REPORT OF THE PROJECT COMMITTEE ON EROSION FOR 1941

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INTRODUCTION

For the past two years the present Project Committee on Erosion has continued the same approach to its problem as was followed by the former Project Committee on Slope Erosion of the Joint Committee on Roadside Development. Since 1935, the principal activities of these two project committees have been, (a) to collect data on highway erosion control practices of the various State Highway Organizations, the Soil Conservation Service, the Tennessee Valley Authority, the U. S. Forest Service, and the National Park Service; (b) to analyze, consolidate and distribute resulting information to the State Highway Organizations and other interested parties; (c) to initiate cooperative highway erosion control demonstration projects among the several States, the Soil Conservation Service, and the Public Roads Administration, and to analyze results of these

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As a principal part of its report for 1941, the project committee has sponsored a paper on 'The Design of Roadside Drainage Channels' by Mr. Carl F. Izzard, Associate Highway Engineer of the Public Roads Administration. (See page 47 for this special paper)

In addition, the project committee has consolidated results of its 1941 studies with previous data to present a condensed review of six years' study. There are many basic principles that are of sufficient importance to warrant reemphasis. For ease of presentation, this review is separated into three general classifications.

I. Proven methods and practices of highway erosion control have been developed and are now widely accepted and used in principle. All of these could be made even better by improved technique and better adaptation to regular highway construction and maintenance practices, personnel, and equipment. In other words, 'the determination of the most effective methods alone will not solve the problem. Methods should be determined which can be coordinated with customary highway engineering practice, using mass production methods which feature the use of common and readily secured seeds and plants to bind the soil, as far as possible without masonry or other artificial structure.' (1)[1] Lower cost control is also one of the objectives sought, particularly for locations where the time factor is not so important. However, good judgment must be exercised in the choice of methods. A low cost practice may be entirely ineffective because too often excessive erosion has destroyed initial highway construction work before such control measures could become effective. This economic relationship of time and cost factors should determine the method.

II. Demonstrated principles of highway erosion control which deserve greater consideration and wider application. There are a number of these principles that are not concerned solely with the technique of erosion control, but becomes of a broader scope which presents administrative and personnel problems there has been some reluctance on the part of highway authorities as a whole to seek

1. Numbers in parenthesis refer to list of references at end.

actively for solutions to the problems presented by these demonstrated principles. (See Appendix II, page 79a for preliminary report on cooperative soil erosion projects).

III. New problems that are continually arising from changes and improvements in the design, construction and use of the nation's highway system.

I - PROVEN PRACTICES IN HIGHWAY EROSION CONTROL

Research and field experience have brought about the realization that erosion control on highways cannot be considered in the same light as erosion control on gardens, lawns, and fields. Basic principles are the same, but they must be interpreted and adjusted to highway conditions and in addition the methods of erosion control thus evolved must be further adjusted to coordinate them with highway engineering practice.

MULCHING: The use of mulch in highway erosion control work is perhaps the practice most greatly improved and most widely adopted in recent years. (2)(3) There now exist a number of variations in mulching technique. Mulch alone, without planting or seeding, has proven its worth as an erosion control measure. It breaks the beating force of heavy rains which, in clay soils particularly, seal over pores of the soil and cause greater run-off. It lessens winter freezing, thawing and heaving. Mulch also conserves soil moisture, improves the physical condition of the soil, and as it decays provides organic matter.

Used in conjunction with seeding, mulch prevents washing of seed and fertilizer and protects young seedlings, in addition to the benefits mentioned previously. When grass or legume hay is used for mulch, seed contained therein often develops sufficient vegetative cover to make supplementary seeding unnecessary.

On relatively steep slopes in particular, where seedbed preparation cannot be done with machinery, the practice of 'premulching' eliminates hand labor preparation. By this method of mulching well in advance of seeding, the retention of soil moisture and moderate freezing and thawing mellows the soil into a satisfactory seed bed onto which seed can be sown through the mulch.

State highway organizations have in roadside mowings an extensive local source of mulching material. Except for noxious weeds (and even these might not be objectionalbe in wooded and wasteland areas) all roadside cuttings are too valuable for erosion control to be burned or disposed of as hay in localities where erosion is a serious problem, regardless of how convenient such disposition may seem at the time.

ORGANIC AMENDMENTS: In many areas where erosion is most serious, land adjacent to the highways has been stripped of topsoil by years of uncontrolled erosion and topsoil is not only uneconomical but actually unavailable. Thus to the roadside technician falls the task of dealing with raw-soil and hastening nature's slow process of developing topsoil. (4)

The use of organic amendments in raw-soil improvement has four principal benefits. They improve soil texture, increase moisture holding capacity, add fertility, and (equally important if not even more important) introduce soil micro-organisms which make plant food available to the plants. Organic amendments hold moisture better than any possible application of topsoil.

Cover crops, green-manure crops, manure, decomposed sawdust (5), cotton oil mill refuse, and composts of many kinds have given surprising results in raw-soil improvement, not only in the initial establishment of vegetative cover but, even more important, in the continued maintenance and growth of that erosion control cover.

Of course, it is on the flatter slopes where machinery can be used that the introduction of organic matter into raw-soil is most easily accomplished, but even where hand-labor methods are required on the steeper slopes, the extra cost of organic amendments has been more than repaid within a few years by the more successful erosion control thus acquired.

TOPSOIL: The possibility of lack of topsoil has been mentioned in the preceding section, but even where the topsoil supply is ample, there is danger of depending too much upon it and considering it as a 'cure-all.' On the steeper slopes in particular the danger always remains that the vegetation initially forced into luxuriant growth by topsoiling will be seriously set back or entirely destroyed by subsequent drought.

Then too, the term 'topsoil' is a broad one with varying interpretations in different sections of the country. In many of the Northern States there are the dark loamy topsoils rich in humus and plant food. In many of the Southern States there are the sterile topsoils of reasonably good texture but low in organic matter and lacking in plant food due to years of leaching and soil-depleting cash crop agriculture. In the drier, sandier sections the term 'soil from the top' might be more descriptive than the term 'topsoil' as it is generally interpreted. In States where topsoil base courses are used for road surfacing, there is too frequently a lack of understanding as to the difference between topsoil for surfacing and topsoil for growing vegetation. As a result much money has been wasted on topsoil for roadside use that is actually subsoil with a 'topsoil color' which 'sets-up' as firmly as surfacing. Such topsoil must be improved with fertilizer and organic amendments to have it equal the existing raw-soil.

In sections of the country where high fertility topsoil is easily available and obtainable at reasonable cost, its use in highway erosion control is recommended, but even in these sections efforts should be made to determine the minimum amount of topsoil needed and thus reduce even further the cost of erosion control.

In sections of the country where topsoil is both poor and scarce, its principal value lies in the roots, seeds and soil microorganisms that it introduces into raw-soil. Very thin layers of topsoil (or 'soil from the top') that is 'alive' with seeds, roots and bacteria should be of greater value than thicker layers of worn-out topsoil.

These comments on topsoil should not be construed as condemning its use for highway erosion control; but greater care should be taken in the selection and use of topsoiling and there should not be a blind dependence and in many cases a false security built up in the minds of technicians just because an area has been 'topsoiled.'

'In many cases, the fertile top soil from cuts is buried in the bottoms of fills leaving only sterile soil on the slopes where the maintenance crew tries vainly to grow sod to prevent erosion.' (6) This statement, made in 1933, is unfortunately still too applicable today. There has been some notable progress in some States in salvaging topsoil during initial construction, and practices have been developed by which vegetative cover can be established on raw soil, but the value of even small amounts of topsoil in establishing vegetation makes it important that more attention be given to saving existing topsoil on new highway locations.

"SANDPAPERED" SLOPES: There has been a gradual but still too slow realization that painstaking slicking or 'sandpapering' of slopes in highway construction is a needless waste of money. The first hard rain destroys the 'sandpaper' finish and erosion is only aggravated by the slick smooth surface which has been shaved and patted by many hours of hand labor.

Also, the establishment of vegetative cover requires a loosened, roughened seedbed that will absorb moisture and allow easier root penetration. Where topsoil is used, a roughened slope surface is essential to obtain proper bonding of the raw soil and topsoil and thus preventing loss of topsoil by washing and assuring the movement of capillary moisture from raw-soil to topsoil.

There is a distinct difference between highway slopes being uniform, which is desirable, and being smooth, which is wasteful. Both cost of construction and cost of erosion control can be reduced by discarding the 'slicking' of slopes.

GENERAL TYPES OF VEGETATIVE TREATMENT: In addition to soil and climate, establishment of vegetative cover on highway slopes is greatly affected by the rate of slope. For ease of presentation, the various slope ratios (stated in ft. horizontally to ft. vertically) are separated into three general classifications.

1. Slopes 3:1 or Flatter. These flatter slopes are generally in the lighter cuts and fills, with soils of A or B horizons. On slopes of this class it is possible to establish and maintain shallow-rooted pasture-type and lawn-type grasses and legumes.

2. Slopes Steeper Than 3:1. These steeper slopes are generally in the heavier cuts and fills, with C horizon raw-soils predominating. In some cases where these steeper slopes occur in A or B horizon soils, the more favorable soil and moisture conditions may allow the type of vegetative cover described in the paragraph above, but these cases form an indefinite transition zone which cannot be listed separately in a general classification.

On these steeper slopes shallow-rooted plants can seldom be satisfactorily maintained, even if established, because of frost heaving and sloughing. Deep-rooted plants, such as the perennial lespedezas, sweet clovers, vine and shrubby ground cover, withstand frost action better and are better able to overcome the scarcity of plant food and moisture.

The 'naturalization' of these steeper slopes by mulching with native plant growth and the encouragement of subsequent volunteer indigenous growth is recommended, and is particularly simple in cool-humid climates and in wooded areas, where natural seeding and volunteer growth results from the abundance of forest growth above the slopes. (3)

3. **Exceptional Slopes.** Frequently slopes are encountered which are so steep or of such extremely poor soil or rotten rock that none of the vegetation previously described can be established or maintained economically. In these cases, if flattening of the slopes is impossible, it is necessary to resort to treatments such as benching, wattling, or the use of Kudzu vine. (7)(8)

Considerable use of Kudzu has been made in the Southeastern States and experience to date seems to indicate that under some soil conditions Kudzu is the most satisfactory and economical control yet developed. Satisfactory results have been obtained in particular on loess soil in Mississippi and on secondary roads where erosion is serious but where more extensive erosion control methods are not economically feasible. There is, however, need for caution in the use of Kudzu vine. It has some decided disadvantages and its use has not been sufficiently tried or observed over a long enough period to justify a belief that it is a 'cure-all' for highway erosion control. Further weighing of its advantages against its disadvantages is urgently needed.

As a general rule, the establishment of vegetative cover is less difficult on fill slopes than on cut slopes, because even though fills are well compacted the soil is more porous on the slope surface and moisture conditions are better than on undisturbed cut slopes.

STRUCTURES VERSUS VEGETATION: During recent years there has been a very desirable trend away from masonry, log, or similar 'ditch checks' or 'check dams' for erosion control in highway drainage channels. Although valuable where gully erosion is a problem in highway cross-drainage, these structures in parallel drainage channels too frequently form traffic hazards and interfere with routine maintenance. Therefore, it is recommended that vegetative ditch cover be employed on better proportioned drainage channel cross-sections designed not by hard and fast template but on the basis of rate of discharge and velocity of drainage water to be handled.

Many installations of vegetative ditch cover have failed in the past, but most of the failures can be traced to two causes: First, overestimating the velocity under which the particular kind of vegetation used will hold up. Second, and the most general cause, using the old standard practice of a uniform cross-section throughout a project or even throughout a State, regardless of soil, grade, or peak flow of drainage water.

The allowable velocity for a number of types of vegetation has been determined reasonably accurately, (9) and study of this question is continuing. In the matter of drainage design, excessive calculations for individual design of each cross-section on a project is of course impractical for highway construction, but recent experiments have shown that it is possible to use a simplified practice that will remedy the faults of the standard ditch cross-sections without overburdening highway designers and construction engineers. (10)(11)

If the velocity is too great, or if conditions prevent the development and maintenance of a good vegetative cover, the use of some type of paved gutter on a uniform grade is recommended rather than the use of masonry check dams or other overfall structures.

On some secondary roads, where steep grades are more frequent than on main highways, and where paved gutters are not justified, the use of ditch checks may prove the most practical erosion control measure; but of course in such locations the traffic hazard and maintenance problems are not as serious as on primary highways.

TREES AND SHRUBS VERSUS GROUND COVER: For highway water erosion control emphasis should be placed on the use of grasses, legumes, vines and low-growing spreading shrubby ground cover rather than on trees and the larger shrubs. By following this policy initial costs are lower, maintenance is much easier and better adapted to routine highway practice, and most important of all a more immediate cover is obtained over the entire area. Trees and shrubs may be helpful in preventing large scale gully erosion, but cannot adequately control sheet erosion and finger-gully erosion.

SODDING: Solid sodding as a method of obtaining ground cover continues to be successful if used on areas where the expected velocities are within the allowable limits, and on slopes of less than 2:1; but due to the cost of this method, it is not economically feasible unless immediate and complete cover is desirable.

Strip sodding with the strips spaced at relatively close intervals on a slope has proven to be almost as expensive as solid sodding. The results have usually been less effective.

IMMEDIATE COVER CROPS: Newly completed highway construction is highly susceptible to erosion and projects are often completed at times of the year when the seasonal operations of establishing permanent vegetative cover cannot be carried on. Under these conditions the use of a satisfactory local mulch material separately or in combination with a temporary cover crop, seeded immediately after highway construction and regardless of the season of the year, has proven of great value in some sections of the country.(12) Sudan grass and small grains, because of rapid germination and strong, early growth, have so far been most effective as cover crops for this purpose.

In addition to immediate erosion control at almost any season of the year, these cover crops have several additional advantages. The root growth tends to aereate tight soil and adds at least a small amount of organic matter. The cover crop also is a source of mulch when permanent vegetative cover is being established later.

Although most of the temporary cover crops used have been annuals, there is a possibility that more permanent perennial vegetation can be established in months of the year now considered as 'out of season.' Small scale experiments to date seem to indicate that by careful mulching and fertilization the seasonal limits for establishing some of the perennial grasses and legumes can be extended beyond the customary limits accepted for farming operations.

II - DEMONSTRATED PRINCIPLES NEEDING WIDER APPLICATION

The proven practices previously described involve principally the adjustment and development of technique. Other principles of highway erosion control, developed by research and field experience, involve questions of administration and policy, and therefore the acceptance and use of them has lagged behind the purely technical practices.

HIGHWAY EROSION AND AGRICULTURAL EROSION: 'Run-off from farm land destroys roads even as run-off from roads cuts gullies on farm land. It is a two-way damage that can be prevented in only one way - by cooperation.'(13) This need for coordination indeed carries over into the broad field of rural and regional planning, and long range planning may eventually solve it. But in the meantime- rain still falls and soil still washes away and there are many current problems that cannot be altered fundamentally or solved in the ideal way.

There have been some notable accomplishments in cooperative handling of this problem. Highway water has been turned into farm terraces, thus avoiding the carrying of large volumes of waters for long distances in the highway drainage channels. In semi-arid sections, this practice has the additional benefit of providing irrigation for the adjacent agricultural land. Farm terrace water has been turned into and satisfactorily handled by roadside drainage channels designed for the combined volume of water, thus avoiding two parallel 'government ditches,' as one farmer expressed it.

But there are still too many cases where highway water is released from the highway drainage area to cut gullies in or deposit silt on good agricultural land. There are still too many cases where uncontrolled water from adjacent land or even terrace-controlled water play havoc with the highway right-of-way.

Of course, it is unfair to expect that either the property owner or the highway organization should handle this problem alone, but through cooperation and coordination much improvement can be made. The Soil Conservation Districts furnish an initial starting point for working out this cooperation because these Districts are already organized and are legally constituted local governing bodies to which the Soil Conservation Service offers various forms of assistance. These Districts as now operating have authority to cooperate in bringing such assistance to private land owners. Laws permitting organization of Soil Conservation Districts have been enacted in 42 states, and 619 such districts have been organized covering 365,000,000 acres of land.

SECONDARY ROADS: County and township roads in many sections of the country have been neglected from the standpoint of erosion control. It is obvious that these light traffic secondary roads do not justify the high-type cross-section or erosion control treatment that are necessary for safety of traffic and economy of maintenance on primary highways. The very same general principles of erosion control, of course, apply to both primary and secondary roads, but more study and trial is needed on the most economical design, correlated with the most economical erosion control methods, to meet secondary road conditions.

SILTING: Too often the silting phase of erosion is not given the attention it should have in highway erosion control, perhaps because it is not as spectacular as gully erosion and does not constitute as acute a danger to the roadway section. But the quiet, unspectacular freezing, thawing, and sloughing of slope surfaces and the lighter forms of sheet erosion cause much damage. Highway ditches are filled, requiring needless additional maintenance. If the volume and velocity of highway drainage is sufficient to wash the soil from the ditches, it is deposited over good agricultural land or it goes farther to choke watercourses, destroy fish life, and ruin good agricultural bottomland. Absence of serious gullies on the highway right-of-way should not be allowed to give the false impression that erosion control is not needed in such locations.

DESIGN FOR EROSION PREVENTION: Even though the economy of erosion control has been amply demonstrated, there still remains in a number of states a reluctance to consider erosion prevention in highway design. Since freedom from erosion is valuable to highway safety and maintenance, it is not logical to build a highway, wait until erosion becomes serious, and then start a job of 'patching' and repair to check that erosion.

Vegetative cover is not a magic 'cure-all' for those defects in highway design which aggravate erosion. Vegetation must have protection against excessive flow of water and in original design and construction is the logical and most economical place to provide this drainage control by ample parallel drainage channels, berm or intercepting ditches, drop inlets, and by the greatest possible flatness of slopes and flexibility of cross-section.

Borrow pits should be seeded or planted immediately after all material needed has been removed and after the rough surfaces have been smoothed by grading. Sections of highways abandoned because of relocations should be treated similarly, because if both are not treated, erosion from them causes silting up of drainage structures.

Berm (or intercepting) ditches parallel to the top of cut slopes, and therefore on a steep grade, should be avoided. These only transfer the erosion problem a few feet farther from the roadway, whereas such ditches properly built on contour and light grades will reduce velocity and allow vegetative control.

Greater use of drop inlets at the intake end of cross drainage culverts will save much grief in the maintenance of parallel drainage channels. Erosion by water flowing into drainage structures too frequently cuts back into the ditch line until long sections parallel to the roadway have gullied out to almost the same depth as the drainage structure itself.

Studies of improved design of the outlet end of culverts to prevent undercutting of the structure show promising results, and deserve continued effort.

Good 'streamlined' cross-sections, with slopes flattened and rounded as much as economically possible, make establishment and maintenance of vegetative cover much less expensive. But even though the highway is thus designed, flexibility in the field to take care of unforeseen local conditions requiring slight modifications in grading should be allowed during construction.

III - NEW PROBLEMS

New problems in highway erosion control arise from year to year, requiring adjustments in old techniques and development of new methods.

IMPROVED ALIGNMENT AND GRADE: As new highway alignments become straighter and new highway grades become flatter, the depth of cuts and height of fills increase and in many cases it becomes an economic impossibility to obtain slope ratios as flat as might be desirable for easy establishment of vegetative cover. Larger and larger areas of raw-soil of C horizon are exposed, and areas become so great that to cover them with a uniform layer of topsoil is impractical because of both the increasing scarcity of topsoil and the cost of application.

With increased areas of relatively steep slopes of raw-soil to be stabilized against erosion, the approach to this problem necessarily must be different than for agricultural land. For continued research on establishment of vegetation on raw-soil, the project committee has adopted a simple classification of types of raw-soil. This classification which is discussed later in the report is subject to change and refinement as additional results of research become available.

SLIDES: The problem of slides is not new, but as improved highway alignments and grades make deeper cuts, the slide problem is increased. Vegetative cover on the slope surface of course will not prevent slides since the plane of slippage is generally below the depth of root penetration, and it also has been found that trees are ineffective in stabilizing 'wet' cuts. Carefully planned sub-drainage to intercept water on the plane of slippage is the essential first step in the treatment of 'wet' cuts, after which routine vegetative treatment of the slope surface can be carried out.

In addition to 'wet' cuts there is also the problem of 'dry' slides due to soil shrinkage and on both problems additional research is highly important.

SHOULDERS: The development and greater use of the strategic defense highway network by military traffic has made the problem of shoulder width, slope, and surfacing more acute than ever. Unsolved questions are the amount of traffic wear that grass shoulders will stand, and the point at which the establishment and maintenance of grass shoulders should be abandoned in favor of some other type of shoulder surfacing.

Establishment of vegetative cover on slopes are affected by soil, climate, slope, and type of vegetation. On shoulders, however, are additional limiting factors affecting sod cover. Traffic 'wears out' the sod or tears it up in wet weather. The tendency for sod to 'build-up' over a period of years is not a consideration on slopes, but on shoulders this building up of the sod frequently interferes with drainage from paved surface to drainage channel. This difficulty is largely alleviated by increasing the shoulder pitch in the design of the cross-section. Grass shoulders require ample moisture; on the other hand moisture is not desired close to the paved surface. Thus the shoulder problem requires mutual study by soils and roadside engineers.

As use of subgrade stabilization increases to the point where the selected material is used for the entire roadbed from ditch to ditch, a question arises as to whether or not it will be at all possible to obtain grass on the shoulder area made up of selected material introduced to form the roadway. Because of the factors just described, the study of erosion control on shoulders is distinct from slope erosion control and raw-soil agronomy. The project committee proposes that because of its importance at the present time, the possibility of growing grass on stabilized shoulders be explored this year.

CLIMATIC CLASSIFICATION OF RAW-SOILS* In locations where soils have not been disturbed enough by highway construction to lose A and B horizon soil, (topsoil and immediate subsoil) methods of erosion control are closely related to usual farm crop methods, and soil types as used by agronomists will determine treatment.

In the majority of highway construction, however, cuts are so deep that slope soils are of C horizon. The soil materials comprising this horizon C are products of climatic weathering of parent material, but they have been affected slightly or not at all by plant life development. These raw-soils have been divided into three climatic groups, with three sub-groups (1) clay; (2) loamy; (3) sandy, under each.

A. **RAW-SOILS OF DRY CLIMATE:** Differences in annual average temperatures are less important in dry climate than they are in humid climates. The weathering of parent material is mostly physical, resulting in a disintegration of parent material into

* Adapted from "The Plant Growing Conditions on Steep Roadside Slopes and Their Improvement," by D. W. Levandowsky, Unpublished Ms., April, 1940. (14)

particles resembling a crushing process. Chemical weathering is limited in this case because of lack of moisture. No leaching of bases takes place hence these soils usually do not need lime. There is little hydration of silicates, hence formation of clay is limited.

B. RAW-SOILS OF COOL-HUMID CLIMATE (Brown Raw-Soils). Ground remains frozen in cool-humid climate longer than in warm-humid climate, hence weathering is limited in depth. The raw-soils of cool-humid climate are less erodible than the raw-soils of warm-humid climate. However, due to shallow rock-strata under cool-humid climate conditions, there is formed the so-called 'clay hard pan' that causes frequent slides. Organic matter content is maintained with less trouble than in warm-humid climate.

C. RAW-SOILS OF WARM-HUMID CLIMATE: (Red and Yellow Raw-Soils). Weathering in warm-humid climate is rapid and penetrates deeply into parent rock, forming thick layers of erodible, soft, rotten rock-like material. The bases and plant food elements are leached out to a great extent. The Kaolin type clay is formed. Soil materials are red or yellow as a result of extreme oxidation and hydration of iron. Organic matter when applied is lost quickly.

Two transitional areas are recognized: one between dry climate and cool-humid climate; and one between dry climate and warm-humid climate. Transition areas are also found in the rough mountains of the West where cool-humid climate raw-soils occur in higher elevations and dry climate raw-soils occur in lower elevations.

REFERENCES

1. Highway Research Board.
1937. Report on Roadside Development. Seventeenth Annual Meeting, December, 1937.

2. Franklin, Sydney.
1939. Mulching to Establish Vegetation on Eroded Areas of the Southeast. U. S. Department of Agriculture, Leaflet No. 190.

3. Hursh, C. R.
1939. Roadbank Stabilization at Low Cost. U. S. Forest Service, Appalachian Forest Experiment Station, Technical Note No. 38.

4. Levandowsky, D. W.
1939. Organic Matter in Roadside Agronomy. Highway Research Board, Report on Roadside Development, Nineteenth Annual Meeting, December, 1939.

5. Levandowsky, D. W.
1940. Sawdust as an Organic Amendment. Highway Research Board, Report on Roadside Development, Twentieth Annual Meeting, December, 1940.

6. Highway Research Board.
1933. Report on Roadside Development. Thirteenth Annual Meeting, December, 1933.

7. Bailey, R. Y.
1939. Kudzu for Erosion Control in the Southeast. U. S. Department of Agriculture, Farmers' Bulletin No. 1840.

8. Kraebel, Charles J.
1936. Erosion Control on Mountain Roads. U. S. Department of Agriculture, Circular No. 380.

9. Highway Research Board.
1940. Report on Roadside Development. Twentieth Annual Meeting, December, 1940.

10. Izzard, C. F. The Design of Roadside Drainage. (See page 47 of this publication).

11. U. S. Forest Service. Trunk Trail Handbook, 1940, p. 461.

12. Kell, Walter V.
1936. Cover Crops for Soil Conservation. U. S. Department of Agriculture, Farmers' Bulletin No. 1758.

13. Davis, Arnold M.
1938. Erosion on Roads and Adjacent Lands. U. S. Department of Agriculture, Leaflet No. 164.

14. Levandowsky, D. W.
1940. The Plant Growing Conditions on Steep Roadside Slopes and Their Improvement. Unpublished Mss., April, 1940.