrument for measuring cover by the point-quadrat concept. This optical device has a set of 10, low-power, short-focus scopes that replace the standard set of pins. A fine wire crosshair is located precisely between two lenses in each scope to provide a parallax-free image similar to that from a rifle scope, but with a short infinite focus point. The main advantage of this instrument is its usefulness in vegetation

of any height. It is faster and slightly more accurate than the conventional pins and frame device, but is much more expensive than pin and frame devices (Vierts 1985).

Size of Point

One potential source of error in precisely measuring cover with the point quadrat is the diameter of the pin. The nearer a point or tip of a pin comes to having no area, the more precise the measurement. Goodall (1952) found consistent bias toward larger estimates of cover as pin diameter increased. The amount of increase was partly related to the morphology of the plant species measured. Estimates of grasses were more affected than broad-leaved forbs by an increase in pin size. Thin intersecting cross-hairs in a sighting tube have been shown to be better than pins for defining a point. In experiments, a sighting tube also gave slightly better repeatability between observers than pins supported in a frame; it also gave lower estimates of cover than pins.

Single Versus Multiple Placement of Points

Binomial theory serves as the statistical basis of point-quadrat cover analysis. This applies only if all sample points are placed randomly and independently so that any point on the reference area has an equal chance of being chosen. For convenience in sampling, however, methods often are used that include restricted randomization in point selection and systematic placement of points. One form of systematic placement of points is the point frame device. In fact, the point-quadrat method most often is used with a frame that holds several (usually 10) evenly spaced pins (Figure 29). The 10 pins within each frame position or setting are not placed independently of each other. Rather, their placement is fixed within a restricted area; only one of the pins could be considered as being placed independently. As a result, more points are needed when aligned in frames to achieve the same level of statistical precision as obtained with single points placed independently.

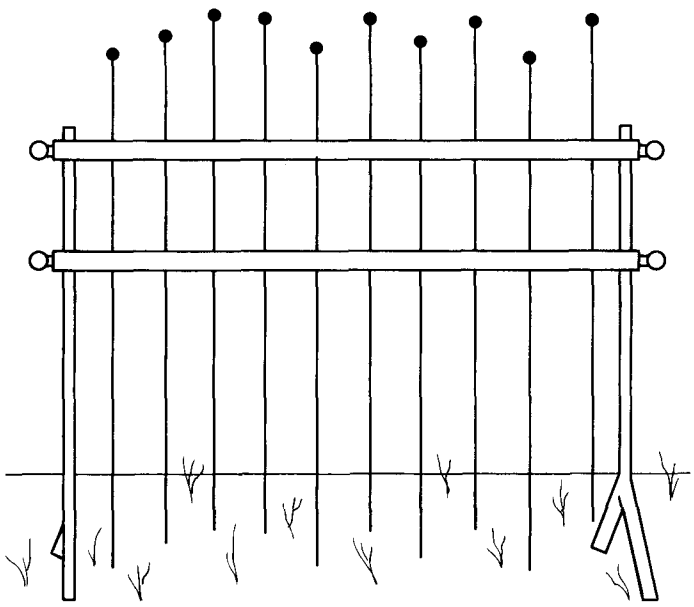

Figure 29. Frame with pins for measuring cover by the point-quadrat method.

Table 13. Values of 95 percent confidence intervals for the binomial sampling distribution with p = 70 percent (modified from Snedecor, 1946).

Confidence Interval (%)	*Sample Size (No. Points, n)*
39–95	10
46–88	20
56–82	50
60–79	100
64–76	250
67–73	1,000

The number of points required to achieve a given level of statistical precision always was less with pins placed independently than with pins in frames (Goodall 1952). Depending on amount and type of cover, from 568 to 902 independently placed points gave the same level of statistical precision as 2,000 framed pins (200 frame positions). However, locating and placing 200 frames may be easier and less time consuming than locating and placing 600 to 900 individual points; thus, the efficiency of using frames seems to compensate for the greater number of total points required.

Binomial theory does not apply to cover estimates made by using frames of pins. It is better to consider each frame as a sample observation that can have a value of 1 to 10. Such samples would fit the normal distribution. The standard error of observations from pin frames can be calculated from the data and using simple equations given in any introductory statistics book.

How Many Points Are Needed?

The number of sample points needed to estimate cover usually is based on a trade-off between the desired level of precision and the time available and required for making the estimates. One consideration is that the number of sample points necessary to make a precise estimate of cover is independent of the size of the area to be examined. Whether the study area is 1 acre, 100 acres, or 1,000 acres, the same number of randomly chosen points will give the same level of statistical precision in each case. This is so because all sites are composed of an infinite number of dimensionless points. In all cases, the same finite number of sample points is chosen randomly so that the relation between sample size and population size is the same. Again, it is important that sample points are chosen at random.

An important factor in choosing the number of sample points is that, as the number of sample points increases, the precision of the estimate of the mean also increases; but this precision increases at a decreasing rate.

Table 13 shows the confidence intervals for the 95 percent level of statistical confidence for a binomial distribution centered at p = 70 percent (the desired cover). As the number of sample points used to make the estimate of 'p' increases, the confidence interval narrows. When only 10 sample points are used, any sample cover value

between 39 and 95 percent is within the limits of 95 percent statistical confidence for a true cover value of 70 percent. It is unlikely that this level of precision would be acceptable for ascertaining if the desired cover is achieved. When 1,000 sample points are used, the confidence interval is greatly reduced, to 70 percent plus or minus 3 percent. This is an acceptable level of statistical error but it could take a long time to examine 1,000 sample points.

The use of 100 sample points might be an acceptable compromise. Data from 100 sample points produces a confidence interval which is suitably narrow for many purposes. When 100 sample points are used, the number of points that intercept vegetation is the value of cover, i.e., the percentage of the ground surface covered by vegetation. Additional discussion on the theory and statistics for handling of point data can be found in Realson and McKee (1982) and other references listed in the Bibliography.

Step Transect

The step transect method can be used for estimating cover at points placed randomly or systematically. In this method, the observer paces across the area to be sampled and the presence or absence of vegetation at a point on the tip of the shoe is noted. A small mark or notch on the tip of the shoe sole can help define the sample point. The occurrence of vegetation, litter, or bare ground can be noted at each observation point to help define distribution of cover. The number of steps between observations can be systematic or varied. It is necessary to lay out one or more random 'walks" to cover the area to be evaluated.

The step transect method is much less precise than using pins in a frame or a sighting tube with crosshairs. It also can introduce bias in that the position of the vegetation can be altered as the foot is placed on the ground. Some judgment must be used to compensate for this situation. However, the step method is fast and relatively easy to use and does not require carrying, handling, or positioning a measuring device. Some of the loss of objectivity by this method can be compensated for by increasing the number of observation points.

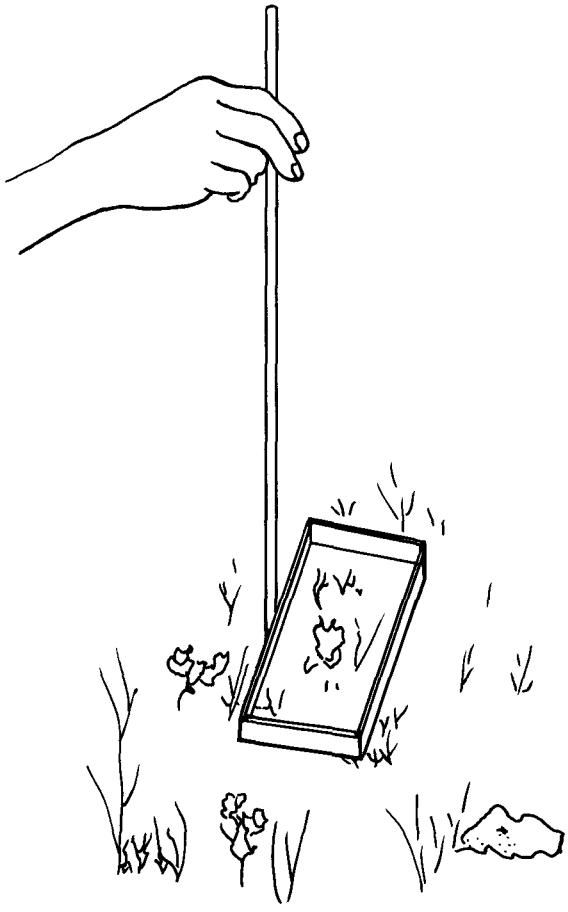

Figure 30. A tiny quadrat is used for estimating ground cover by the rated microplot method.

Rated Microplots

The use of rated microplots takes the concept of the imaginary grid as with the visual estimation of cover with the aid of quadrats, and, as shown in Figure 28, applies it to very small plots (0.5 to 2.0 square inches). The microplot frame is held with a rod attached to it perpendicularly and placed just above the vegetation to be measured (Figure 30). The microplot can be square, rectangular, or circular, but circular plots may be more difficult to subdivide visually. The microplot is arbitrarily subdivided into units such as quarters or tenths, and cover is estimated visually and rated to the nearest subunit (one-quarter or one-tenth) of area occupied for each of the items viewed in the microplot. For example, assume ratings will be made to the nearest one-tenth; then, if vegetation as viewed when looking down through the microplot occupies about four-tenths of the area of the microplot and litter (without vegetation above it) is viewed to occupy an additional two-tenths, a cover rating of 6 (4 vegetation + 2 litter) would be given. Items such as basal area, rocks, and species also can be rated and recorded if such information is desired or needed. A number of readings would be taken on an inventory unit by following one of the sampling designs discussed previously.

In some experiments with several sizes and shapes of microplots, no difference in estimating cover was found among four sizes or between round and rectangular plots. They all provided results similar to the point-quadrat for estimating cover of most vegetation forms and ground-surface items (Morris 1973). A ½- by 1-inch microplot was a good compromise of the plots tested but had no advantage over an 0.8-inch-diameter circle. The rated microplot requires less time than point-quadrats for estimating cover.

Line-Intercept

The line-intercept method is useful mainly for measuring aerial cover of plants and clumps of plants with well-defined canopies and nearly solid crown cover and plants with relatively large basal areas. It is, therefore, more suited for measuring aerial cover of shrubs, small trees, and some forbs than for grasses and most forbs. In mixed communities of grasses and shrubs, it may be desirable to use the point-quadrat or other methods for estimating

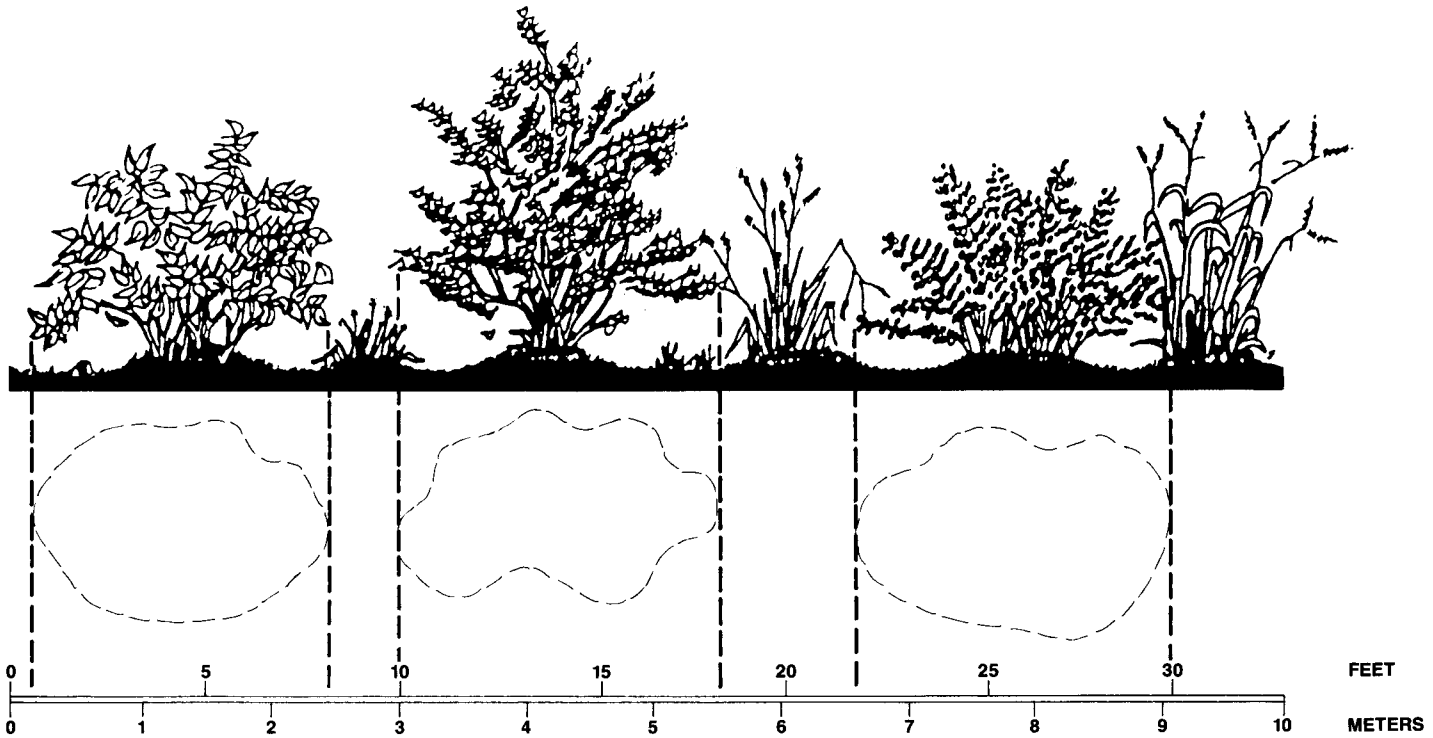

Figure 31. The line-intercept method is best suited for measuring aerial cover of shrubs and similar vegetation with closed, well-defined canopies.

cover of herbaceous vegetation and the line-intercept method for measuring shrubs. Quadrat frames could be located randomly along transect lines laid out to measure shrub cover.

The methodology for the line-intercept is as follows:

1. A line of predetermined length, preferably a tape measure, is stretched tightly across the vegetation or beneath the canopy of taller shrub and tree vegetation. Some type of clamp or holder anchored in the ground is needed to secure the tape on each end. The lines should be located objectively. The best sampling design is a stratified-random one using a baseline with transect lines perpendicular to it.

2. The canopy intersect of each species along the line is measured directly from the tape or with a rule (Figure 31). Where canopies overlap in layered vegetation, it may be desirable to measure the layer at each height separately. The interception along the tape by canopies that are not solid should be interpreted consistently. For example, do not measure as cover the gaps between branches that extend across the tape. Small gaps within the plant canopy can be included as cover.

3. Transect lines can be between 35 and 350 feet long, but many short lines usually are preferred over a few long ones. Short lines are easier to hold and secure in place, but more time is required to locate, place, and move many short lines than a few longer ones. A minimum of 5 to 10 transects usually is required for adequate sampling. Guidance on the determination of sample size is given in Chambers and Brown (1983), Farmer et al. (1981), and other references cited in the bibliography.

4. Percent cover can be calculated for each species, or all species combined, by dividing the length of line intercepted by each or all species by the transect length and multiplying by 100. For an entire inventory unit, percent cover is the sum of the intercepted lengths from all transects divided by the total length of transects sampled, and multiplied by 100. Data are summarized by each transect line for statistical analysis.

Photographic (35 mm Slide) Method

Aerial cover of vegetation also can be determined with the use of 35 mm slides. Individual sample quadrats are first photographed in the field. Later, the percent of the quadrat covered is determined from a grid onto which the developed slide is projected. The procedure is as follows:

1. Sample quadrats are located randomly in the inventory unit by any one of the sampling designs described. The same quadrats used to photograph cover can be used to sample production, but cover must be photographed before production is sampled.

2. The quadrat is labeled according to location, data, and quadrat number. Labeling can be accomplished with individual cards for each quadrat, or a film imprinting system such as the Recordata Back available for Olympus cameras can be used.

3. A tripod and camera bar are used to position the camera vertically over the center of the quadrat. The size of the camera lens used is determined by the size of the quadrat. When viewed through the lens, the quadrat

should encompass the majority of the area outlined in the lens without distortion.

4. The focus, lens aperture, and shutter speed are adjusted for each quadrat and the photograph is taken.

5. The processed slide is projected onto a grid with 100 squares. The vertical and horizontal axes of the grid must coincide with the axes of the quadrat frame. The slide projector is adjusted so that the area within the quadrat matches exactly that within the grid.

6. The number of grid squares covered by vegetation, litter, bare ground, rock, and gravel are counted. The number of squares counted is equivalent to the percentage of each cover category within the sample grid. In sparse communities where individual plants can be identified from the slide, it may be possible to obtain percent cover by species.

7. Data are summarized by quadrat for statistical analysis. Percent cover can be derived for each of the cover categories (total vegetation, litter, bare ground, rock, etc.). In some cases, percent cover also can be determined for life forms and or species.

Other considerations for the use of this method are:

1. The 35 mm slide method is not well suited to sampling schemes that require large quadrat sizes. Quadrats larger than about 0.5 m^2 will not easily fit within the area encompassed by standard lens sizes.

2. This method is not well suited to tall vegetation (over 1 m). In mixed communities of grasses and shrubs, the 35 mm slide method can be used to assess grass and forb cover, and the line-intercept method used to evaluate shrub cover.

Evaluating Production

Several definitions or interpretations can be applied to vegetation production depending on the use or purpose of the vegetation, the plant type or life form, the approved standard for success, or other factors. Production often is defined in a broad sense as the current-year's growth or yield of aboveground plant material (biomass) on a unit of land. This definition may be applicable where total plant growth provides a meaningful measure of production for the plant species and land uses involved, such as grasses and forbs on grazing and pasture land or sorghum and corn grown for silage. However, this definition applies only where production on the vegetated area is compared with a success standard based on total biomass yield. This is most often done where reference areas are used as the success standard. In those situations, production is estimated usually by harvesting all of the current-year's growth of aboveground vegetation from within a sampling quadrat or plot of known area.

This definition does not apply to cropland and hayland where the intended produce is a specified part of the plant's growth or biomass such as seed (grain), fruit, and hay. It also does not fully apply for grazing and pasture land uses where production of the revegetated area is compared to technical standards that are not based on total biomass yield. For example, in the management of hayland, all of the aboveground biomass normally is not harvested, nor is all herbage grazed off in the proper management of grazing land. To properly compare production on vegetated areas with technical standards requires that the revegetated area be harvested or sampled in the same manner as the areas on which the standards are based. This emphasizes that standards and terminology should be clearly defined and understood by all parties concerned with the development of production success criteria.

Where defined as all of the current-year's growth (biomass), production includes diameter growth of stems and branches of trees and shrubs, and may, depending on interpretation, include persistent green, living leaves of evergreen plants. However, measurement of these stems, except possibly twig growth on shrubs, normally will be of little concern in evaluating the success of revegetation. Of primary concern is measuring production of vegetation grown for grazing, pasture, and cropland uses.

Harvest Sampling Method

Except where crops are harvested from an entire area, production most often is estimated by harvesting or clipping vegetation in sampling plots or quadrats of known size. Location of quadrats on inventory units can follow one of the sampling designs described previously. Estimates of cover usually can be made at the same location and same time as production estimates. Vegetation can be clipped by species, by life forms or other groups of species, or all together depending on objectives and requirements for data collection. Harvesting can be at different heights or for different parts of the plant depending on the crop, land use, success standard used, or other objectives. For example, in sampling for production of hay, where success is compared against a technical standard, the height of clipping above the ground should be the same as that normally used in mowing hay of that species in that locality. Where production on areas revegetated for pasture or grazing use is compared with reference areas, the sampled vegetation is clipped at ground level or as close to it as possible. Shrubs, if present, usually are not harvested in such a manner. However, directives may be given in the PAP to determine production of current-year's twig growth.

Following are several factors that may need to be considered when harvesting sample plots of vegetation. Some of these may cause problems and require extra effort to avoid or overcome.

1. What to Harvest—Two options are available in determining which plant material to include and exclude when clipping quadrats. One option is to harvest all plant material within an imaginary three-dimensional volume (cube or cylinder) projected above the quadrat even though the plant may not be rooted within the quadrat. Similarly, portions of plants rooted in the quadrat but overlapping outside the quadrat and not occupying space above it are not included in the harvest from the quadrat. This is called the 'volume concept" (Figure 32). The other option, called the 'basal concept," requires the clipping and saving of all parts of all plants rooted within the quadrat even if portions of the foliage of these plants overhang outside the quadrat. Parts of plants overhanging into but not rooted in the quadrat are not clipped. Where the quadrat boundary divides the base of clumpy-type plants, such as

bunchgrasses, only the portion of the plant based within the quadrat is clipped (Figure 32). The volume concept may have some merit and may be useful without too much difficulty in some vegetation types or structures. However, for sampling most vegetational types, it has less practical substance and injects more human error and bias than clipping by the basal concept. Attempting to delineate the boundaries of vegetation in an imaginary cube or cylinder in waving tall grass, for example, is more difficult and injects more bias than delineating which plants are rooted in or out of an easily visible quadrat frame on the ground. Also, placing the frame on the ground can alter the natural position of the aerial portion of the vegetation, but would have little effect on the selection of plants rooted in the quadrat.

2. Dead Vegetation—To measure only current year's growth (production), the dead standing vegetation should be removed from the harvested samples. This can be tedious and time consuming and it also injects bias. One possible way to avoid including dead vegetation is to randomly select and mark quadrat locations and clip off all dead vegetation shortly before the growing season begins. All of the vegetation harvested at these spots at the appropriate time later in the season would be considered as current-year's growth. One potential problem is that these spots could be selectively grazed by deer or other wildlife.

3. Protection From Grazing—Where grazing is to be practiced on inventory units, the vegetation should be protected from grazing animals at the location to be clipped. This would require use of exclosures or small cages built strong enough to withstand bumping and butting by livestock. Cages also could be used to prevent wildlife use as mentioned in item 2. An alternative to cages is to try to correct for the amount of vegetation used by grazing animals, though the techniques for this are imprecise and could introduce considerable bias into production estimates.

4. Animal Unit Conversion Values—A situation related to item 3 is where it may be necessary to convert technical standards given in animal units of grazing per unit area to weight of forage per unit area. Conversion values for different animal units and appropriate to the area usually can be obtained from State and Federal agricultural resource agencies. A conversion value of 20 pounds of air-dry forage per cow per day was used in Table 10 (page 49) to convert cow days of grazing per acre to pounds of forage per acre. The converted values represent herbage available for livestock under proper grazing management. Where sampled vegetation is clipped at ground level, a weight factor that adjusts for necessary nongrazed herbage should be subtracted from the clipped herbage or be added to the production standard. An alternative is to clip the vegetation at a height comparable to that for proper grazing.

5. Dry Weight—All production samples normally are converted to dry weights. For most situations, especially where reference areas are used for success standards, weight of the harvested vegetation usually is standardized by oven drying at 60° to 70°C. Where harvested vegetation is compared against technical standards, weights should be put on the same dry-weight basis as the standard. For hay, air-dry weights are most commonly recorded.

6. Time of Sampling—Where sampling is intended to reflect the peak or maximum productivity, sampling should be timed to coincide with the seed ripe or mature stage of the majority of the species in the plant community. Where a reference area is used it is logical to sample both it and the revegetated mine area at the same time, or time intervals, and when the majority of the species are at the highest level of production. The samples do not necessarily need to reflect the total year's growth or production of all species of the community, but they should be handled similarly on both areas.

There are numerous plant communities in which there is significant difference between the timing of flowering

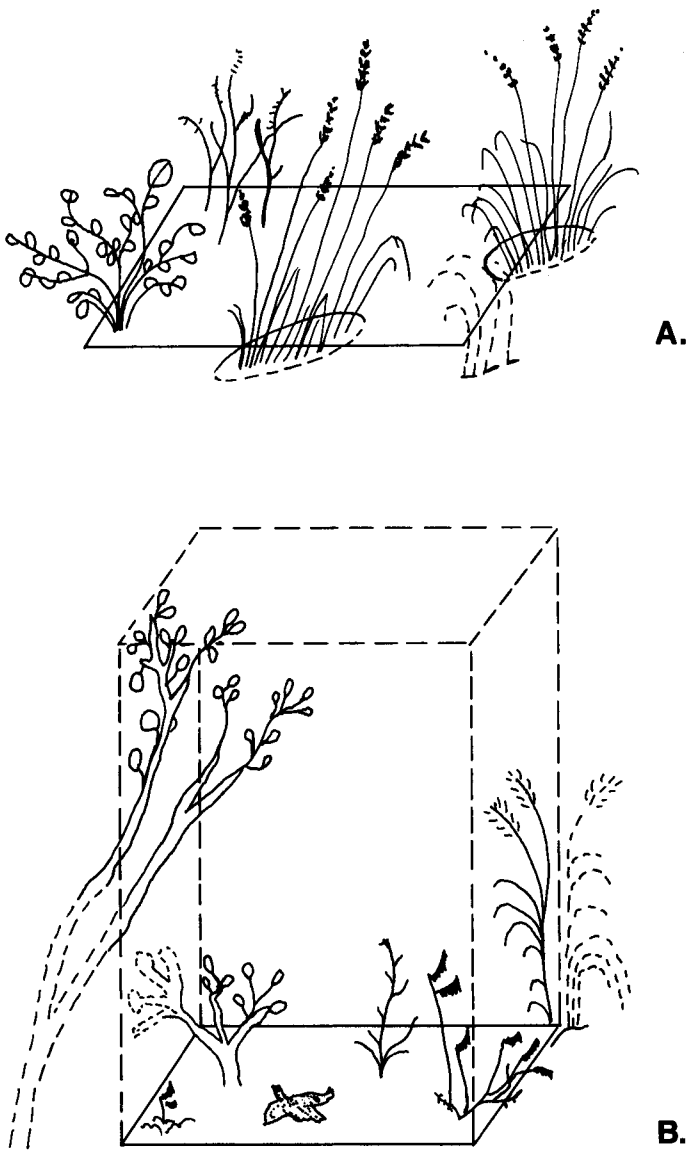

Figure 32. Clipping vegetation within quadrats as perceived by the (A) basal and (B) volume concepts.

and seed production of the major species. Two examples of this are communities with both cool-season (perennial ryegrass) and warm-season (little and big bluestem) grasses, and communities with grasses that flower and mature long before the shrubs. Cool-season plants generally make the major portion of their growth during the winter and early spring. Warm-season plants make most or all of their growth during the spring, summer, or fall, and usually are dormant in winter. In communities with varying seasonality, it may be necessary to sample when overall community production is at a peak. For the community with both cool-season and warm-season species, this would be at some point after the cool-season grasses have matured, but before they drop their seed. The warm-season grasses likely would be approaching maximum foliar growth and nearing the time of flowering. If the periods of peak production of the major species are extremely disparate, it may be desirable to sample at two different times to obtain an accurate estimate of total maximum productivity.

7. Quadrat Size and Shape—Selecting the proper plot size and shape is important for efficient sampling or sampling that will minimize both variance and sampling time. Van Dyne and others (1963) presented the following generalizations concerning the influence of plot size and shape:

- Perimeter-to-area ratios are lowest in circular plots and decrease as plot size increases. Low perimeter-to-area ratios generally decrease sampler error.
- More species generally are included in long, narrow plots.
- Optimum plot size and shape may depend on the distribution of the species measured, with larger plots usually recommended in sparse vegetation.
- Small sampling units, though generally more efficient statistically, often yield skewed data, and thus may not accurately represent the true population.

Both the type of vegetational community being sampled and the parameters being investigated will determine not only the plot size and shape but also the specific methodology to be used. Table 14 presents suggested quadrat sizes and shapes for use in several vegetation types.

8. Harvesting Cropland—For most crops, sampling to estimate production will not be necessary because production of the entire harvested crop can be determined. Where sampling is necessary, randomly placed quadrats or randomly selected rows or parts of rows can be used as sampling units. The crop would then be harvested from the sampling unit and processed in the normal manner for that crop. In sampling for hay production, a small sickle mower or a rotary lawn mower with bag catcher could be used to harvest the crop. Hand clippers and small quadrats also could be used. The cutting height should be the same as that normally used in mowing hay of that species in that locality. Because hay yields usually are on an air-dry basis, the harvested material should be air dried before it is weighed. The length and width (area) of the mowed quadrats should be known so that the yield from them can be converted to the same yield/area units as the standard.

Table 14. Quadrat sizes for sampling production with circular, square, or rectangular quadrat frames.

Vegetation Type	*Metric Measure (m^2)*	*English Measure (ft^2)*
Dense* tall-grass prairie and pastures	0.25–0.75	0.96–2.40
Sparse† tall-grass prairie and pastures	0.50–1.50	1.92–4.80
Woodlands-dense understory	0.75–1.50	2.40–4.80
Woodlands-sparse understory	1.00–2.50	4.80–9.60
Dense mid-grass prairie	0.25–0.75	0.96–2.40
Sparse mid-grass prairie	0.50–1.50	1.92–4.80
Dense shrublands	0.75–1.50	2.40–4.80
Sparse shrublands	1.50–2.50	4.80–9.60

*More than 50% aerial cover.
†Less than 50% aerial cover.

Quadrat Sizes and Conversions

To convert grams per quadrat to pounds per acre, multiply grams by the following conversion factors:

Quadrat area (ft^2)	*Conversion factor*
0.96	100
1.92	50
2.40	40
4.80	20
9.60	10

To convert grams per quadrat to kilograms per hectare, multiply grams by the following conversion factors:

Quadrat area(m^2)	*Conversion factor*
0.25	40
0.50	20
0.75	13.33
1.00	10
1.50	6.67
2.00	5
2.50	4

Kilograms per hectare × 0.89235 = pounds per acre
Pounds per acre x 1.12064 = kilograms per hectare

Double Sampling Methods

Double sampling using the weight-estimate method entails estimating vegetation production in the majority of the quadrats sampled and both estimating and harvesting production in a small percentage of the quadrats. This method allows the estimates of all quadrats sampled to be adjusted or corrected for estimator error by techniques, such as regression. This method lacks much of the precision and accuracy obtainable with the harvest method and generally is not recommended for making a final evaluation of production. Its use may be warranted for interim evaluations. This method can decrease the time and cost involved in sampling, but estimators require considerable training and must constantly check the accuracy of their own estimates if reasonably reliable data are to be obtained. Details on the use of this method are not given here, but can be obtained from numerous references on range measurement techniques, including some listed in the bibliography.

Measuring Stocking Success

Stocking as related to forestry can be defined in terms of volume, basal area, number of trees, crown closure, and other parameters. In relation to the revegetation of surface-mined lands, stocking normally means the number of individual trees and shrubs growing in a given unit area (also called density). Determining tree and shrub stocking is a matter of counting and recording the number of living plants in sample rows, plots, or quadrats, or on the entire inventory unit. This approach seems relatively simple but different sampling techniques may be needed for determining stocking of tree and shrub seedlings established from broadcast seeding compared to those spaced systematically in rows by hand or machine planting.

The most accurate way to measure stocking is to count the living trees and shrubs in an entire inventory unit. This would be too time consuming and costly for large areas, but may be the most expeditious method for evaluating small systematically spaced plantings of less than 2 acres, such as blocks and strips planted for wildlife habitat and shelterbelts. The procedure would be to simply walk the length of each row, count the number of living plants, and record them by species. The observer also may want to look for volunteer woody species and include them in the count. When the count is completed, divide the number of plants by the size of the area to determine the stocking or density. Information on plant distribution could be determined by noting their approximate location on a map or plat, or by keeping a running tally of living and dead or missing plants in each row. A knowledge of the original spacing of planted seedlings is helpful in determining the location of missing plants.

One of several sampling methods can be used to estimate stocking in large planted areas. Some methods for evaluating areas planted systematically in rows entail the random selection of several rows or portions of rows as sampling units. The plants counted in these rows or sampling units are then converted to number per unit area. Two procedures are described:

1. For planted units of uniform shape, such as square or rectangular, determine the area (acreage) and the total number of tree rows on that area by counting all rows or by estimating the number based on spacing between rows. Convert the percentage of sampling rows to acreage and calculate the number of living plants per acre from the number counted in the sampling rows. Example: an 18-acre rectangular area 1,600 feet in the long dimension would have 200 rows running across short dimension at an 8-foot spacing between rows. A sample consisting of 10 percent of the rows (20 rows) = 1.8 acres. If the total count of living trees in 20 rows is 840, then 840 divided by 1.8 acres = 467 trees/acre. Counts by rows would allow statistical testing for sampling adequacy and confidence limits.

2. A modified version of this procedure could be used on any large planted area, even an irregularly shaped area where row lengths are variable. Only the average spacing between rows of planted trees need be known or determined to compute stocking based on counts of living plants. The basic sampling unit is a section of row 209 feet long (an area measuring 209 by 209 feet equals 1 acre). Based on average spacing between rows of trees, the number of parallel rows that could be planted in a distance of 209 feet is the number of 209-foot row sections in 1 acre of area. Thus, the number of 209-foot row sections sampled can be converted directly to area and the number of plants counted expressed as number per acre. Example: the average spacing between rows on a inventory unit is 9 feet; thus, 209 divided by 9 = 23 row sections/acre. Assume 34 row sections (sample rows) counted with total of 446 living plants; 34 counted sections divided by 23 sections/acre = 1.48 acres sampled. Then, 446 total plants divided by 1.48 acres = 301 plants per acre.

Counting the number of tree and shrub plants within randomly placed sample plots or quadrats also can be used for determining stocking of systematically planted seedlings as well as for plantings that are not spaced systematically and those established from broadcast seedings. Quadrats large enough to include several planting spots are needed for evaluating systematically spaced plantings. These quadrats may be from 1/100 to 1/10 acre in size, but those that are 1/40 acre and smaller are easier to manipulate. To determine the number of trees or shrubs per acre, simply multiply the number counted in a quadrat by the denominator of the quadrat's size fraction, i.e., 40 in the case of a 1/40-acre quadrat.

For broadcast-seeded trees and shrubs and randomly planted seedlings (no systematic pattern), smaller quadrats (1/200 to 1/1,000 acre) are adequate to sample stocking. With small quadrats such as a milacre (1/1,000 of an acre), for example, simply recording the presence or absence of living stems gives an estimate of stocking and the distribution of plants. In fact, for forestry, this method of measuring stocking relates better to density of stocking in the future when stands are old enough to be evaluated by forest productivity parameters.

Quadrats for estimating stocking can be located within inventory units by one of the sampling designs described previously. Ground cover and stocking can be estimated at the same time. However, quadrats used for estimating stocking normally are too large to make reasonably accurate estimates of cover. A smaller quadrat, such as a square meter, or other device, such as a point-quadrat, could be placed at the same sampling point at which the larger quadrat for estimating stocking is located.

Quadrat shape has little effect on the accuracy of stocking measurements, especially in uniformly distributed vegetation. Circular quadrats probably are the most efficient shape for field use because a rope, wire, or stick of prescribed length can be used as the radius in circumscribing the plots. For example, a 1/100 acre circular plot has a radius of 11.7 feet; a milacre (1/1,000 acre) plot has a radius of 3.72 feet.

An alternate procedure may be convenient for estimating stocking in certain difficult conditions, such as on steep slopes. Here a rectangular plot or quadrat is used. The length of the plot could vary with the length of the slope and the width could be defined by a hand-held stick of a length that in relation to plot length provides a plot of known area. On a steep slope, for example, a rope tied to a tree or vehicle at the top of the slope would provide the long axis of the plot. Knots tied in the rope or marks painted on it would indicate the length of the plot, 33 feet,

for example. A stick 6.6 feet long and held perpendicular to and centered over the rope (or on one side of it) by the observer delineates the width of a 1/200 acre plot as he or she descends or climbs the slope. The rope also provides the observer with something to hold to, if necessary, when climbing and descending the slope. The number of tree and shrub plants are counted within the boundary of the plot delineated by the stick and rope and multiplied by 200 to provide the number of plants per acre. A relatively narrow plot as illustrated here may give biased results if used in plantings spaced systematically.

Plant Community Structure and Species Diversity

Revegetation success can be evaluated and described by a variety of characteristics including those already discussed—cover, production, and stocking or density. Measuring and describing the structure and species diversity of plant communities also may be useful in judging the success or quality of revegetation, especially on native grassland and shrubland communities. Data for describing plant community structure and species diversity can be obtained in conjunction with the collection of cover, production, and density data.

Table 15. Comparison of Shannon's index, Spearman's R_0, and Sorenson's similarity index.*

Characteristic	*Shannon's Index H'*	*Spearman's R_0*	*Sorenson's Similarity Index*
Requires species or life form list	X	X	X
Requires measure of importance (production, cover, or density)	X	X	X
Requires same number of species or life forms in both areas		X	
Does not require same number of species or life forms in both areas	X		X
Tests apportionment of species or life forms between areas		X	X
Does not test apportionment of species or life forms between areas	X		
Independent diversity index for each area	X		
Diversity measure derived from comparison of both areas		X	X

*A discussion of the applicability of these methods along with illustrated examples is given in Chambers and Brown (1983). Application of the Shannon-Weiner Diversity Index to revegetated mined land is given by Larson (1980).

Community Structure Analysis

Community Structure Analysis is used to estimate the relative position of plant species within a community by calculating an importance value (IV) based on density, dominance, and frequency (Pase 1981). *Density* is the number of individuals per unit area. Actual counts of individuals of a species or class are needed per plot of known size. *Dominance* of a species can be expressed in several ways—size, basal area, or production of standing crop. From a practical standpoint, cover provides an easily measured characteristic that expresses the influence of one species on other community components, and on the site itself in terms of site utilization and protection from erosion.

Density and dominance values alone give no indication whether a species is well distributed over a site or occur only in infrequent (though possibly large) units. The number of plots or sample units on which a species occurs is termed *frequency*, and indicates how well a species is distributed on a site. For some species and some land uses, spacing of plants is more important than number of individuals or total cover.

The *importance value* for a species is a composite "score" that is determined from density, cover, and frequency values, and indicates the relative importance of that species in a plant community. The IV score tends to de-emphasize the unique characteristics that may exaggerate the importance of any given species.

In practice, density, cover, and frequency data can be obtained in conjunction with the collection of cover, production, or stocking data by procedures and sampling systems described previously. Details on the application of the Community Structure Analysis method are found in Pase (1981) and Aldon (1984). A computerized program for analyzing data by this method is available from the latter.

Species Diversity

The concept of species diversity also provides an evaluation of the structure and composition of a plant community. The diversity concept contains two basic components, species richness (number of species in a defined area) and species evenness (proportionate distribution of individuals among species). Assessed together, these components are sometimes called "heterogeneity." Diversity usually is discussed in terms of species, but it also can be thought of in terms of life forms. In fact, the use of life forms in comparing the diversity of a reference area with that of a revegetated area may be more appropriate, especially where species different from those in the reference area are planted in the revegetated area.

Several methods of comparing the diversity of two areas are available to the investigator. These generally can be categorized as diversity indices, rank correlation tests, and similarity indices. Similarity indices probably provide the best available method for comparing reference and

revegetated areas. Diversity and rank correlation indices have several shortcomings that make questionable their applicability for comparing reference and revegetated areas. The characteristics of three methods are compared in Table 15.

Statistical Procedures

Several of the references listed in the bibliography provide details on statistical procedures for determining adequacy of sampling (number of samples needed) and confidence limits and for comparing revegetated and reference areas. Also, most textbooks on statistical methods provide procedures for determining sampling errors, variances, regression, etc.

REVEGETATING COAL SURFACE-MINED LANDS IN THE EASTERN COAL REGIONS

The purpose of this chapter is to (1) briefly describe the coal regions in the eastern United States, (2) list and describe plant species suitable for revegetating surface-mined lands and criteria for selecting those species, and (3) suggest species and species mixtures for different uses of reclaimed land.

The coal and lignite regions in the eastern United States lie primarily east of the 100th meridian. They include the Appalachian Coal Region, the Interior Coal Region, and the Southern Lignite Region.

Appalachian Coal Region

The coal fields in the Appalachian Coal Region cover approximately 72,000 square miles in parts of nine states, extending from Pennsylvania to Alabama. For the purpose of this handbook, all of five states—Pennsylvania, Maryland, Ohio, West Virginia, and Virginia—and the eastern part of Kentucky are assigned to the Northern Appalachian Coal Region; three states—Tennessee, Georgia, and Alabama—are assigned to the Southern Appalachian Region (Figure 33). Eastern Kentucky, Virginia, and the southern third of West Virginia physiographically form the central part of the Appalachian Region and for revegetation purposes have commonality with both the Northern and Southern Appalachian Coal Regions.

Geology

The coals of the Appalachian Region are of Pennsylvanian Age, and are essentially coextensive with the Appalachian Plateau physiographic province. The most abundant coal-bearing rock types in Appalachia are the fine-grained siltstones and shales. Although less abundant, sandstones and conglomerates are conspicuous because of their resistant nature, frequently forming bold outcroppings and capping mountains. Limestone is prevalent in western Pennsylvania and Ohio, but in the rest of Appalachia, where present at all, lime is found mostly in calcareous shales or as a cementing agent in sandstones and siltstones. The coalbeds are distributed throughout the sequence of Pennsylvanian rocks.

Many of the coal-bearing strata contain varying amounts of the mineral pyrite, which is of considerable importance because of its potential for producing acid spoil and acid-mine drainage. However, with local exceptions, the patterns of acid-mine drainage affecting major stream systems indicate that this problem is most prevalent in Pennsylvania, portions of eastern Ohio, and a band along the boundary of Kentucky with West Virginia and Virginia in the Northern Appalachian Region and in north-central Tennessee in the Southern Appalachian Region. Coal-bearing strata that chemically are strongly alkaline are found in a few areas, but these strata are of minor consequence to the region.

Physiography

The Appalachian Coal Region occupies a high plateau that in most parts has been deeply incised by a dendritic stream pattern, giving rise to a rugged mountainous terrain. Altitudes range from 900 to 4,800 feet above sea level, with relief in the mountainous areas ranging from 500 to 1,500 feet. Slopes exceeding 30 degrees are common throughout much of the Appalachian region, with steeper slopes and vertical cliffs along major rivers. Terrain of this nature has necessitated contour and mountaintop-removal mining and has created severe erosion and stream sedimentation. In addition, transportation is hampered by the difficulty and expense of building and maintaining roads and railways.

Climate

Precipitation over all of the Appalachian Coal Region averages 47 inches annually. It ranges from 35 inches in Pennsylvania to a high of 55 inches in Alabama (Figure 34). The precipitation is fairly well distributed throughout the year, though any month could have the most or least precipitation in a given year. Approximately one-half of all precipitation is lost through evaporation and transpiration. Short periods of dry weather occur occasionally; longer periods occur infrequently, usually in late summer to early fall.

Average annual temperature ranges from about 50°F in Pennsylvania to a little over 60°F in Alabama. Average maximum temperature ranges from about 90° to 100°F, while average minimums range from around -10° to 10°F. Seasonal variations in temperature and precipitation are influenced to some extent by local topographic extremes. Some mountaintops and adjacent valleys may experience nearly as much climatic variation as occurs between the northern and southern parts of the region. However, largely because of its relative abundance overall, the variation in precipitation caused by topographic extremes is not great enough to produce extreme diversity in vegetation types. Average frost-free periods range from about 120