REPORT OF SUBCOMMITTEE
ON
EROSION

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HISTORY AND DEVELOPMENT OF PROJECT

The project on Slope Erosion Control was set up by the Joint Committee at the 15th Annual Meeting of the Highway Research Board in 1935. The following agencies were invited to cooperate: Highway Research Board, Soil Conservation Service, Bureau of Public Roads, Tennessee Valley Authority, and representatives of the various State Highway Departments in selected key areas.

The statement of the problem prepared by the subcommittee at that time may be summarized as follows:

> The prevention of erosion along highways is a national problem the solution of which has often proved very costly and not always entirely successful. The solution involves engineering factors of highway location with respect to topography, cross-section, and drainage and incidental structures, as well as the applied principles of forestry, agronomy and soil analysis affecting the selection and establishment of plant growth.

The problem was divided into the following parts:

I. Erosion on watershed areas in relation to the highway.

- a. Watershed areas below highway drainage structures.
- b. Watershed areas above highway drainage structures.

II. Erosion in highway ditches.

III. Erosion on cut and fill slopes.

The objectives of the subcommittee as set forth at that time were to study methods, demonstrate practices and determine materials, structures and plants best adapted for the prevention of erosion along highways under varying conditions of cross-section, soil type and climate. The study was to include relative initial cost as well as subsequent maintenance.

SUGGESTED SPECIFIC PROBLEMS

In comparison with the final objectives attained and the results secured, it is interesting to note the variety of specific problems which were suggested and which were included in the early studies. The suggested list as of December 1935 is as follows:

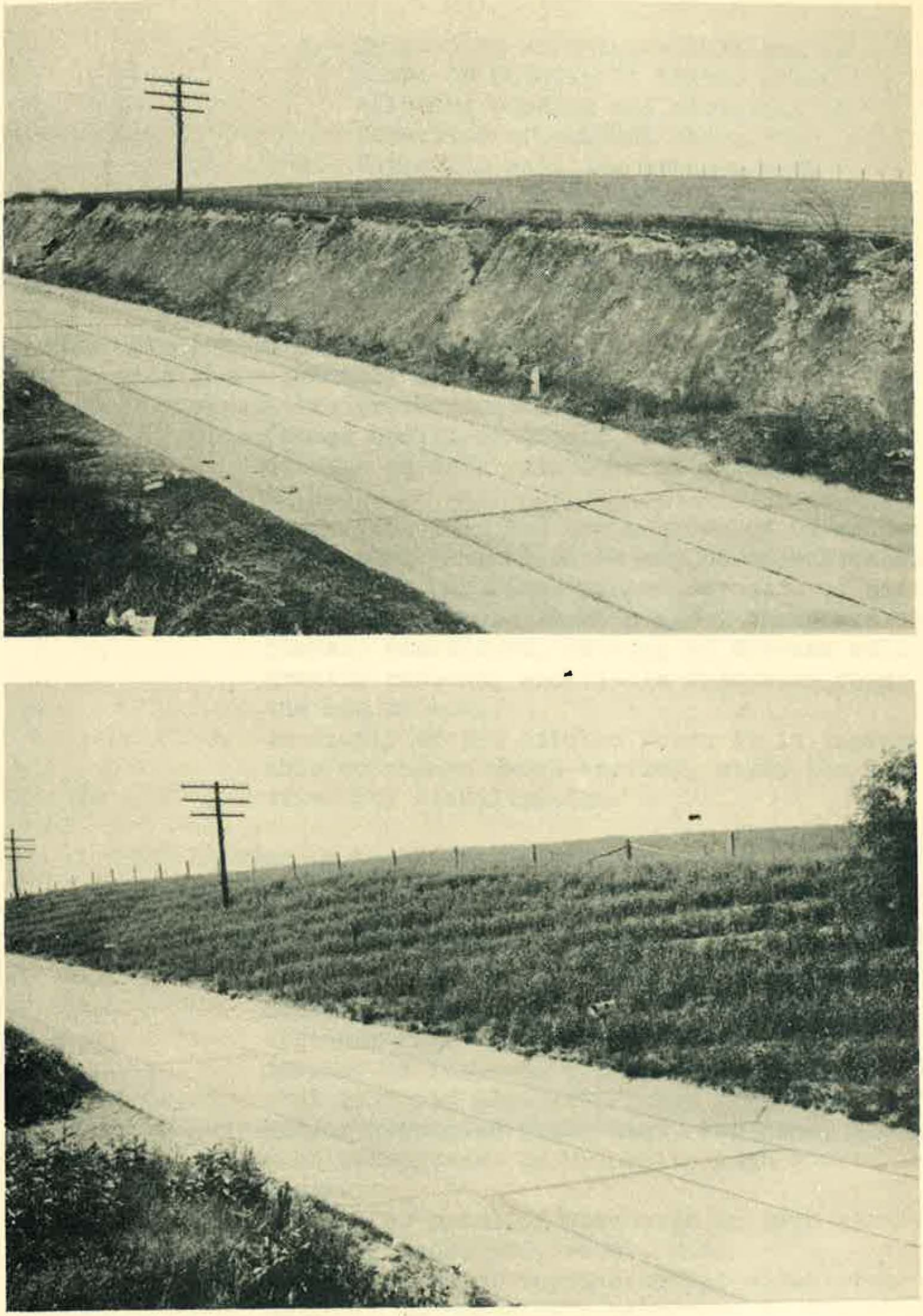
"I. Watershed areas in relation to the highway.

(A) Watershed areas below highway drainage structures.

1. Demonstrate methods of disposal of road water that will be less harmful to farm lands and highway lands.
   a. Use of wide sodded channels.
   b. Stabilization of flow line grade mechanically or with vegetation.
   c. Diversion with tile.
   d. Deepen highway ditch and carry water to stabilized natural water course.
   e. Practical relocation of small highway drainage structures to take advantage of natural outlets or to move outlet to location where erosion will be more easily controlled.
   f. Riprapping, use of willow mats, flexible plastics, or planting fills and banks adjacent to drainage structures or waterways.
   g. Use of water in semi-arid sections.

(B) Watershed areas above highway drainage structures.

1. Demonstrate methods of stabilization of overfall gullies cutting headward above highways.
   a. Sloping head and sides and seeding, sodding, or planting. (See U.S.D.A. Bulletin No. 1813 on Gully Control.)
   b. Flumes or drop structures. (See U.S.D.A. Bulletin No. 1813 on Gully Control.)
   c. Addition of drop inlets (or head spillways) to existing structures.



Virginia trench method of establishing vines.
Top-Before treatment. Bottom-One year after treatment.
Soil Conservation Service

d. Relocating existing structures up slope or raising to higher elevation allowing ponding and elevation of flow line of channel above road.
e. Replacing existing bridges with highway fills and drop inlets. (Not erosion - but flood control.)
f. Riprapping or planting fill slopes adjacent to structures.

VII. Erosion in highway ditches.

(A) Where quantity of runoff and grade indicate that vegetative protection will be satisfactory.

1. Change design of ditch. (Broad, flat bottom ditches on same principle as terrace outlets.)
2. Study effect of sod and methods of establishing. (Sod in road ditch may be objectionable because it sometimes causes deposits of silt and clogs ditch. Where highway banks are completely stabilized, silting of ditches will be greatly reduced, and little objection found to the use of sod.)
3. In deeply eroded ditches where it is impracticable to change cross-section, study the use of vines for stabilization.

(B) Ditches in locations where quantity of run-off, grade, soil type or other conditions make the use of vegetal protection impracticable.

1. Study effectiveness and cost of various methods of mechanical control: Overfall masonry, or concrete dams with aprons, spreader dams without aprons (low overfall masonry or concrete structures in broad flat bottomed ditches), loose rock dams, and/or creosoted plank dams, log dams, etc., when nececessary to resort to such structures.
2. Control at point of discharge by drop structures, flumes, sod, vines, etc.
3. Proper design of terrace outlet structures where it is absolutely necessary to discharge terrace into highway ditches.
4. Improvising of new, less expensive highway checks for temporary or permanent use, with due regard for traffic safety requirements.

"III. Erosion on cut and fill slopes.

(A) Treatment and design of back and shoulder slopes and highway embankment.

1. Study cross-section of roadway to determine possibilities of reducing the degree of slopes: In sandy and light loamy soils consider reduction of slopes of 3 to 1 to 4 to 1, heavier soils of approximately 2 to 1.
2. Determine proper angle of repose for sodded embankments on various soil types.
3. Study possibility of using berm ditches or intercepting ditches above cut slopes, such ditches to be located approximately on contour and designed for a non-erosive velocity. Their use will depend on (a) quantity of runoff and (b) the existence of a satisfactory point of discharge. The use of berm ditches or intercepting ditches parallel to edge of top of cut should be discouraged.
4. Consider use of temporary shoulder curbs and discharge flumes on fills.

(B) Study the effectiveness of seedling tree planting in controlling erosion on highway slopes. This study should include such factors as soil type, tree spacing and trees naturally adapted. The element of safety to users of the highway must be considered and no trees planted in locations where they will eventually obstruct lines of vision.

(C) Study the effectiveness of vines and shrubs in controlling erosion. Should include such factors as soil types and vines naturally adapted, and methods of planting.

(D) Seed mixtures of grasses and nurse crops to be tested under different exposures, climatic conditions, and soil types.

(E) Study the various methods and factors to determine the most effective methods to establish sod on varying degrees and finish of slope and soil types.

1. Carefully finishing surface and seeding with and without addition of top soil.
2. Leaving surface rough and seeding on existing soil.
3. Effect of mulching with straw or litter of 1 and 2 above.

4. Planting countersunk sod strips, and seeding between. Compare effectiveness and cost with 1 and 2.
5. Method of establishing sod vegetatively.
6. Effect of fertilizer treatments on 1, 2, 3, 4, and 5.

(F) Prevention of Wind Erosion.
In blown sands, oil spray methods are to be discouraged in favor of the planting of stolons or other vegetative methods of establishing grasses suitable under various sand conditions. (Special report of Simsberry Slope, Connecticut State Highway Department.)

(G) Prevention of Slips (Several projects started - results later.)
1. Planting deep rooted trees.
2. Mechanical method such as piling, cribbing, diversion ditches, intercepting tile, blind drains, etc."

CONTRIBUTIONS OF INDIVIDUALS
OTHER THAN JOINT COMMITTEE MEMBERS

Valuable contributions were made in the initial stages of this work by the Soil Conservation Service, especially by their Engineer, Mr. T. B. Chambers. The Carnegie Institute of Washington, D. C., made available to the Joint Committee the services of Dr. F. E. Clements with his background of ecological research. The T.V.A. made its contribution through C. C. Davis, J. W. Hamilton, and John E. Snyder.

METHODS

On May 6, 1937, at the suggestion of the Joint Committee, there was made effective by the Bureau of Public Roads a memorandum of understanding between the Soil Conservation Service of the Department of Agriculture and the Bureau of Public Roads relative to demonstration of methods of erosion control along highways. This memorandum was sent to the various District engineers on July 16, 1937, and followed later by instructions for the submission of preliminary reports and survey data for each project. Two types of projects were provided for the Highway Departments:

(1) two party agreements between State and Soil Conservation Service, where no Federal-aid funds were involved; and

(2) three party agreements between State, Soil Conservation Service, and Bureau of Public Roads.

The Soil Conservation Service also made its services available to the State highway departments on erosion problem areas common to both the highway and adjacent lands.

The above outline suggested many different combinations and possibilities and led to some very interesting results. It offered the best engineering skill available in the field, and many of the States, especially in the South where erosion problems are more acute, availed themselves of this demonstrational work.

The first summer meeting of the Joint Committee was held July 6-11, 1936, at St. Louis, Missouri, at the invitation of F. W. Sayers, Roadside Engineer for the State Highway Department. At that meeting considerable time was spent in coordinating the points of view of the several cooperating agencies. All of those attending committed themselves definitely to the program as outlined on page 72.

Early in September, the State of Arkansas started a project some five miles in length. Other States also started demonstration projects. The La Crosse County project in Wisconsin was located near research demonstrations of the Soil Conservation Service. Unusually fine opportunities were thus offered for observation and experimental projects in connection with the demonstrations along a ten-mile section of highway, five miles of which was accomplished under the cooperative method, and the other five under contract and force account methods.

EROSION CONTROL IN THE T.V.A. AREA

The intensive work which had been started in the T.V.A. area was continued throughout 1936, and included control of erosion in the following:

1. Cut and fill slopes;
2. Highway ditches;
3. Waterways below highway drainage structures; and
4. Waterways above and leading down into highway drainage structures.

Erosion control on cut and fill slopes was the most obvious of preventive work. The Bureau of Public Roads had recently made a very valuable contribution to the solution of some of the slope erosion problems by work which urgently furthered the stream-lining of highways. The few examples of highway projects in which the engineer had built a stream-line cross-section, rounding back the slopes instead of leaving the usual railroad-type angles and scars, were sufficiently outstanding to attract the attention not only to the safety factors involved, but also to the problems of maintenance and the alleviation of erosion difficulties.

Cross section revised and area seeded to grass.

Soil Conservation Service

EMPHASIS ON THE USE OF NATIVE PLANTS

At the Joint Committee meeting in December, 1936, Dr. Frederic Clements of the Carnegie Institute of Washington and Consulting Ecologist for the Soil Conservation Service sounded a note of warning to those using foreign or exotic plants for erosion control. Japanese Honeysuckle which had established itself in many sections of the southeastern States, was being accepted generally in certain sections of the country as a means of controlling erosion on back and fill slopes. Dr. Clements said in part:

"When we see the disastrous effects......the choking out of large blocks of native vegetation.....due to dissemination of this plant in the Pennsylvania and Virginia areas, we must of necessity be in doubt. This may lead to acceptance of the principle that only native and indigenous plants or those which have been thoroughly tried over a period of at least a century should be used for the prevention of soil erosion. The promiscuous dissemination of introduced foreign or immigrant plants may be the source of many troubles in the years to come. The following considerations may act as a practical guide in roadside development:

(1) By the use of native plants, the cost of maintenance is necessarily reduced to the lowest possible point.
(2) They require lower costs in time and cash outlay.
(3) A definite ecological succession can thus be established.
(4) Greater returns to the individual and to the community through a closer acquaintance and a greater sympathy with the out-of-doors environment in which recreational and spiritual values are to be secured."

CERTAIN HIGHWAY EROSION PROBLEMS OUTSIDE OF RIGHT-OF-WAY

Besides the more obvious highway erosion problems which relate themselves directly to highway right-of-way, the study of the erosion of waterways above and leading down into highway drainage structures was urged. The 1936 report briefly states the problem thus:

"An important observation......is that the problems of erosion do not terminate with the legal limits of the highway. It is often necessary to set up projects in cooperation with adjacent property owners. The changing of the water table by highway construction methods often creates difficult land use problems for the adjacent and sometimes unsuspecting farmer. Erosion in waterways above and leading down into highway drainage structures likewise has its engineering, forestry, and landscaping aspects. In the solution of these two problems, it might be observed that adequate land use and zoning are important factors. If definite areas adjacent to the highway could be set aside for the tree growth and maintained under good woodlot practices, very often much of the work of erosion control would be simplified.

"Thus we see that problems which appear to be only problems of erosion soon carry us into the broader field of rural and regional planning. There rests upon the highway engineer an ever widening responsibility. The welfare of farming depends upon farm to market roads as well as upon through highways but what the engineer does with the drainage system he establishes may also be important in determining what is good farming practice."

RECOMMENDATIONS FOR 1936

The subcommittee report at the 16th Annual Meeting of the Highway Research Board presented the following recommendations:

"I. We urge upon the various State Highway Departments the importance of availing themselves of the opportunity of roadside demonstrations in soil erosion prevention, and also of such as the following in the research studies of this project.

1. Outstanding climatic conditions.
2. Special nature of surface and subsoil conditions.
3. Variety of exposure to sunlight.
4. Seasonal nature of planting and seeding; i.e., spring and autumn.

"II. We urge the cooperation of the State Highway Departments in the collection of obtainable data either of an engineering or landscaping nature which are of value in the field of erosion control.

"III. The basic factors of selection of plants for erosion control on the highway and adjacent erosive areas where the runoff affects highway maintenance and protection are as follows:

1. The indigenous character of the adjacent landscape should be accentuated and preserved.
2. Native plants, those found in the area before the advent of the white man, should be used and restored wherever possible.
3. The highways should be "roadways back to nature".
4. Native plants have acquired resistance to fungus diseases and insect attacks.
5. Being a part of the balance established by nature, epidemics of disease or insect attack are balanced by diversified groups of plants.
6. Exotic species, because they are out of balance with other plant life, if used too extensively may be wiped out in the future by an epidemic of insects or disease.
7. The conservation and restoration of native plants offer better protection, food, and nesting places for song and insectivorous birds as well as small game. All of these are essential in the maintenance of the balance established by nature.
8. The application of these basic principles for the preservation and restoration of nature's balance will assure economical highway maintenance. The problem of erosion when thoroughly understood becomes very simple."

PROGRESS IN 1937

By October 1, 1937, eleven States were actively cooperating with the Soil Conservation Service of the Department of Agriculture on seventy-one erosion control research projects. Seventeen other States had indicated progress in this direction. Several States, including some outside of the Soil Conservation Service regions, had undertaken soil erosion projects in accordance with the outline prepared by the Joint Committee.

The Soil Conservation Service, in recognition of the importance of this work and at the request of the Bureau of Public Roads, had assigned one of its technicians, Mr. Arnold Davis, to coordinate highway erosion control research projects throughout the country. A review of these special research projects by the subcommittee in its 1937 report brought out the following points:

"Research Project Set-Up

1. Erosion control research projects are located primarily where the Soil Conservation Service has most of its C. C. C. camps. The greater part of the work to date has been done in the Mississippi Valley and Middle West.

2. A joint agreement between the Soil Conservation Service and the State Highway Departments involved, clearly delineating the responsibilities of each party, is drawn up.

3. Plans are prepared by the Soil Conservation Service and the highway department, based on standards already set by the States in their regular roadside development work. These consist of typical cross-section, estimate and layout sheets based on regular construction blueprints in highway department files.

"Methods Used in Carrying Out Research Projects

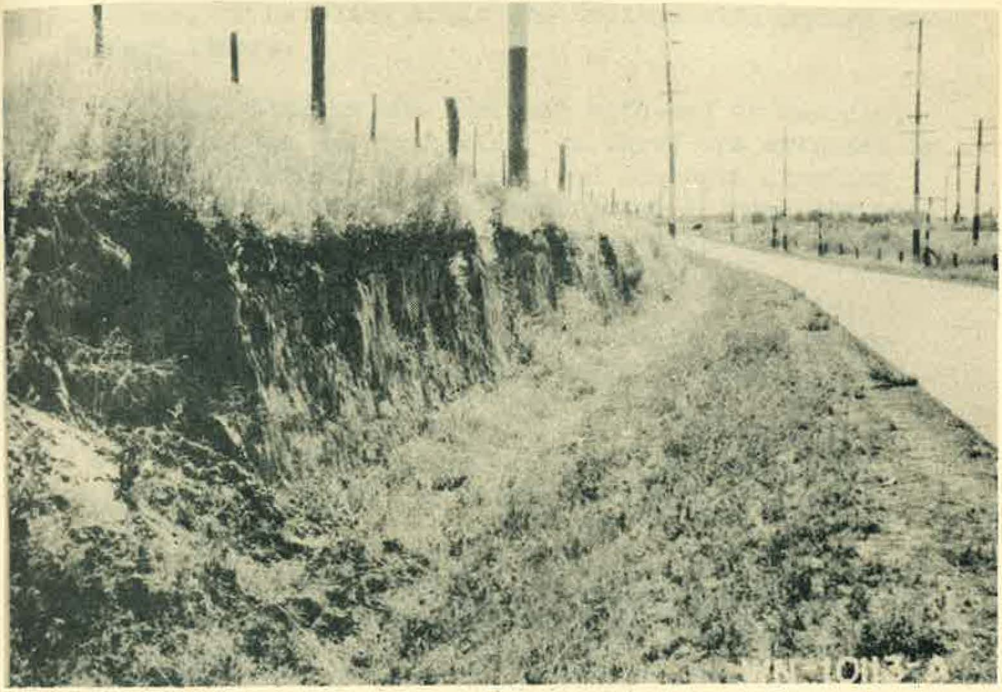
While the methods used in erosion control projects differ to meet regional climatic and soil conditions, all projects agree in their essential approach to the problem:

1. Rounding and flattening of existing highway cross-sections form the base for all following stages of erosion control work.

2. Slopes are flattened to meet existing soil conditions, and the best available types of vegetative ground cover materials are selected.

3. Ditch cross sections are rounded and flattened to reduce the abrasive force of surface water per square inch of surface./1

/1 - The Soil Conservation Service recommends that the ditch section be designed for a velocity which will not cause scouring and at the same time will minimize silting when the road ditch is intercepting outside water. It has been demonstrated in the south and southwest that Bermuda grass will carry water at a velocity of 8 ft. per sec. without causing scour.



Before and after treatment in the Pacific Northwest.
Soil Conservation Service

4. Topsoil is restored on seed beds or planting areas, or existing soils are treated with manure or fertilizers.

5. Ditches are surfaced with sod or masonry, ditch checks are installed, culverts are extended or modified, riprap is placed, and concrete or other types of check dams are constructed to meet the requirements of each project where vegetative control methods alone are not effective./2

6. Solid sodding, strip sodding, sprigging, seeding and combinations of these methods are used to establish grass as a ground cover.

7. Spreading vines or low woody shrubs are planted on slopes too steep for effective grass establishment.

8. To a limited extent, black locust and other tree seedlings are planted in highway areas to control erosion.

9. In all cases, native grasses, vines, shrubs, and other plants are featured as far as supplies of such materials are commercially available.

"Summary and Recommendations

Factors Affecting Erosion Control:

In all erosion control projects, emphasis is being placed on analysis of existing vegetation, soil and drainage on the roadsides and adjacent lands. Methods applied are based upon such conditions.

The factors which appear to be most important in all erosion control research on highway areas are:

/2 - Special attention should be given to improving the designs of culvert cross drains. Drop inlet or head spillways should be designed that will not only prevent erosion but will not prove hazardous to drivers. The outlet end of the culvert should be designed to reduce the velocity of water after it has passed through the culvert, either by flaring the end or by making use of de-energizers. A solution to the latter problem will prevent damage to adjacent agricultural land. In numerous cases side drains have been eliminated and driveway ramps constructed. These ramps are not only economical, but are more effective in preventing erosion.

1. The erodibility of existing soils.
2. The dimensions and degree of slope of bare soil areas.
3. The velocity and volume of surface water which reaches the highway from adjoining lands, depending on land use.
4. The design of highway slope and ditch sections and of highway drainage structures.
5. Types of ground covers existing off the highway and existing or established on erodible areas within highway limits.

In general, all methods of erosion control must be adjusted to meet the erodibility of the soils on highway areas as affected by these combined factors. Proper design of the highway cross-section plus establishment of well selected native plant materials will remain the backbone of successful erosion control work.

Factors Contributing to Soil Erosion:

1. Highway slopes have been too steep for stabilization of existing soils and have thus prevented ready establishment of vegetative ground cover.
2. Highway cross-sections have featured steep slopes with flat plane surfaces which have tended to encourage erosion.
3. Highway slopes and shoulder areas have not been provided with proper sub-surface drainage. Earth slumpage and slides have resulted.
4. Topsoil has not been conserved during construction operations and sterile soil surfaces have been left upon which vegetation cannot be established until fertility is restored.

5. Ditch section, culvert, and inlet and outlet design have in some cases favored surface soil erosion on highway lands.

Basic objectives of both highway erosion control and roadside development are:

<u>1. The demonstration of:</u>

a. Improved rounded and streamlined earth cross sections which will resist erosion, make possible the establishment of vegetative ground covers and which can be incorporated with new highway construction at reasonable cost. These streamlined cross-sections should not be standardized,, but varied to meet the needs of existing soil and topography.

b. Effective and economic methods of topsoil conservation and restoration and successful experimentation with chemical and organic combinations of fertilizers with existing soils where topsoil cannot be restored or, being restored, is found to be of poor quality.

c. Effective methods of control of excess water before it reaches the highway. Such control may be secured by establishment of vegetative ground cover, by the use of baffles, or check dams in drainage channels, by diversion ditches, or by terracing or under-drainage to direct water away from the roadway.

2. The determination of:

a. The relation between the physical character (erodibility) of existing soils, degree of slope and the factor of site aspect, and the selection of types of vegetative ground cover.

b. Best methods of establishing grasses, legumes and herbaceous plants by means of seeding, sprigging and chunk, strip or solid sodding, or combinations of these, under various roadside conditions.

c. Best methods of establishing woody vines or low woody shrubs by planting collected or nursery-grown materials selected to meet various roadside conditions.

d. Best type of structures to prevent erosion in ditches, on slopes, or on other highway areas under extreme conditions where vegetative methods alone are not effective.

"Conclusions

The Committee recommends that the following points be kept in mind in all future erosion control research:

1. A primary purpose of the work is the improvement of highway construction and maintenance methods leading toward future highways which will be free from the costly and damaging effects of soil erosion.

2. The first need in highway erosion control is to provide a reasonably fertile soil surface on a degree of rounded earth slope favorable to the establishment of common and existing available types of native or naturalized vegetation.

3. Special erosion control highway research projects should provide demonstrated facts upon which improved roadside development and eventually improved highway design will be based.

4. Erosion control research and demonstration projects must be selected as to site and planned as to methods used, with the object of solving existing highway design, construction, and maintenance problems.

5. The determination of most effective methods alone, will not solve the problem. Methods must 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 structures."

ACTIVITIES OF 1938

By 1938 the results of the demonstrations of the past two years were evident in many sections of the nation. The data accumulated were effectively used in several of the States and the demonstrational value of these projects was definitely established.

One hundred projects were under way in thirty-one States by November 1938. Over two hundred miles of highway were either planned or under construction in accordance with the outline of this committee through the cooperative arrangement of the Bureau of Public Roads and the Soil Conservation Service. In general the work was done by C.C.C. forces of the Soil Conservation Service which were operating in the vicinity of the project. In cases where the solution of the problem was obvious and the answer definitely known, the project was posted as an educational demonstration. Wherever the answer was sought and the solution of the problem was not conclusive, the techniques of research were applied.

The following statement was included as part of the subcommittee's 1938 report:

"<u>Slope Design and Treatment</u>

In the study of slope design some results must be immediate, although the cost may be relatively high. In such cases the best possible solution of the problem, as ascertained in the light of past experience, was the one which was chosen.

In general, low cost of control was one of the objectives sought, although the time required for such control to become effective was often two, three, or four years.

Often low cost controls with long-time objectives were failures because excessive erosion would destroy the initial highway construction work before the controls could become effective.

"Ditch Design and Treatment

Certain field tests and experiments were initiated, these to be checked against information obtained in the hydraulic laboratory. Some of these were:

1. Determination of the maximum permissible velocity of flow of water over the different varieties of grasses and soil types without scouring, or the minimum without silting.

2. Proper width and depth of ditch in relation to the drainage area, soil type, and cover material used.

3. Effects of minimum ditch design required for safety and maintenance against the theoretical capacity design.

"Findings and Results for 1938

The following results are based on observations in the different States and on the different projects where this type of research is being conducted.

1. The proper design of cross-section is the basic requirement of controlling most all types of erosion. The responsibility for this work can be met only by a man of wide experience and thorough knowledge of the problems that are involved and the dangers and damages which are likely to occur from improper cross-section design. Sufficient data have been secured to show conclusively the inadequacy of poor design. There is a crying need for more detailed examinations of projects and more careful training of division and district engineers who make field inspections to observe carefully the erosion factors involved and to study the likely damage which may occur. In many cases the average em-

ployee who is charged by the designing engineer with the responsibility of laying grades, balancing yardage, and designing slopes and ditches is inadequately trained to handle a job of such enormous responsibility.

2. With the use of Bermuda Grass, effective covers may be established in ditch cross-sections where maximum velocities of 8 ft. per sec. may be expected.

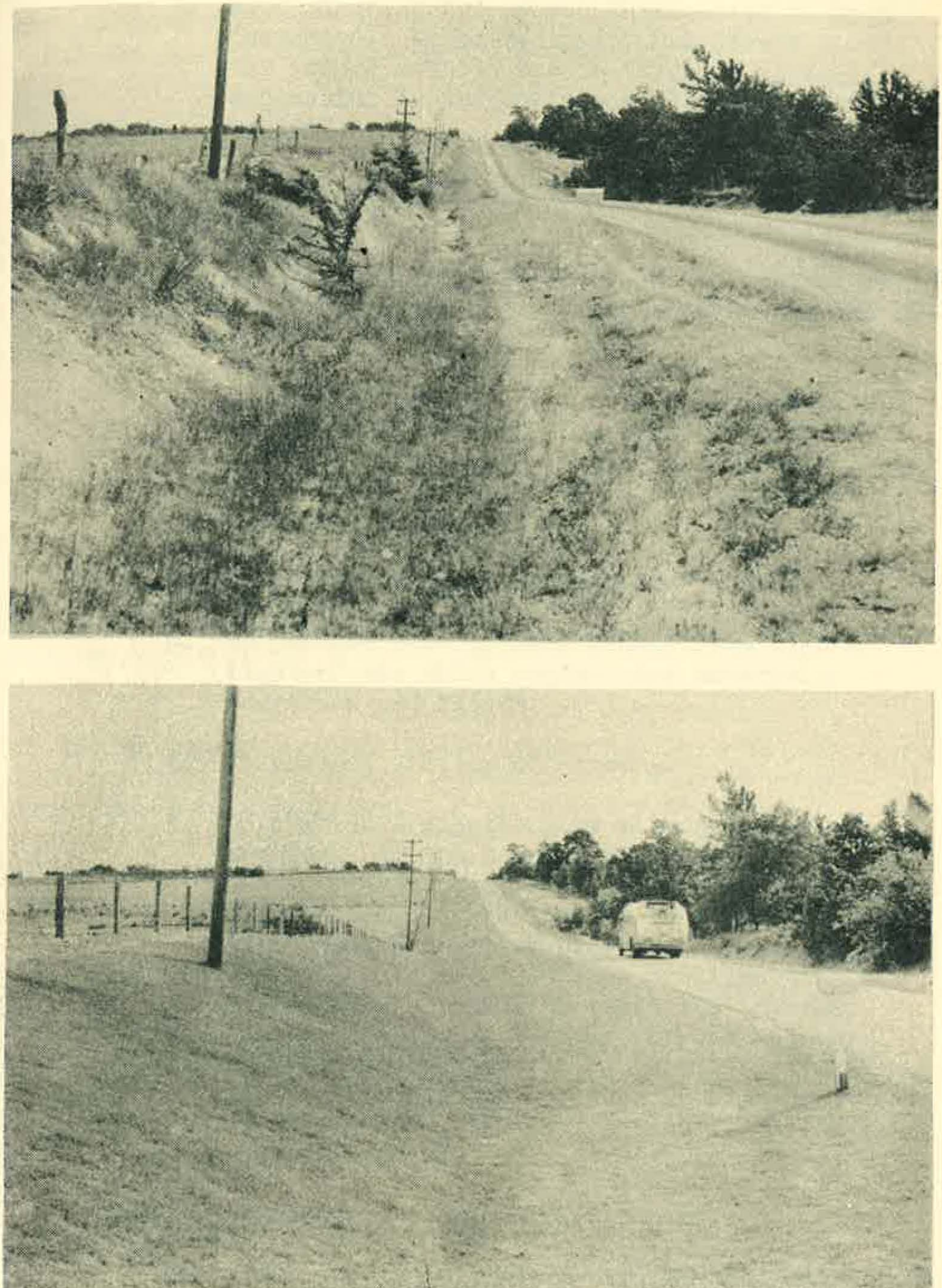
3. Fertilizers are definitely more efficient in the establishment of Bermuda Grass than dense planting because dense planting means greater labor costs.

4. Strip sodding is effective in some areas when the strips are placed on very short spacings. However, the cost of sodding by this method is almost as much as solid or block sodding, and the results are not nearly so good. When the strips have been placed on slopes with intervals of 4 ft. on erodible soils, serious trouble has developed from benching and eroding between the strips. Even when nurse crops or mulches are used, the results have not proved to be an economical method of sodding.

5. Broadcast or streak sodding has proved very effective on high fertility soils. On some projects adequate permanent cover was obtained after the first growing season at a cost of less than two cents per square yard. This method offers possibilities and further developments will be observed during the coming year.

6. In the establishment of grasses by seeding, brush and straw mulch has proved very effective in some areas. Especially is this true if plantings are made during the seasons of heavy rainfall. There is a need for more information on low fertility grasses.

Mechanical covers such as cotton cloth, twisted paper, and burlap have proved successful in holding the soil until plantings develop. However, the costs are such that this use must be confined to critical areas and to seeding on raw soils.



Controlling erosion in Texas with Bermuda grass.

Soil Conservation Service

7. Spot planting has proved ineffective in most instances. Experimentation has proved that the trench method used in Virginia is highly successful in the soils and climate of that region.

"Benefits Accruing from Slope Erosion Control Outside of Highway Right-of-Way

A successful program of slope erosion control will be beneficial to adjacent land and the landowner in the following ways:

1. To prevent gullies from extending into farm lands and destroying farm structures (sloughing banks have passed right-of-way fence lines and in many instances destroyed farm boundaries).

2. To prevent silting of adjacent lands.

3. To prevent fast (flash) runoff from highway right-of-way which contributes materially to overflows and floods.

4. To prevent silting of streams.

5. To provide irrigation and eliminate surface erosion. In the semi-arid regions of the United States, water may be diverted (by the use of terraces and levees) to adjoining pasture lands and spread over wide areas for irrigation purposes. On some small watersheds it has been possible to treat the adjacent land by the use of contour furrows and level terraces so that little or no surface water reaches the highway, or runs in highway ditches or over slopes, thus automatically eliminating surface erosion.

"Results of Experiments on Culvert Design

The ideal design of a culvert is one that will function properly in carrying the water under the road without erosion above or below the culvert. It must, above all, fulfill the requirements of modern highway design.

The problem with which the erosion engineer is confronted is the improvement of designs so that damaging features of the culvert may be eliminated and proper functioning permitted. Improvements have been made in drop inlet and head spillway structures for use at the inlet end of the culvert.

The design of the outlet end of the culvert has been sadly neglected. Research has been undertaken with the use of "de-energizer" and "flared ends" to prevent erosion at the outlet. Apparently the maximum increase in width of the lower end of the culvert should not be over a ratio of one ft. in ten. From results obtained in hydraulic laboratories, the water will not spread any faster than this ratio. The improvements sought are to decrease the velocity of flow and prevent the undermining of the culvert itself.

"Ecology

The projects that have been undertaken have been developed along the lines of establishing native plant material on the affected areas in the most economical manner. During the first year most of the work consists of establishing grasses and vines. During the coming year the projects will be extended to the use of shrubs and low woody plants when such plant material can be adapted to the conditions. It must be realized that objectives of the cooperative work being carried on by the Soil Conservation Service and the various highway departments is primarily to control erosion. The correlation of the aesthetic improvements must necessarily be left entirely to the State department landscape engineer.

The Joint Committee established a subcommittee on Plant Ecology, which will work with the subcommittee on Erosion in the final selection of plants to be used for slope erosion control purposes in the various sections of the United States.

"Water Conservation

Control of erosion and the conserving of moisture on highways and adjacent lands will be beneficial to the farmer by increasing the capacities of underground reservoirs, which will increase the amount of moisture for plant growth. Drainage areas contributory to the highway must be considered when improvements are made in the conditions on the right-of-way. The highway departments and agencies interested in conserving soil as well as moisture have a common problem that can be solved only by close cooperation of highway engineers and adjacent landowners. When the landowner understands the benefits that will be derived from concentrated efforts by all parties, little difficulty will be encountered in securing additional right-of-way at little or no cost for the solution of slope erosion problems.

"Methods of Evaluating and Disseminating the Final Results and Recommendations

It is realized by the committee that the final answers to these problems will vary throughout the United States. In order that the results may be properly applied only within an area where successful results may be expected, it has been necessary to divide the United States into "Problem Areas" according to:

1. Soil type
2. Climatological data
    a. Rainfall, its amount and intensity
    b. Temperature
3. Altitude
4. Plant adaptability

Within each problem area there must be established the most desirable season for construction and planting. Recommendations must also be made for plantings and protection of same when work is executed during other seasons.

The formation of these problem areas is being developed for immediate use in the choice of plants in the present program. The areas will be revised at the end of each year if it is deemed advisable after evaluation of the current season's results and observations.

"Slope Erosion Control on County Trunk and Farm-to-Market Roads

One of the means of measuring the effectiveness of demonstration and research projects is in the acceptance of the methods employed by other agencies which have similar problems. In some sections of the country the results of research projects have been so outstanding that requests have come from farmers, landowners, and county highway agencies for help in the solution of their problems. There are also instances where farmers have requested that their local highway officials cooperate with the Federal agencies in the elimination of paralleling ditches and duplicating structures. This is a very significant indication of the practical value of the demonstrations and research projects. Due to these requests and demands, the Soil Conservation Service, through the coordinator, has initiated and planned erosion control projects with 175 county highway departments in the United States. Programs are being developed to prevent erosion on the county roads in critical areas where agricultural land is being seriously damaged. This program is correlated with the demonstrational work that the Soil Conservation Service is doing on agricultural land. This work consists to a large extent of resectioning county roads along modern lines and stabilizing the highway ditches and slopes so that the highway drainageway may be utilized to carry off concentrated flow from water disposal systems on agricultural lands.

The practice of discharging water into unstabilized highway ditches is being discouraged in order to eliminate damage to public property or to abutting private lands.

For economical reasons, one drainageway should be used to serve both purposes, namely, the runoff of the highway right-of-way itself as well as the adjacent farm land. The solution of this problem can be obtained only by full realization of the various aspects of the problem by both cooperating parties. The correction of a damaging condition that is destroying public property and decreasing land values of private property holders can be made most economically where the officials charged with soil erosion control work have the willing and hearty cooperation of the county highway officials whose roadways traverse the area involved.

"Other Activities

There is another approach to slope erosion control quite within the scope of scientific research, namely, a survey and analysis of methods now being used or inaugurated in the various State departments. This past year the subcommittee headed by John L. Wright, Director of Roadside Improvement for the Connecticut State Highway Department, and Frank H. Brant, State Landscape Engineer for the Highway Department of North Carolina, by a well-planned questionnaire have inquired into such topics as the highway cross-section most desirable as a foundation for erosion control work; slope drainage; drainage structures; topsoiling, fertilizing, seeding, sodding, mulching; and the planting of trees, shrubs, and vines for erosion control. Survey lists were sent to a mailing list of 24 in 22 States. Eight of these were consistent contributors.

These and intermittent replies from 14 accounted for a response of slightly more than 50 per cent.

The explicit replies received in this survey have enabled this subcommittee to gather, and subsequently disseminate, much interesting and valuable information. The replies have also indicated the wide recognition of the economical importance of sound highway slope erosion control.

Analysis of the various replies/3 indicates the following general rating of soil erosion control methods:

1. Desirable cross section
2. Topsoiling
3. Berm ditches
4. Seeding
5. Mulching
6. Sodding
7. Paved ditches
8. Fertilizing
9. Planting
10. Drop inlets
11. Ditch checks
12. Underground drainage
13. Wing and outlet ditches

"Proposed Extension of Slope Erosion Control Projects

A geographical survey of the distribution of the various research and demonstration projects indicates that most of these are located in the southern half of the United States. The reasons appear to be:

(1) Greater need for the work in this area; (2) readiness on the part of the highway departments in requesting this service for their States; (3) availability of men who have had experience in highway construction work as well as erosion control projects; and (4) the economical and practical value of concentrating the projects in order to minimize the expense and the amount of time involved in travel from project to project.

/3 - A complete tabulation containing information on topsoiling, seeding, fertilizing, ditch checks, and paved ditches will be found in the reports at the 18th Annual Meeting by the Joint Committee.

The subcommittee recommends that additional help be made available through the Soil Conservation Service to reach those areas in the Northern States that also have serious erosion control problems. They further urge upon the various highway officials throughout the Northern States that they make a closer study of the research projects, become familiar with their values, and request this service for their highway departments."

ACTIVITIES OF 1939

The demonstrational work that has been carried on cooperatively by the Soil Conservation Service and State highway departments for the past three years has been very successful as a means of field application of the ideas of various technical groups in the field of roadside improvement. The 100 projects that were under way at the beginning of this year have been practically completed. Ten new projects that were initiated this year are at the present time in various stages of construction. The final reports on completed projects have been slow in coming in, due to the time interval of several growing seasons required for such conclusions to be evaluated. Preliminary reports will be turned over to the subcommittee for study and evaluation immediately upon completion and information considered to be of value in highway engineering will be submitted to the subcommittee on Education and Public Relations for publication in the quarterly, "Roadsides".

In only a few regions of the United States has demonstrational work covered a sufficient number of the problem areas, and there is need for additional demonstrations during the coming year in the Northeastern, North Central, and Pacific Coastal States. The subcommittee would recommend that demonstrations be established in these areas insofar as such work will fit into the work units of the Soil Conservation Service. The subcommittee suggests that the work during 1940 be similar to that recommended for 1939. The problem of highway erosion in Soil Conservation districts will be treated in numerous cases along with the treatment of the adjacent agricultural land. The Soil Conservation Service will assist local districts cooperating with county or State road agencies to improve roadsides when such improvement will benefit the adjacent land. This cooperative approach will necessarily have a wide application to all types of roads. It is recommended that the Soil Conservation Service keep the subcommittee informed as to the progress of the work, especially results obtained that might be valuable from a research point of view.

A special meeting of the Joint Committee held at Brainerd, Minnesota, August 28-30, 1939, discussed the following subjects pertaining to erosion control:

(1) Desirable qualifications for an individual to be appointed by the Public Roads Administration in the various districts as erosion control engineer.

(2) Graphic Solution of Ditch Design for Erosion Control.

(3) Form and presentation of the reports on highway erosion control demonstration projects.

(4) Preparation of educational film on slope erosion control in the different districts of the nation.

An unusual opportunity was afforded to study slope erosion control as well as other related phases of roadside development during the tour from St. Paul to Brainerd and return. This was exceptionally well arranged by the Minnesota Department of Highways and proved very enlightening to those who participated.

The subcommittee has made arrangements with the Department of Agriculture through the Soil Conservation Service, to publish a joint bulletin on highway erosion prevention as it affects farm lands.

The Joint Committee has approved for publication facts and materials compiled from information developed by the Soil Conservation Service. This publication, "Graphic Solution of Highway Ditch Design for Erosion Control", gives definite information on the cross sectional design of highway side ditches, especially in areas where diversion of surface runoff is practiced on adjoining lands. It deals with such subjects as relationship of various plants to different velocities of flow of water and different conditions such as soil types, climate, and geographic location. It will be of special value to the highway engineer who has erosion control problems and is interested in the reduction of maintenance costs. The manual is included as Appendix IV of this report.

An outstanding development during 1939 was the recognition of the fact that erosion control methods which had been demonstrated, have been effective in reducing maintenance costs and protecting highway investments. This has been emphasized in the assignment by the Public Roads Administration of experienced engineers to coordinate highway construction work with roadside erosion control activities in two of its districts. Further emphasis is added by the fact that the requests for such a step came from the field, and by the ready acceptance of the announcement by various districts and State highway departments.

In this final report of the subcommittee on Erosion of the Joint Committee on Roadside Development, the findings and recommendations are presented in a manner to conform to the outline of specific problems as suggested at the 1935 meeting of the Board. For information on the selection of plant materials to be used in erosion control, reference should be made to the report of the subcommittee on Ecology, Vol. 19, Proceedings, Highway Research Board, page 248.

I. WATERSHED AREAS IN RELATION TO HIGHWAY

A. Watershed Areas above highway drainage structures.

1. Importance of Soil Conservation districts in treating drainage areas that affect highways.

Due to the fact that in numerous instances uncontrolled water discharged onto the highway presents a problem that cannot be economically solved without sufficient treatment on the lands above the highway, the Soil Conservation district offers assistance in the solution of these problems. This district to which the Department of Agriculture offers various forms of assistance, is a legally constituted local governing body that has the authority to cooperate with private land owners in controlling erosion and runoff waters. Thirty-six States have passed laws permitting Soil Conservation districts to be organized and the formation and operation of these districts is well under way at the present time. Many of these districts have availed themselves of the opportunity to assist local and State road agencies in solving problems of highway erosion.

2. Gully Control.

The need for the control of gullies was recognized in the early stages of the subcommittee's work and since the problem also confronts various agencies of the Department of Agriculture, this Department has published an excellent bulletin on treatment of gullies (No. 1813 U.S.D.A.). This bulletin is recommended to the attention of highway engineers who have problems of gully control.

3. Relocation of existing highway structures.

This problem has been given consideration since the beginning of the subcommittee's work. It is felt at this time (1939) that little effort should be expended in the relocation of existing structures, but that future work should avoid errors

Vegetation treatment supported by head spillway.

Soil Conservation Service

now recognized in the older work. The properly designed structure will be so located in the initial construction program that erosion problems will be adequately solved.

4. Riprap.

The various State highway departments have experimented with numerous methods of riprapping and adequate information should be available from these sources. It is recommended that the subcommittee make the collection of these data one of their projects for 1940.

B. Watershed Areas below highway drainage structures.

1. Demonstrate methods of disposal of road drainage to prevent damage to agricultural lands.

a. Use of wide sodded channels.

Sodded channels, as outlined in the Manual on Ditch Design,/4 have been very effective for disposal of runoff waters below the highway.

b. Stabilization of flow line grade structurally or with vegetation.

Various methods of vegetative stabilization of flow line grade have been successful when the expected velocity was in the lower brackets. Where velocities of flow were well above 6 ft. per sec., structures such as masonry or concrete overfalls have been effective. The application of vegetative treatment has been more economical in the humid section; while in the arid and semi-arid section, structural treatment has been more widely used.

2. Highway Ditches.

Controlling sub-surface and surface drainage with one common ditch has been tried in numerous instances. It is recommended that further study be made of this problem by the subcommittee on Highway Types and Roadside Areas, based on the Manual for ditch design.

/4 - Appendix IV.

3. Relocation of highway drainage structures.

The subcommittee recommends, under this topic, the same procedure as outlined under I, A., 3.

4. Riprap.

The recommendations in Item I, A., 4 above are applicable to this problem. However, in the semi-arid sections of the United States there has been successfully used a combination of pipe and wire in arroyos and barrancas. This structural treatment has been supplemented with native vegetation. The subcommittee recommends that further research be made on this type of treatment in 1940, in cooperation with the subcommittee on Ecology.

5. Use of water in semi-arid sections of the United States.

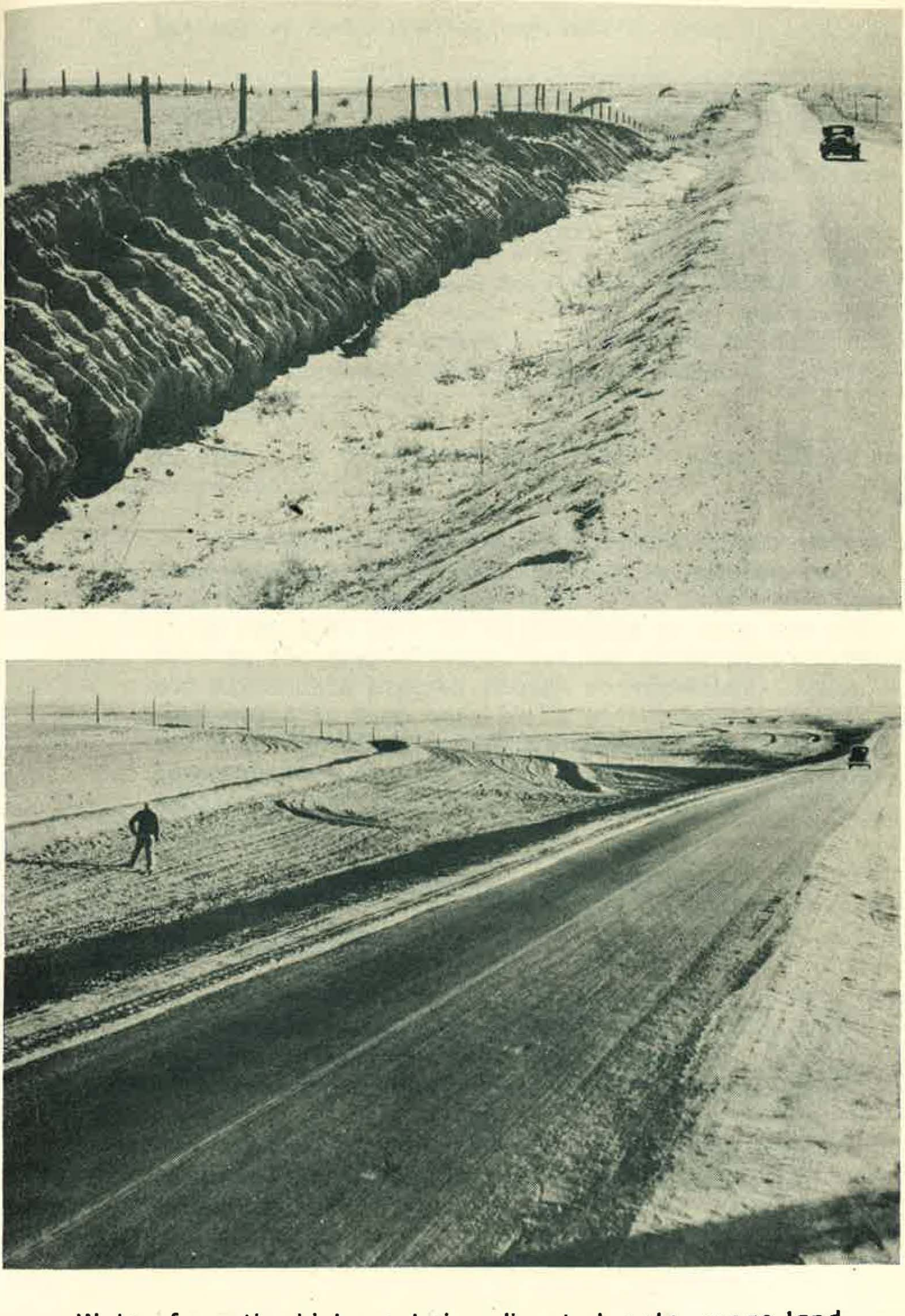
It has been found economically feasible to divert water from highway structures onto the range land in this section by the use of diversions and various forms of spreading systems. This work has been carried on cooperatively by the farmer through the Soil Conservation Service, with the State highway department. The subcommittee recommends that considerable emphasis be placed on this type of treatment since the erosion damage is not only eliminated, but the water is put to profitable use.

II. HIGHWAY DITCHES

A. With vegetatuve protection.

1. Ditch design.

The subcommittee has recognized the failure of numerous methods of establishing vegetation in highway ditches due to improper design of the ditch. The establishing of cover in ditches has been successful over wide areas but the vegetative cover would not withstand the velocities of flow produced by improper designing of ditches. The subcommittee has recommended for publication, information on ditch design for erosion control, which is included as Appendix IV of this report.



Water from the highway being diverted onto range land.
Top - Before treatment. Bottom - After treatment.
Soil Conservation Service

2. Methods of establishing vegetative cover by sodding.

Various methods of establishing sod have been developed to fit local soil and climatic conditions, which consider the availability of plant material. In general, block or solid sodding is not recommended by the subcommittee, except on critical areas where an immediate cover is required. Various methods of planting permanent cover such as sprig sodding and mulch sodding have been successful in limited problem areas. In general, strip sodding is not recommended unless the areas between the strips are mulched with material that will prevent erosion and aid in establishing ground cover.

3. Treatment of deeply eroded ditches without change in cross-section.

The subcommittee recommends that deeply eroded ditches along modern highways not be treated for erosion unless the cross section has been redesigned. It is realized that it is possible to stop the erosion in the deep ditches, but the cross-section would not fit modern highway design requirements. Such work would in time have to be destroyed to improve the road to modern safety standards. On county and local roads where the cost of redesigning the cross-section is prohibitive, this recommendation is not applicable.

B. Structural treatment without vegetative aid.

1. Effectiveness and cost.

Permanent structural treatment in highway ditches may be effective but does not fit into the complete coordinated improvement program. Therefore, the subcommittee recommends that structural treatment not be used in highway ditches except in extreme cases. This treatment refers to drop overfall structures and not to paved gutters or other similar structures.

2. Control at point of discharge.

Experiments with methods to reduce the velocity of flow and prevent erosion at the outlet end of drop structures have been numerous, but results are inadequate at this time to permit making recommendations for treatment. The subcommittee recommends further study of this subject in 1940.

3. Design of terrace outlet structures.

Design of terrace outlet structures discharging terrace water into a road ditch has progressed considerably during the past year. In previous years years terrace water was discharged without considering protection to the highway. In 1935 the subcommittee favored the design and construction of masonry controlled outlets. During the years of 1936 and 1937 the subcommittee's attitude changed to favor the use of vegetation for the construction of the outlet. The construction was limited to the terrace channel and the approach to the road ditch. During the past year the subcommittee has followed closely the work of the Soil Conservation Service in designing and constructing terrace outlet structures discharging water into highway ditches. Their methods of treating the entire roadside ditch together with slopes have proved very effective. The subcommittee understands that the Service has established a policy of treating the entire area of the highway right-of-way rather than the individual outlet structure. This includes re-cross-sectioning the road and designing the ditch section to discharge the water at velocities that will not erode soil properly protected by vegetation.

4. Highway check dams.

The subcommittee recognizes the need of temporary check dams only when they are used to encourage the establishment of vegetation as the ultimate permanent control, and when they do not form a traffic hazard.

III. CUT AND FILL SLOPES

A. Treatment and design of back and shoulder slopes and highway embankment.

1. Determination of proper angle of repose for sodded embankments on various soil types.

Due to the wide variation in soil types, sod cover and moisture conditions, the subcommittee is unable at this time to make definite recommendations as to the proper slopes for the widely varied conditions. However, the subcommittee feels that under ordinary conditions, extreme caution should be exercised in sodding embankments when the angle of repose is steeper than 2 to 1.

2. Study possibility of using berm ditches above cut slopes, such ditches to be located approximately on contour and designed for a non-erosive velocity. Their use will depend on (a) quantity of runoff and (b) the existence of a satisfactory point of discharge. The use of berm ditches parallel to edge of top of cut should be discouraged.

The use of berm or intercepting ditches located parallel to the center line of the highway and constructed without protection against erosion is not recommended. In areas where the drainage area above the ditch is small and a quick vegetative cover can be obtained, ditches constructed parallel to the center line may be used in special cases. The subcommittee recommends that berm or intercepting ditches be constructed around the cut on nonerosive grades and vegetation be established by the same methods recommended for establishing vegetation in ditch sections.

3. Consider use of temporary shoulder curbs and discharge flumes on fills.

The use of temporary shoulder curbs has been satisfactory in some instances. The subcommittee recommends that when such curbs are desirable, they be constructed of earth protected with vegetation, or of concrete, masonry, or similar materials. In both cases the discharge channel over the fill should be constructed of material such as creosoted timber, concrete or masonry.

B. Study of the effectiveness of vines and shrubs in controlling erosion should include such factors as soil types, vines naturally adapted, and methods of planting.

Vines and low shrub ground covers have been effectively used in the North Atlantic and Southern States. The use of Kudzu in the extreme Southern States has been very effective. Further observation and study should be made on the use of this and other material by the subcommittee on Ecology.

C. Seed mixtures of grasses and nurse crops to be tested under different exposures, climatic conditions, and soil types.

The subcommittee has received little definite information on this subject. However, the final reports of the demonstrational projects will include definite recommendations for various seed mixtures to be used in the specific problem area in which the demonstration was located. The subcommittee recognizes the economical advantages of establishing vegetation by seeding and has recommended that the Soil Conservation Service make extensive studies of seed mixtures wherever applicable. This will go on cooperatively with the subcommittee on Ecology.

D. Study the various methods and factors to determine the most effective methods to establish sod on varying degrees and finish of slope and soil types.

The subcommittee should obtain some definite information on methods and factors effective in establishing sod from the various preliminary and final reports on the demonstration project as they are made available.

1. Carefully finishing surface and seeding with and without addition of topsoil.

Experiences of the Soil Conservation Service and various highway agencies clearly indicate that surfaces should not be finished smooth before seeding, sodding or the application of any materials in preparation for establishing vegetative cover. Seeding with the use of topsoil has been successful without the addition of fertilizer. The addition of fertilizer depends on the soil analysis. Specific recommendations will be made on this subject as the final reports on the demonstrations are available.

2. Leaving surface rough and seeding on existing soil.

This method of seeding has proved satisfactory in some localities. More information on this subject will be available as the final reports on the demonstrations are received.

3. Effect of mulching with straw or litter of 1 and 2 above.

Mulching of seeded areas has proved effective, and has progressed more in the past year than any other method of controlling erosion. It is recommended that a special survey be made during 1940 of the various methods of mulching, together with the kinds of materials used and the results obtained by various State agencies.

4. Planting countersunk sod strips, and seeding between. Compare effectiveness and cost with 1 and 2.

The subcommittee does not recommend this method of control unless an application of mulch is used between the sod strips.

5. Methods of establishing sod by transplanting.

Various State highway departments, in cooperation with the Soil Conservation Service, have developed improved methods of transplanting permanent cover. The specifications for these methods, in some States, are being included in the standard specifications for road construction. The subcommittee does not wish to make recommendations for any one general method of establishing sod by transplanting since the methods vary according to the type of sod, soil and climatic conditions. It is thought that the information should be disseminated locally to the various highway departments rather than make specific recommendations for each of the problem areas.

6. Effect of fertilizer treatments.

Where vegetation is to be established in sterile or raw soil, the addition of fertilizer is definitely advisable. Recommendations for kinds of fertilizer and rates of application will be made for the various areas after the final reports on demonstration projects now under construction or observation have been made and evaluated.

E. Prevention of Wind Erosion.

In blown sands, oil spray methods are to be discouraged in favor of the planting of stolons or other vegetative methods of establishing grasses suitable under various sand conditions. Mulching appears to offer the best results to date.

Wind erosion originating on the highway right-of-way is usually a localized problem and one on which little information has been obtained by the subcommittee. It is recommended that the subcommittee request representatives of the various State highway departments to furnish information on this subject, especially States in the humid section of the United States. In the semi-arid section, wind erosion is a common problem on all lands. Various methods of treating this land have been developed by Soil Conservation Service which are applicable in most instances to highway wind erosion. It is suggested that where this is a constant problem the States contact the local offices of Soil Conservation Service and obtain the desired information in regard to wind erosion control.

F. Prevention of Slides.

1. Planting deep rooted trees.

In general, the subcommittee and representatives of the various State highway departments feel that deep rooted trees or other vegetative growth are not particularly effective in preventing slides.

2. Structural method such as piling, cribbing, diversion ditches, intercepting tile, blind drains, etc.

Various methods of treatment such as cribbing, piling, diversion ditches, intercepting tile, blind drains, etc., have been attempted. However, in most cases, this work has proved to be very expensive and should only be undertaken when the economics of the problem permit it. It has been found that most slides are caused by the presence of water in a soil plane. For this reason it is recommended that before any slides are treated a thorough investigation be made of the moisture content of the slope and steps be taken to divert the water from this soil plane. Some experiments are being made to divert the water by amalgating the soil plane by the use of dynamite. These experiments are in the initial stage and no information is available at this time.

CONCLUSIONS

The effectiveness of erosion control work has been clearly demonstrated. It has been an important factor in aiding highway departments (1) to promote the streamlining of their highways; (2) to solve their highway slope erosion control problems; (3) to promote friendly relations between county and federal agencies and landowners

Wind erosion in the Southwest.
Top-Before treatment. Bottom-One year after treatment.
Soil Conservation Service

working in the same area and having common problems; (4) to establish definite techniques for the collection of data and presentation of results; and (5) to investigate problem areas, which is another step in the regional approach to sympathetic and harmonious study of slope erosion on highways.

* * *

SLOPE EROSION CONTROL QUESTIONNAIRE

In August of 1939 the Joint Committee sent a questionnaire to all State highway departments for the purpose of determining practices of slope erosion control. Replies which were received from all except eight States have been arranged in tabular form and will be supplied to those interested. Those desiring copies should address their requests to the Highway Research Board asking for the summary of the Slope Erosion control questionnaire.

APPENDIX IV

GRAPHIC SOLUTION OF HIGHWAY DITCH DESIGN FOR EROSION CONTROL

Cross-Sectional Design as Related to Slope Erosion

The proper cross-sectional design of highway side ditches is of utmost importance to those who have the responsibility of planning the drainageway and selecting the proper plants to produce ground cover, especially in areas where diversion into highway ditches of surface runoff from adjoining lands is practiced. It is not the intention of this report to emphasize further the importance of moderate slopes or the elimination of sharp transitions in them, but to consider the proper drainageway design as related to the control of erosion within such a waterway.

It is well known that various plants will withstand different velocities of flow of water even when other conditions, such as soil type, are the same. For this reason it is the opinion of the subcommittee that the design of the drainageway for a desired velocity of flow under normal conditions is of utmost importance. The subcommittee is well aware that it is not always possible to construct the proper-sized ditch because of limitations in right-of-way, increased excavation cost, and many other factors, but there are numerous cases where a design of the ditch is feasible. The drainageway should be constructed for velocities that are safe, and the design should favor the lower velocities until the various plant materials have been tested under various conditions as to how well they can withstand the higher velocities.

In the high rainfall areas of the United States where runoff control on agricultural land is a problem, it is especially important that the waterway be carefully designed. In many instances the highway ditch will receive the discharge from adjoining terraced fields, which fact must be considered in designing the highway ditches. When these are properly designed, the water velocity will not change appreciably along the course, even though additional water is discharged into the ditch at various points down the slope. This uniformity of velocity may be accomplished by increasing the bottom width beyond points where additional water is intercepted.

The design of the drainageway by ordinary mathematical solutions involves tedious and laborious cut-and-try methods. For this reason there is presented herein a graphic solution that will make it much easier for the designing engineer to determine the proper bottom width of a ditch under the varying conditions for which provision must be made. As previously stated it is the subcommittee's belief that in order to accomplish the proper ditch design which will be favorable to the control of erosion, it is necessary that improved technique in cross-sectional design be made as easy and practical as possible.

It is also evident that there is need for basic information on the safe velocities that various plant materials will withstand. There is included in Table No. 1, the estimated allowable mean velocities for well-vegetated channels for some of the common types of cover.

The attached charts can be used in the field when the P.S. & E. is made, or by the office designing engineer. Charts 3, 4 and 5 are for trapezoidal channels where the front slope is 4:1, and the back slope 4:1, 3:1, and 2:1 respectively, while Chart 6 is for triangular channels.

The Manning Formula

The Manning formula is used extensively by American engineers in computing open channel velocities and dimensions. It lends itself readily to solution by diagrams or tables, appears to be more accurate for a greater range of conditions, and is simpler in form for analytic solution than most other formulas commonly used. For these reasons it has been selected for use in the development of the charts in this report.

The Manning formula is:

$$V = \frac{1.486}{n} R^{2/3} S^{1/2}$$

For solving various types of problems it is combined with the continuity equation $Q = AV$, and expressed as:

$$Q = \frac{1.486}{n} AR^{2/3} S^{1/2}$$

where Q = discharge in cubic feet per second,

n = coefficient of roughness[1],

A = water cross-sectional area in square feet,

R = Hydraulic radius in feet $\left(\frac{\text{cross-sectional area}}{\text{wetted perimeter}}\right)$

S = slope of channel in fall per foot (uniform flow),

and V = mean velocity in feet per second.

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1 - "Coefficient of retardance" appears more appropriate for "n" in vegetated channels because of the diverse retarding influence of vegetal linings.

Channel Velocities

Securing adequate capacity and avoiding detrimental scouring and silting velocities are pertinent factors in the design of earth or vegetated channels. Safe maximum channel velocities are dependent upon the erosion resistance of the respective channel linings. Different types of sod covers vary in their ability to resist water velocities. Unlined earth channels offer the least resistance to erosion and must be designed for comparatively low velocities. The velocity in a channel increases not only as the slope of the channel increases, but as the hydraulic radius (approximately the average water depth) increases, and as the channel resistance (coefficient of retardance) decreases. Once the drainageway location and type of protection are selected, it is usually impractical to change materially the channel slope or retardance factor, so velocity control is largely obtained by regulating the average water depth by changing the channel proportions. Wide, shallow channels produce lower velocities than narrow, deep channels.

Observations in the field and available experimental data indicate that the velocities in Table 1 will be safe and should be adopted for design purposes where vegetal covers are good. These figures apply for comparatively short flow duration with intervening vegetal recovery periods. Where the development and maintenance of a good vegetal cover cannot be depended upon, or where other adverse conditions prevail, proportionate reductions in velocity should be made.

Table 1. Allowable mean velocities for well-vegetated channels

Type of lining	Allowable velocity "V"
Bermuda grass	6
Bluegrass	5
Smooth brome grass	5
Western wheat grass	4
Buffalo grass	4
Sudan grass (annual, temporary cover)	3
Common lespedeza (annual, reseeding)	3
Lespedesa sericea	3
Bare soil (non-erodible)	2

Low channel velocities may cause undue silting in vegetated outlets, and ultimately lead to inadequate channel capacity. It is not always possible to eliminate entirely silting velocities in drainageways, but excessive silting can be minimized to a large extent if adequate conservation practices are used on the contributing drainage area, if excessive terrace grades and spacing are avoided on adjacent agricultural lands, and if the drainageway channels are properly maintained. Where necessary, channel cross-sections can sometimes be adjusted, even on comparatively flat slopes, to minimize silt-depositing velocities.

Channel Cross Sections

Side slopes of 4:1 or flatter are ordinarily recommended for shallow vegetated channels in order to facilitate the establishment of vegetative cover and the maintenance work. Further adjustments of channel cross-sections may be necessary to secure desired velocities and discharge capacities. For example, the use of triangular or V-shaped channels will aid in maintaining non-silting velocities on mild slopes during low runoff stages, or in drainageways where small peak rates of discharge are involved. Flattening the side slopes of trapezoidal cross sections beyond the 4:1 has the advantage of increasing discharge capacities and reducing the corresponding velocities. Field experience indicates that the bottom width of shallow, vegetated channels with trapezoidal cross-sections should seldom exceed 20 feet. Where large volumes of runoff are encountered, parallel adjacent channels separated by a flat-sided ridge can sometimes be used to advantage.

Width-Depth Ratio

To secure adequate velocity control in sloping channels there may be a tendency to make them extra wide and shallow in order to reduce the hydraulic radius. When this practice is carried to extremes, the flowing water tends to cut a deeper water course in the bed of the channel. Little is known of the mechanics of this entranching action except that water will not flow in thin sheets over an erodible material. In the design of earth or vegetated channels, therefore, it seems that some limitations on the maximum ratio of bed width to depth of flow should be used. The most suitable value for this ratio undoubtedly depends upon the slope of the ditch and the scour-resisting characteristics of the bed material; but at the present time sufficient information is not available to permit definite evaluation of these factors or to establish limitations for vegetated ditches. Present field experience indicates, however, that harmful channeling will rarely occur in channels having a width-depth ratio of less than 15. Until more definite information is secured it seems advisable to adhere to some such limiting ratio for flat-bottom channel designs wherever practical.

Retardance Coefficients

The factor "n" in the Manning formula is intended to be a measure of the effect of roughness and all other flow retarding influences in the channel. Trained judgment and due consideration of all data relating to similar known conditions are necessary in selecting the proper value of "n" to use in a specific case. Since comparatively little experimental data are available on values of "n" for various types of small vegetated channels, scientific guess work must be relied upon and an attempt to secure a high degree of refinement becomes impractical.

A review of the limited experimental data now available indicates that the value of "n" for vegetated channels varies considerably not only with various types and conditions of covers, but also with changes in channel slope, hydraulic radius, and velocity. Also a trend is indicated toward higher values than was originally anticipated, particularly for low depths. Field application of the results makes it impractical to consider all the influencing factors individually. It is felt that an "n" value of 0.04 will be most applicable in determining maximum design capacities for the majority of vegetated drainageways in which good channel conditions prevail and a value of about 0.06 for fair channel conditions. Good channel conditions imply well maintained, pliant grass covers, such as bluegrass or Bermuda grass and design flow depths of 6 inches or more. Fair channel conditions apply to maintained coarse covers such as lespedeza, low flow depths, or to poorly maintained, pliant grass covers. Intermediate channel conditions will require proportional adjustments in the corresponding "n" values.

Flood Flow Discharges

Both rainfall and drainage-area characteristics have a marked influence on the rates of runoff that can be expected. With other factors constant, high rainfall intensities, steep slopes, poor covers, impervious soils, or short watersheds tend to produce higher rates of runoff than low rainfall intensities, flat slopes, good covers, pervious soils or long watersheds. The maximum rate of runoff for any specific watershed usually occurs when rains of high intensities fall on saturated or frozen soil and during periods when vegetal cover is depleted or dormant.

Determining the capacity for which channels should be designed is a difficult problem due to the variety of runoff conditions which exist. Local information on the rates of runoff from various watersheds should be utilized to the fullest extent possible. Where reliable records are available, runoff rates from similar watersheds in the same vicinity form a valuable guide.

Charts 1 and 2 have been prepared to serve as a guide in estimating runoff rates from various drainage areas. They may be used directly where other information is not available or as a supplement to such local information as may be available. Chart 1 indicates the rate of runoff that may be expected for various-size drainage areas from storms occurring theoretically on an average of about once every 25 years. It will be noted that some allowance is being made for effect of watershed characteristics on rate of runoff as indicated by the curves in the chart and the summarized table accompanying the curves. The rate of runoff should be selected from the curve that most nearly fits the particular drainage area in question.

Since the curves are based on the rainfall factor 1.0 shown in Chart 2, it will be necessary to make further adjustments to runoff rates from drainage areas falling under other rainfall factors. These adjustments can be made according to the rainfall factor in Chart 2 that is representative of the geographic location of the drainage area.

When designing for storms of 10-year occurrence (frequency) reduce the rate of runoff in Chart 1 by about 14 per cent and increase it about 21 per cent for storms of 50-year occurrence. For 100-year storms, a 43 per cent increase should be made.

Precautions

While the attached charts should serve a valuable purpose in the solution of channel dimensions, they must be used with caution and not indiscriminately applied. It should be noted that the channel dimensions determined from the charts are only the actual depth and width required to carry the estimated rate of runoff and do not provide for any freeboard. Freeboard additions should be made, proportioned to the field conditions, because of the uncertainty of runoff estimates, channel coefficients, obstructions, probable loss of channel capacity due to silt accumulation, or to conditions resulting from the surfaces of poorly drained soils where drainage of the subbase is desired. An attempt should be made to secure as uniform a velocity as practical throughout the entire channel. Where channel conditions are not uniform, designs should be made by sections, and adjustments made in each section to compensate for changes in rate of runoff, grade, or channel-flow retardance factors. Changes in channel cross-sections should be made gradually and uniformly so as to avoid channel eddying.

Sequence of Drainage Channel Design

1. Determine the contributing drainage area in acres or square miles.

2. Read from chart 1 the base discharge "Q" in cubic feet per second (c. f. s.) for such drainage area according to whether the area is extreme, high, normal or low in flood-producing characteristics.

3. Multiply such base "Q" by the proper factor taken from chart 2 according to geographic location of the drainage area.

4. Since chart 1 is based on storms of 25-year frequency, it will be necessary to further modify the value "Q" if other frequencies are desired.

5. Take from Table 1 the safe velocity "V" for the design soil cover.

6. Divide the final design "Q" by V to obtain the channel cross-section area, A.

7. Determine the channel slope S in per cent.

8. Decide upon the value of n; if it be 0.04 use the bottom scale of velocities on charts 3, 4, 5 or 6, and if it be 0.06 use the top scale. Note that other values of "n" can be used by interpolation.

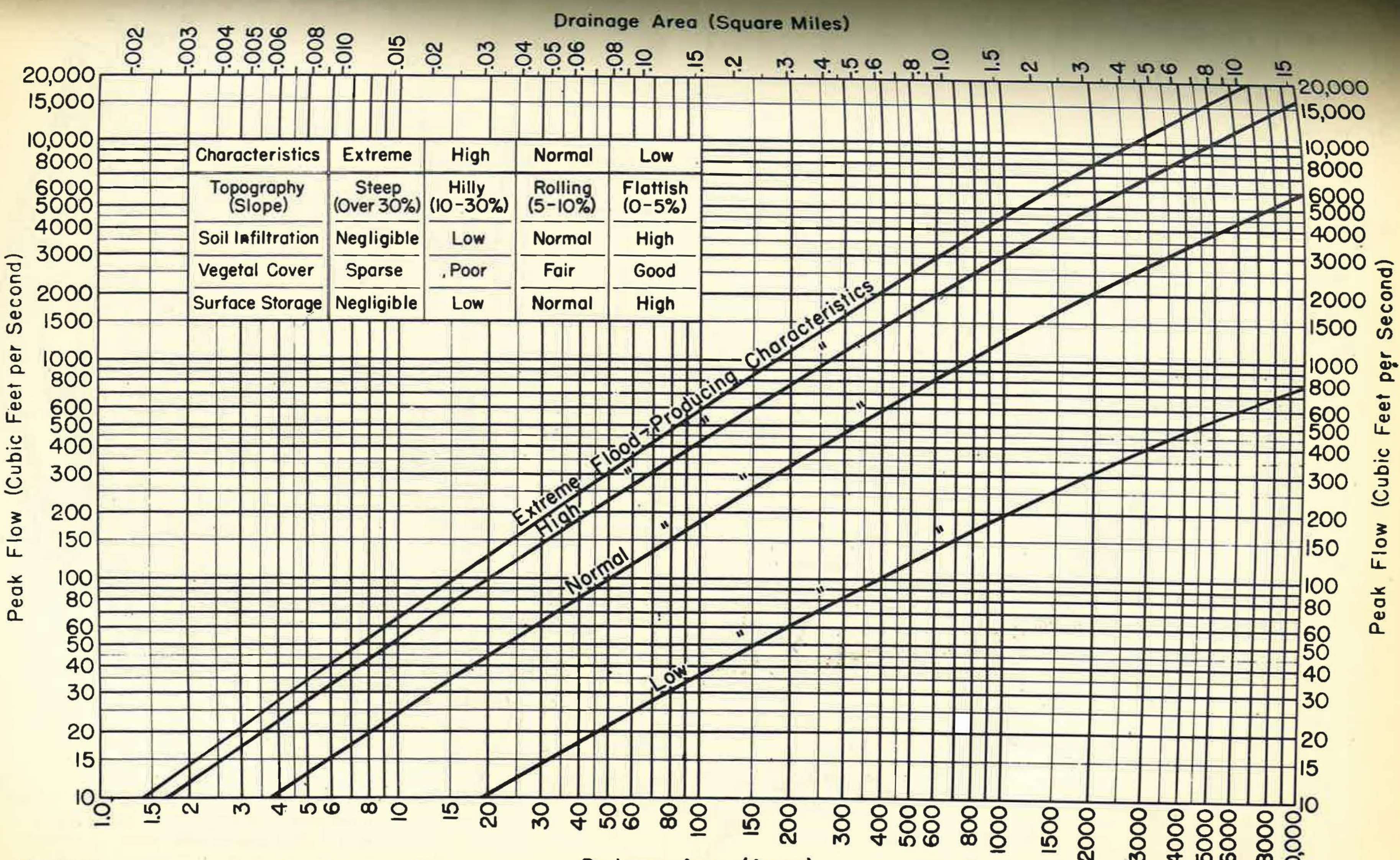
9. Decide upon the side slopes for the channel.

10. On charts 3, 4, 5 or 6, depending upon the selected channel and side slopes, take V on the bottom (or top) line; run vertically up (or down) to the inclined line for the proper slope S; then horizontally to the left to the solid curved line for the proper area A; thence vertically down to the bottom line of the chart. The latter point will be the channel bottom width in feet.

11. The intersection with the area line "A" of a line brought horizontally left from the slope S also gives the channel depth in inches which can be interpolated between the dotted curved lines representing depth.

12. Increase the net channel depth as may be desired to provide needful freeboard.

13. Sample solution is shown by dotted line on chart 5 for assumed values of $V = 4\frac{1}{2}$; $Q = 45$; and $S = 3\%$: Therefore $A = \frac{45}{4.5} = 10$. By following the steps outlined under 10 and 11 the bottom width and depth are found to be 12.8 feet and 8 inches respectively.

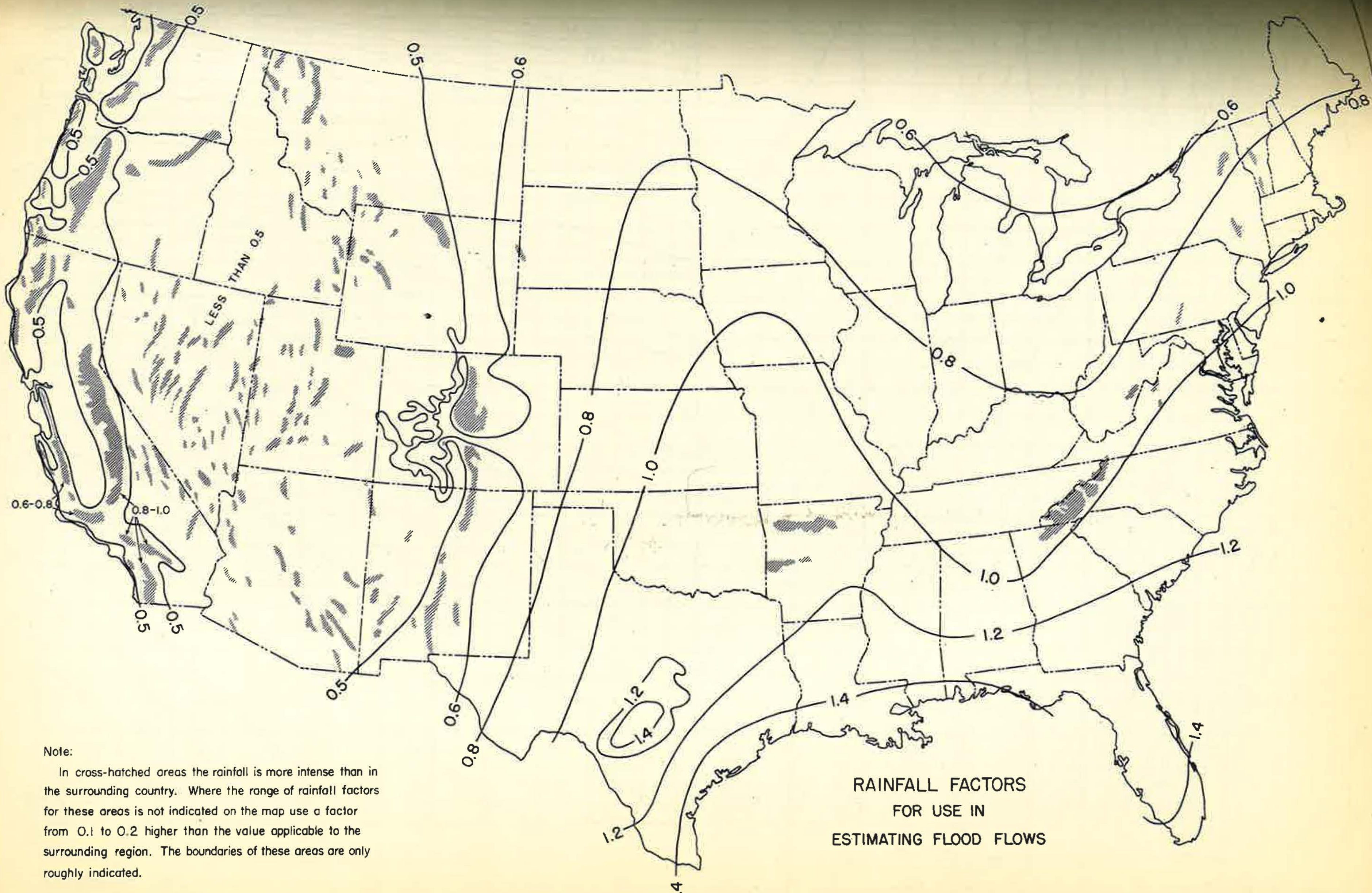


Characteristics	Extreme	High	Normal	Low
Topography (Slope)	Steep (Over 30%)	Hilly (10-30%)	Rolling (5-10%)	Flattish (0-5%)
Soil Infiltration	Negligible	Low	Normal	High
Vegetal Cover	Sparse	, Poor	Fair	Good
Surface Storage	Negligible	Low	Normal	High

Flood-Producing Characteristics — SCS — 3/21/40 — 0-2692

CHART 1

0-2692



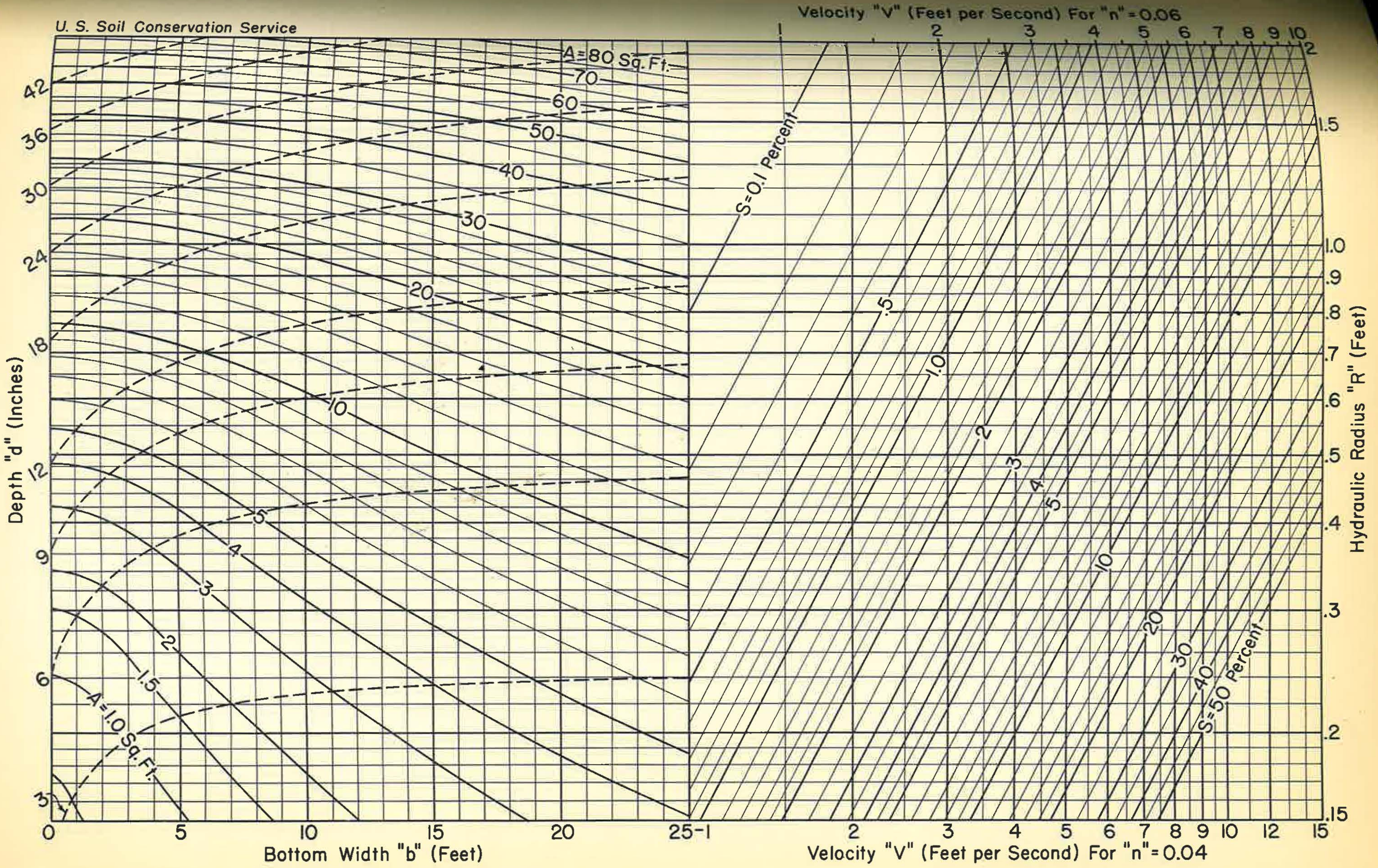
Note:

In cross-hatched areas the rainfall is more intense than in the surrounding country. Where the range of rainfall factors for these areas is not indicated on the map use a factor from 0.1 to 0.2 higher than the value applicable to the surrounding region. The boundaries of these areas are only roughly indicated.

RAINFALL FACTORS
FOR USE IN
ESTIMATING FLOOD FLOWS

CHART 2

A.S. 110092

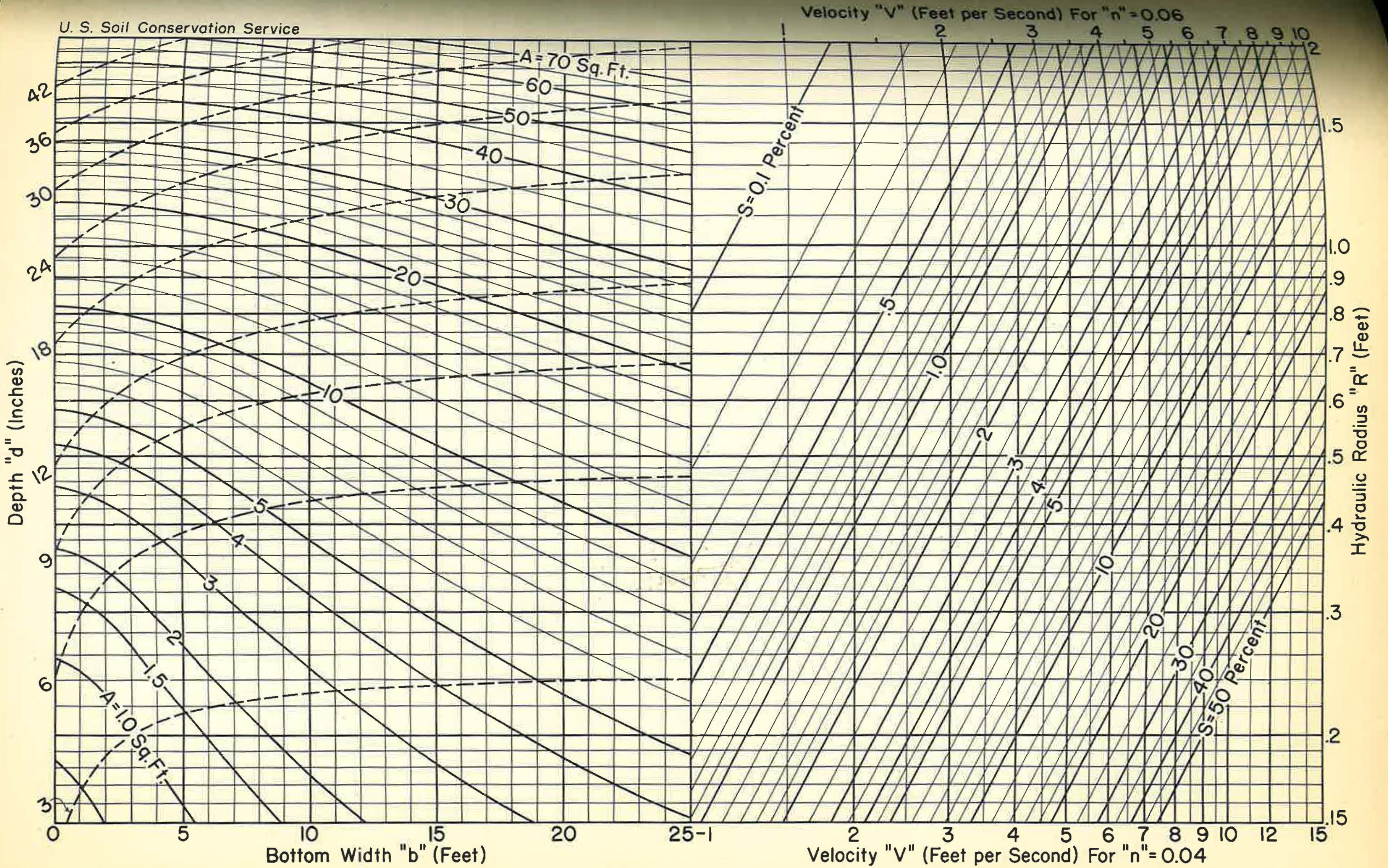


GRAPHIC SOLUTION OF VEGETATED CHANNEL DIMENSIONS. (Trapezoidal Cross Section with 4:1 Side Slopes)

By Manning Formula

Top Width = Bottom Width + 8Depth

CHART 3

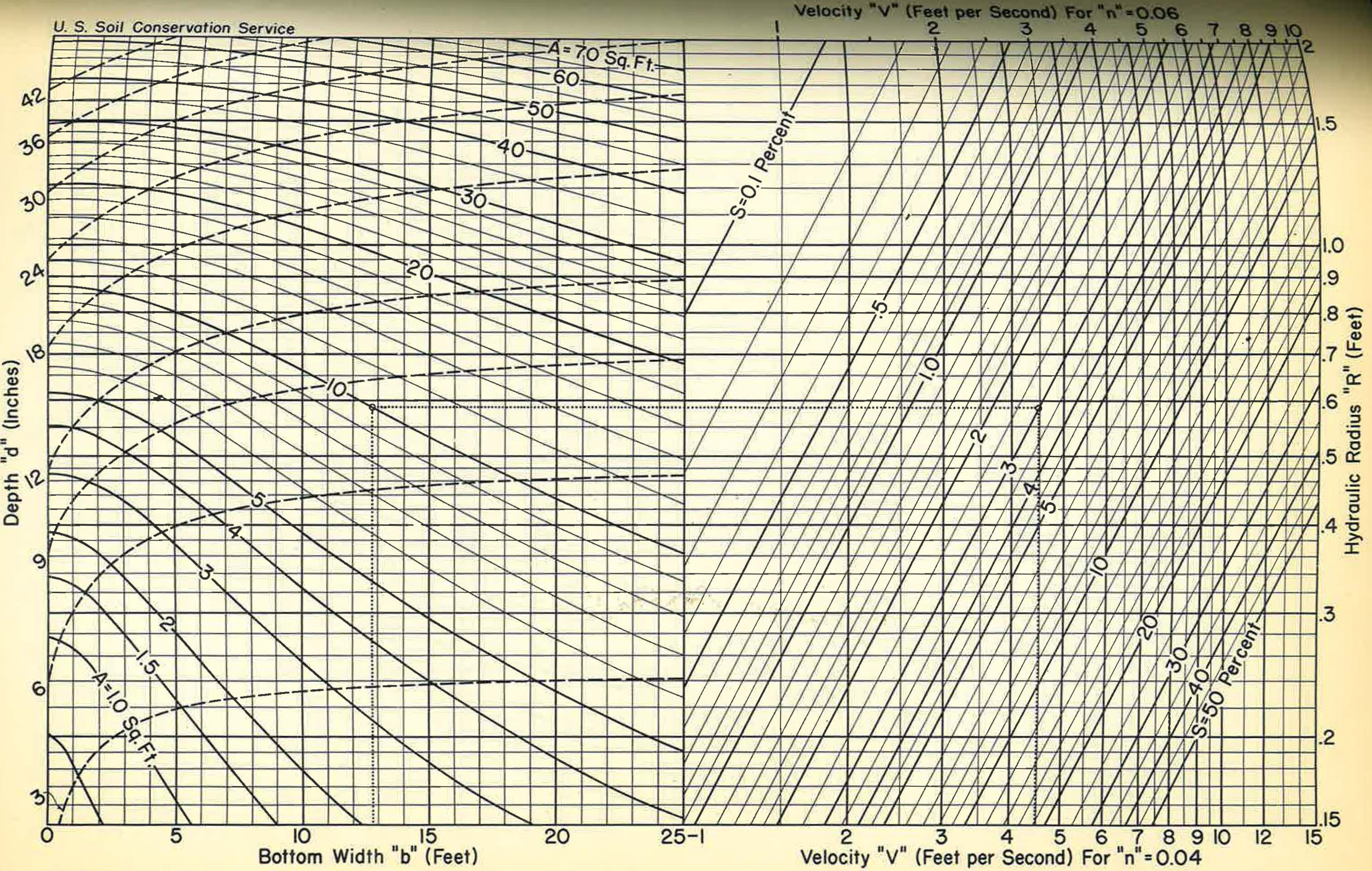


GRAPHIC SOLUTION OF VEGETATED CHANNEL DIMENSIONS. (Trapezoidal Cross Section with 4:1–3:1 Side Slopes)

By Manning Formula

Top Width = Bottom Width + 7Depth

CHART 4

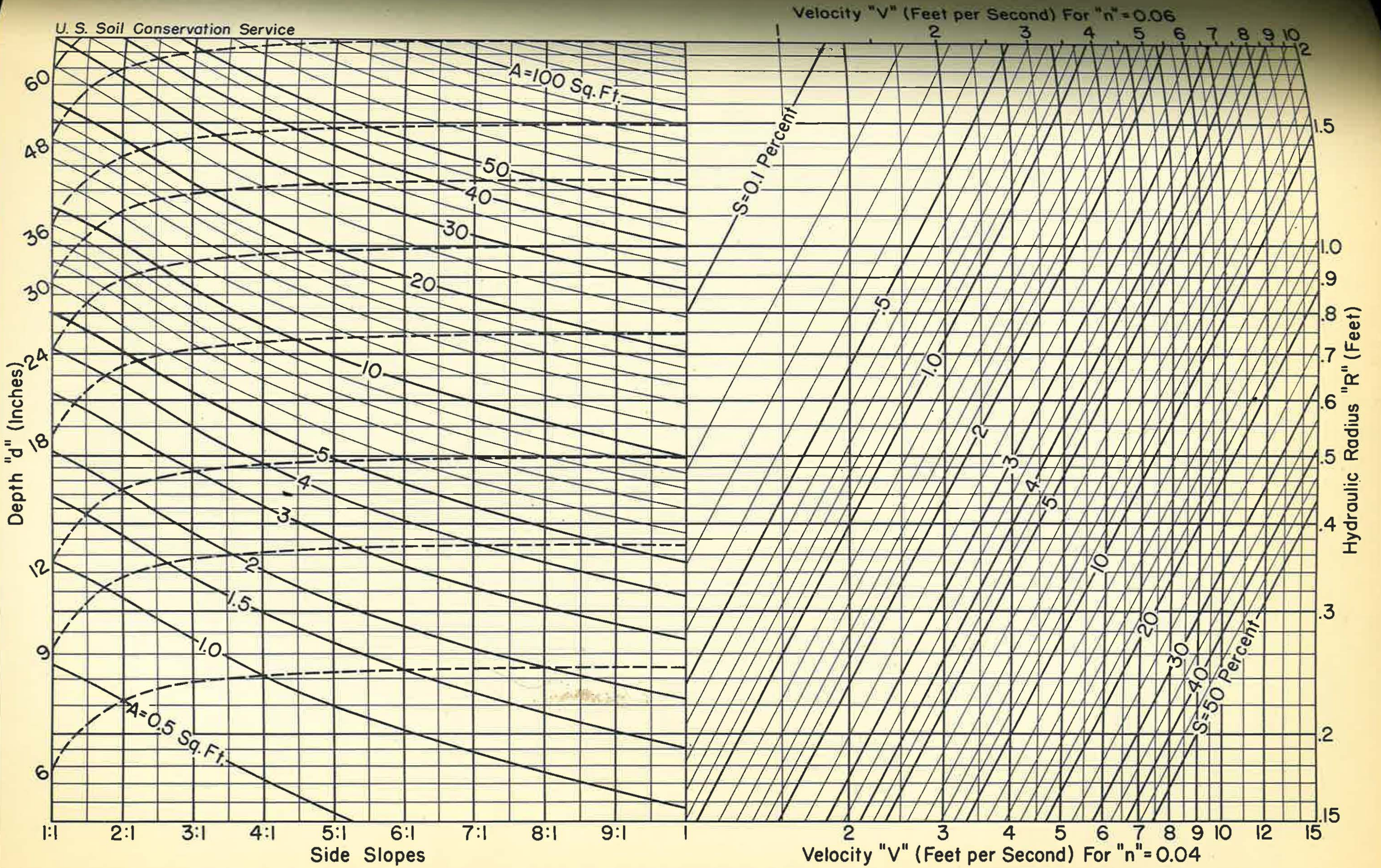


GRAPHIC SOLUTION OF VEGETATED CHANNEL DIMENSIONS. (Trapezoidal Cross Section with 4:1–2:1 Side Slopes)

By Manning Formula

Top Width = Bottom Width + 6Depth

CHART 5



GRAPHIC SOLUTION OF VEGETATED CHANNEL DIMENSIONS. (Triangular Cross Section for Various Side Slopes)

By Manning Formula

Top Width = 2 Depth (side slope ratio)

CHART 6