S
61
.R47
No.493
1961

Methodology of Programming Small Watershed Development

by George A. Pavelis, Howard P. Johnson,
William D. Shrader and John F. Timmons

Department of Agricultural Engineering
Department of Agronomy
Department of Economics and Sociology

Economic Research Service
United States Department of Agriculture
cooperating

AGRICULTURAL AND HOME ECONOMICS EXPERIMENT STATION
IOWA STATE UNIVERSITY of Science and Technology

RESEARCH BULLETIN 493 APRIL 1961 AMES, IOWA

IOWA STATE TRAVELING LIBRARY
DES MOINES, IOWA

CONTENTS

SUMMARY

This is a study of some physical and economic aspects of planning for the conservation and development of soil and water resources on a small watershed basis. Specific problems covered are: (1) applying multipurpose concepts which have guided river-basin planning to the evaluation of conservation needs and development opportunities in much smaller drainages, (2) reconciling the economic objectives and management plans of farmers who control watershed uplands with the objectives and plans of other private or public economic subunits affected by upland use and (3) formulating optimal development programs for small watersheds, defined as programs that will maximize discounted net benefits without forcing any economic subunit to incur net losses. The study's main objective was to treat these problems by illustrating procedures both for evaluating development possibilities and for devising alternative optimal development programs. Empirical investigations focused on the 480-acre Nepper Watershed, which includes parts of seven farms in Monona County of western Iowa and drains into the Maple, Little Sioux and Missouri rivers.

Planning in the Nepper Watershed was directed toward determining particular combinations of land treatment and structural measures effective in achieving a community objective, or "planning norm," from a complex of land, labor and capital resources available at a given point in time (specified as the year 1947). Potential beneficiaries of cooperative development were seven farm operating units, Monona County and the offsite area.

Interests of farms in watershed development centered around finding opportunities for obtaining the benefits of increased productivity and additional benefits from reduced sheet erosion, gully erosion or flood damage to onsite crops. The interest of Monona County was to reduce or eliminate the expense of maintaining a bridge damaged frequently by flood runoff. Reduction of downstream flood damages along the Maple River represented an offsite public interest in the Nepper Watershed development.

The planning norm to be achieved by optimal development in the Nepper Watershed was presumed to be maximum net returns from primary agricultural production discounted over the period 1947-97. All gully damage, flood damage and damage-control outlays were charged as costs of this output. In these terms, optimal development programs represented combinations of land-treatment activities (land-use changes) and structural activities promising a maximum increase in discounted net returns for the watershed community of private and public interests.

Benefits and costs of each land-treatment activity were estimated as the changes in costs and returns induced by shifting land use on each farm field from the system of land use that prevailed in 1947—the benchmark year. Benefits of increased productivity, for example, were estimated as the discounted values of increases in yields of corn, oats or hay obtained either by adopting new rotations, practicing contour tillage, applying commercial fertilizer or by building terraces. Gully-control benefits were computed as the amounts by which maximum average annual gully damage (as projected from conditions in 1947) would have been reduced by the same changes in land use. Flood-control benefits were estimated as the amounts by which maximum average annual flood damage to onsite crops, the county bridge and offsite areas would likewise have been reduced. Benefits from increased yields were credited to farms on which land-use changes would have been made. Other benefits were credited to the public or farmer-participants initially damaged.

Costs of land treatment included any additional recurring expense of obtaining increased yields, plus any charges associated with the installation and maintenance of terraces or permanent pasture. All were allocated among beneficiaries in proportion to the discounted values of total credited benefits. This criterion assumed that costs would have been shared willingly on a basis permitting equal rates of net return on the resources contributed for program purposes.

Structural alternatives for reducing gully erosion and flood damage in 1947 were considered to be the facilities installed in the Nepper Watershed in 1948 under the Little Sioux Flood Control Program. Interdependent structures were evaluated as grouped measures. One structure was found to return less in discounted benefits than its installation cost. Therefore, it was eliminated as a development activity. As in the case of land treatment, costs of each feasible structural measure were allocated among beneficiaries in proportion to any discounted gully-control and/or flood-control benefits.

Principal restrictions on combining land-treatment and structural measures in development programs for the watershed were land and capital. Additional labor needed for some land-treatment activities was found to have been available on all farms. Land resources were subclassified into 27 fields scattered among the seven farm units. Individually, the fields represented 27 unique (with respect to soils, location and topography) classes of land restrictions for which inputs and outputs characterizing numerous treatment activities were determined.

Following benefit-cost analyses of watershed-treatment alternatives and a specification of planning restrictions, optimal development programs were formulated by the technique of linear programming. Forty-seven land-treatment activities and three structural activities were considered for programming. The technique indicated which of the 50 activities should have been undertaken (and at what intensity) in 1947 to maximize net benefits through the Nepper Watershed as a whole, without imposing net losses on any of the seven onsite farmers, Monona County or offsite interests.

Results of the study are presented for three types of programs: (1) one of very limited scope because of severe capital restrictions, (2) one of a somewhat expanded scope, as a moderately increased expenditure was allocated optimally and (3) a program of a

scope limited only by the availability of noncapital resources or by technological restrictions.

The limited program for the Nepper Watershed with 1947 as the planning base included only land-treatment activities that would have been very profitable in providing net development benefits, whether initiated on upland or bottomland areas.

The expanded-scope type was a program devised by allocating optimally an annual expenditure of about $3,700. This program would have yielded total annual benefits of $11,899 and net benefits of $8,193.

With no limit on expenditure, the program of the third type would have annually returned $15,384 in total benefits for an outlay of $5,716. Thus, it would have yielded a maximum of $9,668 in annual net benefits distributed among the seven watershed farmers, Monona County and the immediate downstream area along the Maple River.

Methodology of Programming Small Watershed Development[1]

BY GEORGE A. PAVELIS, HOWARD P. JOHNSON, WILLIAM D. SHRADER AND JOHN F. TIMMONS[2]

Watersheds are defined hydrologically as geographic areas tributary to given streams or points on streams. Viewing watersheds as areas within which concepts of economic efficiency can be applied is of fairly recent origin. In this report, therefore, the terms "watershed" and "watershed development" are given the following economic interpretations:

A hydrologically defined watershed is a center of economic activity and the physical basis for an aggregated economic decision-making unit or "watershed firm" made up of two or more private and/or public decision-making subunits. To the extent that offsite areas (downstream private or public subunits) are measurably affected by onsite decisions, the scope of watershed activities is analytically broadened to include their offsite effects. Each onsite or offsite subunit is a potential participant in watershed development.

Watershed development is a welfare-oriented economic reorganization in which welfare can be increased by: (1) a more efficient allocation of the resources currently available to participants and (2) an efficient allocation of any additional resources made available for development purposes. Welfare in the aggregate can be increased only to the extent that the welfare of any individual participant is not decreased through the execution of development programs.

The investigation is conducted within a planning framework best adapted to projects of so-called tangible merit—those yielding benefits readily evaluated in monetary terms. Such intangibles as the saving of human lives through flood control are not considered. When only tangibles are involved, watershed projects can be evaluated on their tangible merits but approved as welfare-increasing only if aggregate net benefits (benefits to all subunits) are positive and no subunit suffers net losses.

GOALS AND PROBLEMS IN WATERSHED PLANNING

Although they may emphasize different aspects of watershed development, current watershed programs commonly have these goals: (a) formation of a development project consistent with some standard of productive efficiency—usually defined or implied to mean a project yielding maximum benefits for given costs, (b) an equitable allocation of costs among project beneficiaries which, considering one current policy statement on cost-sharing, can be deduced as an allocation among participants in the same proportion that discounted monetary benefits are received[3] and (c) creation of institutional arrangements whereby programs can be financed, installed and maintained. Major problems encountered in developing plans to achieve these program objectives may be listed as follows:

1. Determining physical relations between land use in various source-consequence[4] watershed sectors and then utilizing these relations in economic appraisal of alternative, as well as existing, patterns of watershed land use.
2. Reconciling conflicting interests of potential participants, either in the selection of improvement measures to be included in programs or in the distribution of costs (including compensations) to meet possible objections to specific measures.
3. Selecting or devising analytical techniques appropriate for the specification of optimal development programs.

The main objective of this study was to demonstrate small watershed planning within a multipurpose framework, emphasizing measurable benefits and costs. Considering problem 1, a multipurpose approach to planning accounts for hydrologic source-consequence relations within and among various watershed sectors and includes such relations in economic appraisals. This approach was considered essential for an adequate evaluation of existing watershed conditions and alternative measures for development and, consequently, essential for the specification of the partic-

[1] Project 1266 of the Iowa Agricultural and Home Economics Experiment Station, in cooperation with the Economic Research Service of the United States Department of Agriculture.

[2] Agricultural economist, Farm Economics Research Division, Economic Research Service, United States Department of Agriculture; associate professor of agricultural engineering; associate professor of soils; and professor of economics, respectively, Iowa State University of Science and Technology.

[3] In practice, this criterion can be applied only with respect to costs associated with project functions legally termed fully reimbursable. It cannot be applied, for example, to flood-prevention costs of programs installed under the Watershed Protection and Flood Prevention Act (Public Law 566), because the federal government by law therein bears all construction costs allocable to flood prevention. For a statement of this general criterion, see: Presidential Advisory Committee on Water Resources Policy. Report on water resources policy. 84th Cong., 2nd sess., H. Doc. 315. U. S. Govt. Print. Off., Washington, D. C. 1956. pp. 8-9.

[4] The source-consequence concept refers not only to all the physical and economic effects of land management on the watershed subarea managed, but also to the associated effects on other subareas.

ular measures that would have maximized the net benefits of development.

Multipurpose planning also was useful for dealing with problem 2 but, in this connection, was supplemented with principles of welfare economics, particularly the compensation principle. This was necessary to make measures which were optimal in the aggregate also acceptable to all concerned economic interests.

Considering problem 3, benefit-cost analysis was used to identify the treatment measures promising net benefits. Combining promising measures to maximize watershed - wide net benefits was accomplished through linear programming.

The Problem Area

The area selected to demonstrate watershed planning was the 480-acre Nepper Watershed in Monona County, Iowa. The major factor in its selection was the availability of reasonably adequate data on the economic and hydrologic consequences of particular methods of land use. The data were based on crop-yield and runoff-erosion experiments conducted either nearby or at other Midwest locations and on land use records or prior research for the same area.[5] A secondary factor was that the Nepper Watershed was partly developed in 1948 under the Little Sioux Flood Control Program, a factor permitting evaluation of an actual development program within this study's framework. This was also the reason for taking the year 1947 as the benchmark or planning date, although the Little Sioux program as such is not discussed.

Plan of the Report

Watershed planning, as applied in the Nepper Watershed, proceeds through the following five stages:

First, a general description of the watershed as a hydrologic-economic unit of observation and study is made, with the description including physical features and major agricultural and related public service activities. Important to adequate descriptions and subsequent planning is the delineation of those farms and specific fields within farms which contribute to hydrologic problems.

Second, the relations of intrafarm and interfarm land use to the extent of watershed damage problems are discussed, and such relations are then quantified.

Third, discounted returns and costs related to existing land use and capital improvements are summarized as accruing to all affected private and public decision-making units that are potential participants in watershed development programs. This situation is regarded as the benchmark or predevelopment situation from which discounted program benefits and costs are estimated. The predevelopment situation in the Nepper Watershed is specified as that existing in 1947.

[5] Karl Gertel. Benefits and costs of land improvements. Unpublished M.S. thesis. Iowa State University Library, Ames, Iowa. 1949. Also see: Iowa State University. Departments of Agronomy, Agricultural Engineering and Economics and Sociology. Integrated analysis of watershed development, including physical, economic and institutional aspects. Iowa Agr. and Home Econ. Exp. Sta., Ames, Iowa. June 1956. (Mimeo rpt.)

Fourth, the land-treatment and structural activities possibly included in watershed development plans maximizing net benefits are delimited. These activities are shown to be physically and economically feasible and also consistent with some subjective attitudes of participants.

Fifth, combinations of treatment measures maximizing aggregate net discounted benefits are selected. Such combinations are limited to those which do not result in uncompensated losses by any private or public participant. Alternative programs requiring different amounts of capital for installation and maintenance of measures are formulated. Three types of alternative programs described for the Nepper Watershed include: (1) one limited to activities termed critical in providing net benefits for a very limited outlay, (2) one resulting from an optimal allocation of a somewhat larger outlay and (3) a program resulting from an optimal allocation of a maximum justified outlay. The latter includes all measures or measure-combinations adding to discounted aggregate or participant net benefits. Programs of all three types are formulated through linear programming.

PREDEVELOPMENT RESOURCES AND PROBLEMS

Soils, Hydrology and Predevelopment Land Use

Located 2½ miles south of Mapleton in Monona County, Iowa, the 480-acre Nepper Watershed is tributary to the Maple, Little Sioux and Missouri rivers. The watershed has soils characteristic of the Monona-Ida-Hamburg soil association—a hilly topography overlain with deep calcareous loess deposited over the Kansan glacier drift plain. Principal soil series include the Ida, Monona, Napier and McPaul. All are silt loams, and all except the Monona are calcareous to the surface.[6]

A major portion (52 percent) of the Nepper Watershed is occupied by the Monona series, a dark soil developed under grass vegetation and typically found on moderate ridges and lower slopes of ridges. Ida soils, next most prevalent (19 percent), also have been formed under grass and are found on steeper slopes or sharp ridges. The McPaul series (15 percent) is an alluvial soil washed from Ida and Monona uplands, while the Napier soil (14 percent) is colluvial and located along lower slopes and principal drainageways. Slope phases within the various series are shown in fig. 1 and tabulated by farms in table 1.

Portions of seven farm operating units were within the Nepper Watershed in 1947. The boundaries of these farms, a field-by-field summary of 1947 land use and the general relation of the latter to watershed-damage problems are shown in fig. 2.

Under predevelopment conditions, about 53 percent of the watershed was in corn or its erosion-runoff

[6] Iowa Agricultural and Home Economics Experiment Station and United States Soil Conservation Service. Soil survey: Monona County, Iowa. Series 1952, No. 2. Jan. 1959.

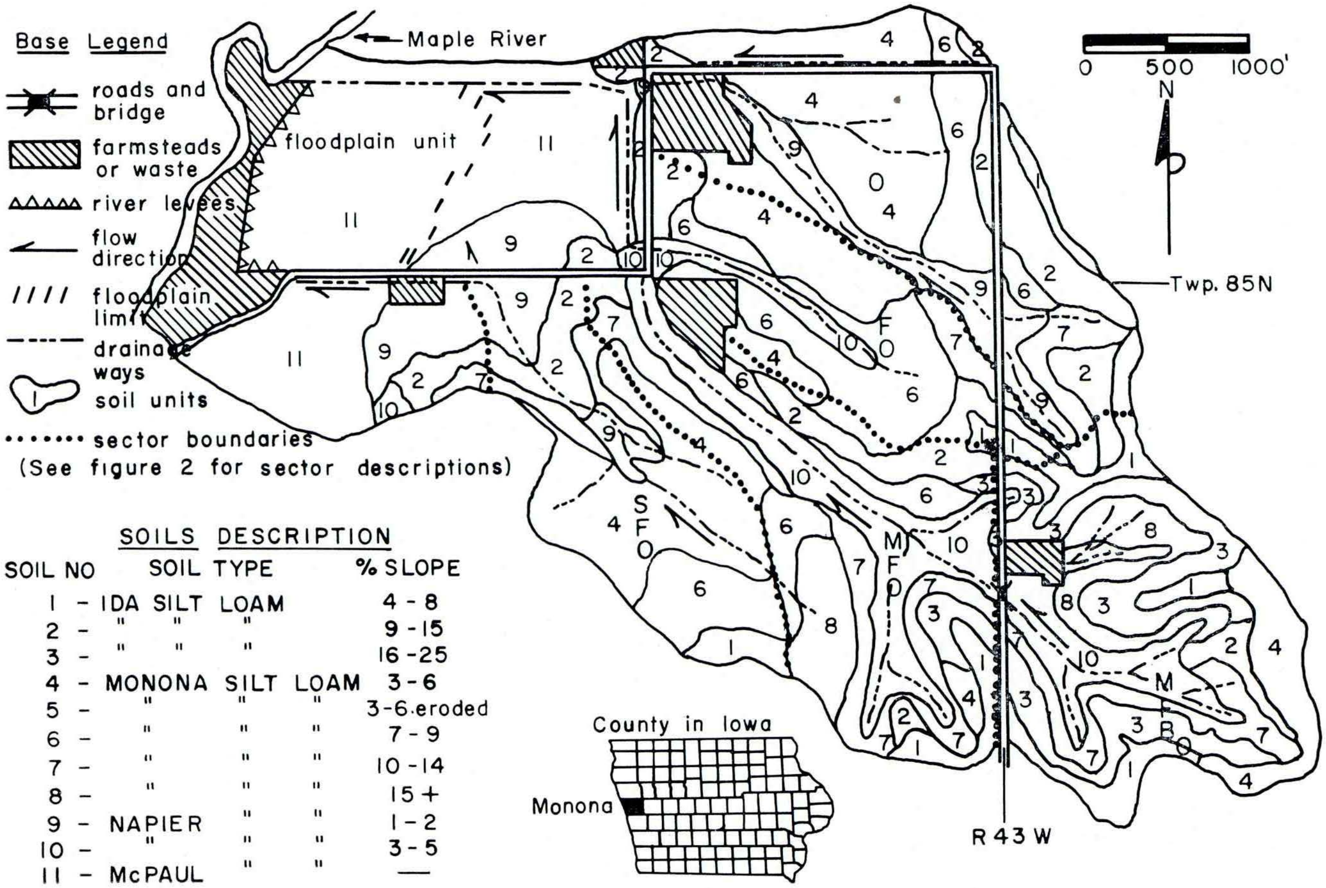

Fig. 1. The Nepper Watershed; with principal physical features affecting planning.

TABLE 1. DISTRIBUTION OF NEPPER WATERSHED SOILS AND DAMAGE SECTOR RELATIONSHIPS.

	Onsite private participants (farms)							Watershed
	1	2	3	4	5	6	7	total
Soil types by slope phases				*Soil types among and within farms (acres)*				
Ida silt loam, 4-8 percent	..	3.4	5.7	1.6		8.0		18.7
Ida silt loam, 9-15 percent	..	0.2	14.1	3.7	9.8	10.6	6.8	45.2
Ida silt loam, 16-25 percent		6.4	1.7	12.9		4.5		25.5
Monona silt loam, 3-6 percent	3.5	2.9	..	6.7	5.7	42.3	39.7	100.8
Monona silt loam, 3-6 percent (e)[a]		..		..	..	8.5		37.5[b]
Monona silt loam, 7-9 percent	0.8		1.0			37.9	11.2	50.9
Monona silt loam, 10-14 percent	..	4.6	15.5	4.7	3.1	21.5	..	49.4
Monona silt loam, 15+ percent	..	..	0.6	10.0	..	1.0		11.6
Napier silt loam, 1-2 percent	..	..	3.3		10.7	4.6	13.5	32.1
Napier silt loam, 3-6 percent	..	1.4	0.2	11.5	0.4	20.2	1.7	35.4
McPaul silt loam, level		..	..	..	18.9		54.8	73.7
Total areas	4.3	18.9	42.1	51.1	48.6	159.1	127.7	480.8[b]
Watershed damage sectors				*Damage source-areas among and within farms (acres)*				
Main gully	..	18.9	11.8	51.1		68.4	..	157.5[c]
Southwest gully	..				13.1	44.1		57.2
Onsite crop flooding	..	18.9	10.1	51.1	13.1	147.8	43.4	293.1[c]
Onsite bridge damage		18.9	11.8	51.1				88.9[c]
Offsite flood damage	4.3	18.9	42.1	51.1	48.6	159.1	127.7	480.8[c]

[a] Eroded phase indicated by (e).
[b] Includes 29 acres classed as Monona silt loam, 3-6 percent (e) in Monona County roads.
[c] Of the total road area of 29 acres, 7.3 acres are included in the main gully sector, 8.7 acres in onsite crop flooding sector, 7.1 acres in the onsite bridge-damage sector and all 29 acres in the offsite flood-damage sector (or watershed).

equivalent, 19 percent was in oats, and 28 percent was in meadow.[7] A negligible proportion of the cropland was contoured or fertilized, and no terraces were installed. Farm-by-farm comparisons of cover conditions, labor use and erosion losses can be made from table 2. Gross crop values were calculated from assumed commodity prices, the land-use pattern of fig. 2 and yield estimates such as those given in example form in table A-1 (Appendix A).[8] If projected direct production expenses only were deducted from respective gross crop values, net crop values in 1947 ranged from \$146 on farm 2 to \$4,208 on farm 6, with such incomes for all farms aggregating \$14,033. The net crop values entered in table 2, however, are estimates of projected net crop values if all damages of an interfarm or watershed nature are also considered.

[7] In erosion and runoff evaluations, farmsteads and roads were assumed to have the same cover potential for erosion and runoff as continuous corn not on the contour.

[8] Price assumptions are discussed more thoroughly in outlining planning qualifications.

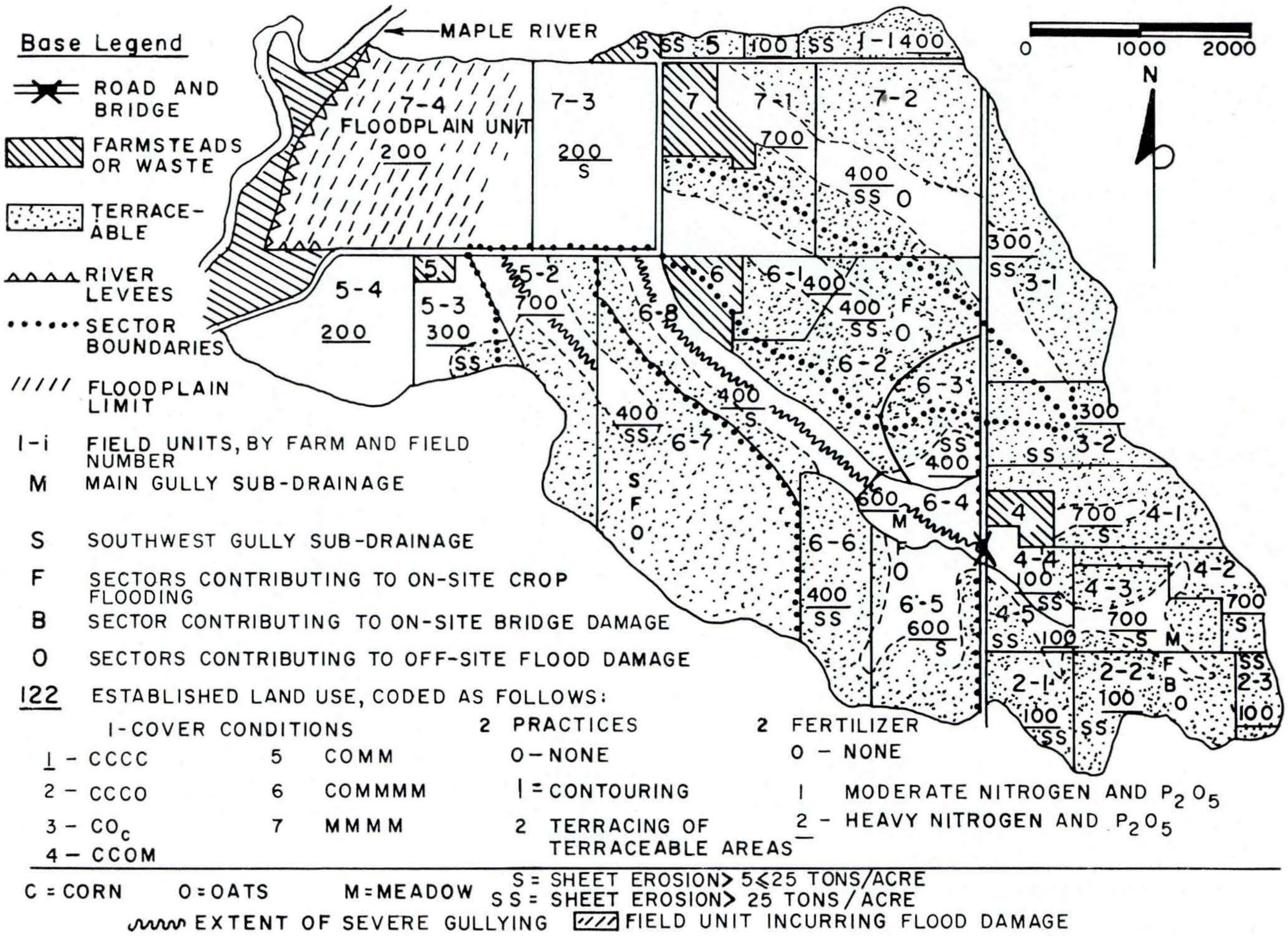

Fig. 2. Predevelopment land use and associated damage problems in the Nepper Watershed.

TABLE 2. PREDEVELOPMENT RETURNS AND COSTS DISTRIBUTED AMONG POTENTIAL PRIVATE PARTICIPANTS.

Items by private participants	Farm identity[a] 1	2	3	4	5	6	7	Total private[b]
Annual returns								
Gross value of crops produced (dollars)	247	513	1,152	2,004	2,152	7,616	6,066	19,750
Annual costs[c]								
Direct production expense (dollars)	95	367	763	781	881	3,403	2,422	8,717
Gully damage; main drainage (dollars)	0	4	1	30	0	66	0	101
Gully damage; southwest drainage (dollars)	0	0	0	0	22	14	0	36
Flood damage; onsite crops (dollars)	0	0	0	0	0	0	2,803	2,803
Total annual costs (dollars)	95	371	764	811	903	3,488	5,225	11,657
Net value of crops produced (dollars)	152	142	388	1,193	1,249	4,128	841	8,093
Watershed area in corn (percent)[d]	50	100	50	26	31	46	57	50
Watershed area in oats (percent)	25	0	50	0	21	23	20	21
Watershed area in meadow (percent)	25	0	0	74	48	31	23	29
Labor use (man-hours)	33	132	253	525	374	1,231	944	3,489
Rates of sheet erosion (tons per acre)	27	206	84	53	22	31	15	72

[a] Farms numbered as in fig. 2.
[b] Transferred to column 1 of table 3.
[c] Cost items included in table 3 but omitted here are uniformly zero.
[d] Farmstead cover, for damage-evaluation purposes only, was assumed equivalent to continuous corn with no supplemental practices.

Damages Associated With Predevelopment Land Use

Average annual precipitation in the Nepper Watershed approximates 25 inches. Amounts per flood-producing storm, however, have reached 5.6 inches and average 2.2 inches for the April-September flood season. Average annual flood-producing rainfall for the same period approaches 6.3 inches (see table C-1 in Appendix C).

The general course of runoff from uplands of the Nepper Watershed is indicated by the drainage pattern of fig. 1. Two outlets into the Maple River are shown, although minor discharges from the 20-acre low area in the extreme southwest corner were ignored in this study. Five different water-control problems are described. These resulted in 1947 from excess runoff originating on source-areas, collecting in drainageways and, thence, either overflowing McPaul bottomlands within the watershed or leaving the northwest outlet to enter the Maple River.

PRODUCTIVITY LOSSES FROM SHEET EROSION

The principal source-area damaging effects of runoff were the loss of water for growing crops and the loss of topsoil through sheet erosion. The latter was especially serious on the Ida and Monona soils predominating on the uplands, which generally increase in slope southeastward from the township line road corner, shown in figs. 1 and 2. Roughly 385 acres were subject to sheet erosion, with average annual rates per farm ranging from about 15 to 200 tons per acre (see table 2).[9] The relative degree of sheet erosion on fields within farms can be noted from fig. 2. Crop yields associated with various rotation-fertilizer-practice combinations or land-use systems given in table A-1 of Appendix A are stabilized minimums, and the long-term effects of continued losses of topsoil are reflected in the projected gross values of table 2.

GULLY DAMAGE[10]

As shown in fig. 2, two gullies were advancing through the watershed in 1947. The largest had destroyed about 5.8 acres within the 157-acre area termed the main subdrainage. This subdrainage included the two sectors lettered as MFO and MFBO. The main gully had advanced at an average rate of 0.133 acre per year. Over the period 1947-97, it could thus have been expected to destroy an additional 6.65 acres within farms 2, 3, 4 and 6. The land-destruction rate was converted into an annual equivalent of the discounted value of net crop values lost through land destruction. The average annual damage which probably would have been incurred by the four farms, if land use on source-fields had continued as in 1947, would have approximated $101 per year. The interfarm incidence of this amount as an annual cost is shown in table 2. The converse distribution as to farms of origin is given in table C-7 of Appendix C.

The second gully had destroyed 0.89 acre by 1947 in the 57-acre southwest subdrainage, the sector denoted by SFO in fig. 2. Advancing at an average rate of 0.047 acre per year, this gully would have destroyed 2.35 acres within farms 5 and 6 over the period 1947-97. The annual income sacrificed because of this uncontrolled gully would have amounted to $36—distributed between the two affected farms as shown in table 2.

This procedure for predicting gully damage (described more fully in Appendix B) was based mainly on the history of gully damage. The effects of changing management as it related to gully damage were introduced by assuming a relationship between the 10-year peak discharge and gully damage. Quantitative information completely relating the variables involved in gully damage is not available; therefore, the accuracy of the predictions of gully growth was limited by the validity of this assumption.

FLOOD DAMAGE TO ONSITE CROPS[11]

A third predevelopment problem, affecting one onsite farm (farm 7), was flood damage to crops on the Nepper Watershed floodplain and was caused by runoff originating from all sectors denoted by F in fig. 2. Under the land-use conditions prevailing in 1947 on this 293-acre source-area, approximately 32 acre-feet of runoff annually overflowed the 41.6-acre floodplain (field 7-4 in fig. 2).

To relate flood damages to the interdependence of land use on the source-area and the floodplain, a series of estimates of average annual flood damage to crops was derived as shown in figs. C-1, C-2 and C-3 in Appendix C. Figure C-1 was based on the size and topography of the floodplain and indicates the acreages flooded to specified depths resulting from given volumes of overflow, the latter reflecting source-area land use. From the relations of fig. C-1 and estimates of crop damage under various water depths given in table C-5, fig. C-2 indicates how net crop values on the floodplain would have declined with increasing volumes of overflow, depending on the floodplain cropping system. Net crop values per floodplain acre with no flood hazard, or zero average annual overflow, are the intercepts of the net return axis of fig. C-2. The losses, computed as the difference from net returns with no flooding, are then plotted as damages in fig. C-3.

If land use on the 293-acre upland source-area had continued to result in 32 acre-feet of overflow and floodplain land use had continued as in 1947, net crop values per floodplain acre would have approximated $-6.50 (point A, curve CCCO-F_o, fig. C-2). Flood damages would then have been estimated as $38 per acre (point A curve CCCO-F_o, fig. C-3).

[9] Sheet erosion rates were estimated in this study by application of Browning's procedure which integrates the independent variables of soil type, degree of field slope, slope length, antecedent erosion, fertility practices, rotations and conservation practices. For an explanation of the method, see: R. K. Frevert, G. O. Schwab, T. W. Edminster and K. K. Barnes. Soil and water conservation engineering. John Wiley and Sons, Inc., New York. 1955. pp. 122-125.

[10] See Appendix B for the procedure used to evaluate gully damage under predevelopment and other land-use patterns.

[11] See Appendix C for the detailed procedures whereby various forms of flood damages under predevelopment and other land-use patterns were evaluated.

To consider the possibility that the floodplain might have been managed for maximum net returns, the damages that would have resulted from the predevelopment volume of 32 acre-feet in overflow under this system are estimated in fig. C-3 as $67 per floodplain acre, or $2,803 for the 41.6-acre floodplain (point A, curve CCC-F_2, fig. C-3). To reflect a maximum of potential benefits obtained by either reducing runoff on the upland source-area or installing structural works of protection, this estimate of predevelopment crop flood damage is entered for farm 7 in the cost-return summary of table 2.

Because of the assumptions used in predicting flooding frequencies in the Nepper Watershed and those concerning probable future floodplain use, the flood damages derived as in fig. C-3 may be overstated. Limitations of the flood damage analysis are discussed further in Appendix C. Although this study emphasizes planning techniques, the high estimates of flood damage to crops suggest a need for a more thorough understanding of agricultural hydrology, particularly in its relation to flood damage.

ONSITE DAMAGE TO TRANSPORTATION FACILITIES

This class of damages was represented in the Nepper Watershed in 1947 by an average annual expenditure of $325 for frequent repair of the Monona County bridge shown in fig. 2. Damage to the bridge was caused by runoff originating from the 89-acre sector designated as MFBO in the figure. The runoff, based on land use in 1947 over the contributory sector, annually averaged about 19 acre-feet. The $385 estimate of onsite public damages included in the cost-return summary of table 3 is the estimate of $325 for 1947 converted into a long-term basis from comparative repair-cost indexes.

OFFSITE FLOOD DAMAGES

Under the land-use conditions prevailing in 1947 in the Nepper Watershed, approximately 55 acre-feet of net flood-storm runoff left the watershed annually, causing downstream flood damage amounting to $140. This net volume originated on fields within sectors indicated by 0 in fig. 2. It was computed as the total seasonal volume of 85.70 acre-feet of flood-producing runoff from watershed uplands, less the portion of this runoff, 32.36 acre-feet, appearing as floodplain overflow (see table C-1 in Appendix C.) Offsite damages of $140 associated with net runoff under 1947 conditions were estimated from information for 1955 for similar unimproved watersheds located on the lower reaches of the Maple River. In 1955, combined floodwater-sedimentation damages to farmland and public facilities along the Maple River were approximated at $187 per square mile of contributing watershed.[12] This figure was the basis for the $140 in annual damages estimated to originate from the 480-acre (0.75-square mile) Nepper Watershed. The $140 amount was accepted as a long-term estimate projected from 1947 conditions because it did not appear that land use in the Nepper Watershed had changed materially between 1947 and 1955 with respect to runoff potentials and also because the relevant projected (1947-97) index of repair costs was essentially equal to the comparable index for 1954. Offsite flood damage is the final element of watershed cost entered in table 3.

TABLE 3. PREDEVELOPMENT RETURNS AND COSTS DISTRIBUTED AMONG POTtENTIAL PRIVATE AND PUBLIC PARTICIPANTS, IN DOLLARS.

Items by participants	Onsite			Offsite	Total	Watershed
	Private[a]	Public	Total	public	public	total
Annual returns						
Gross value of crops produced	19,750	0	19,750	0	0	19,750
Annual costs						
Direct production expenses	8,717	0	8,717	0	0	8,717
Gully damage; main drainage	101	0	101	0	0	101
Gully damage; southwest drainage	36	0	36	0	0	36
Flood damage; onsite crops	2,803	0	2,803	0	0	2,803
Flood damage; onsite bridge	0	385	385	0	385	385
Flood damage; offsite	0	0	0	140	140	140
Total annual costs	11,657	385	12,042	140	525	12,182
Net value of crops produced	8,093	-385	7,708	-140	-525	7,568

[a] Transferred from table 2.

Allocation or Routing of Damages to Source-Areas

In describing resource use in the Nepper Watershed in 1947, tables 2 and 3 include projected costs and returns which would accrue to various farmer and public interests if no development project were undertaken. All damages attributable to land use were routed back to contributing fields or source-areas and then aggregated by farms to determine farm allocations.

Damage-routing procedures are explained in Appendix B (for gully damages) and Appendix C (for flood damages). The objective was to estimate damages originating from each contributory watershed field, farmstead or road area, considering not only such physical features as field area, degree of slope and slope length, but also land use in terms of cover conditions, tillage practices and possible fertilizer

[12] Cecil A. Saddoris, Soil Conservation Service, USDA., Des Moines, Iowa. Information on damages from the Nepper Watershed. (Private communication.) July 1955.

TABLE 4. PREDEVELOPMENT MAXIMUM AVERAGE ANNUAL DAMAGES IN RELATION TO THE HYDROLOGIC VARIABLES ASSOCIATED WITH WATERSHED LAND USE, WITH DAMAGES DISTRIBUTED AMONG POTENTIAL PRIVATE AND PUBLIC PARTICIPANTS.

Evaluation items or participants	Onsite gully damage		Flood damage			Total gully and flood damage
			Onsite		Off-site	
	Main drainage	Southwest drainage	Flood-plain crops	County bridge		
Damage evaluation based on land use in 1947						
1. Hydrologic variable	Peak runoff	Peak runoff	Over-flow	Total runoff	Net runoff	. . .
2. Hydrologic units	Runoff index	Runoff index	Acre-feet	Acre-feet	Acre-feet	. . .
3. Evaluated units	52	46	32.36	18.71	55.36	. . .
Distribution of damages by participants (dollars)						
4. Watershed farms	101[a]	36[a]	2,803[a]	0	0	2,940
5. Monona County	0	0	0	385[a]	0	385
6. Offsite public	0	0	0	0	140[a]	140
7. All participants	101	36	2,803	385	140	3,465
8. Damage per hydrologic unit[b]	1.92[c]	0.76[d]	86.59	20.51	2.52	. . .

[a] Approximate because of rounding.
[b] Computed as ratios of damage for all participants (row 7) to evaluated hydrologic units (row 3).
[c] As unaveraged, the weighted index approximated 8,218; unit damages on the latter basis were $0.01232.
[d] As unaveraged, the weighted index approximated 2,641; unit damages on the latter basis were $0.01361.

applications. These estimates were required to pinpoint major source-areas of gully or flood damages as areas where adjustments in land use would be expected to yield substantial benefits in the form of reduced damages.

Areas of each farm in the different gully- or flood-damage sectors are given in table 1. The sectors overlap considerably because land use on only one farm and field (field 1-1 in fig. 2) was associated with a single class of damages. Predevelopment damages allocated to farms of origin and the county road system are itemized in table C-7 in Appendix C. Table 4 summarizes results of applying damage-evaluation procedures to land-use conditions that existed in the Nepper Watershed in 1947. Also indicated is the incurrence of damages among potential private and public participants in watershed development and among these participants grouped by location.

DEVELOPMENT POSSIBILITIES IN THE NEPPER WATERSHED

Watershed Development and Optimal Resource Use

With respect to the predevelopment situation just described, section 1 of table 5 presents projected cost and return data for each group of potential participants in development programs for the Nepper Watershed. The objective to be achieved from development of the watershed was then presumed to be a maximum discounted net value of crops produced over the 50-year period 1947-97, with publicly incurred values discounted at 2½ percent and farmer-incurred values discounted at 5 percent. All remaining gully or flood damages, as well as damage-control outlays associated with development programs would (as in section 1, table 5) be charged as costs incurred in obtaining net crop values. In these terms, optimal development programs were to be formulated as combinations of changes in land use and of structural improvements promising maximum net benefits, or a maximum increase in the discounted net value of crops produced over the relevant planning horizon 1947-97. In effect, a maximum of net benefits would imply a maximum increase in the $7,568 amount entered as item 8, column 4, table 5. The $9,668 amount entered as item 19, column 4, is such a maximum of net benefits for a development program to be described later in considerable detail. A major objective of watershed planning, especially as illustrated in this report, is to indicate how such maxima can be achieved.

Consistent with the accounting scheme used in table 5 to summarize the predevelopment situation, the Nepper analysis considered as program benefits any (a) increases in gross crop values on farms, including enhanced land use on the floodplain, (b) decreases in normal farm production expense and (c) decreases in any land-use-associated damage item. Costs included (a) decreases in gross crop income on farms, (b) increases in normal farm production expense, (c) possible increases in associated damages and (d) direct outlays for damage control. Benefits of types

TABLE 5. DISTRIBUTION OF PREDEVELOPMENT RETURNS AND COSTS IN DOLLARS, AND OPTIMAL DEVELOPMENT BENEFITS AND COSTS AMONG FARMERS AND PUBLIC INTERESTS IN THE NEPPER WATERSHED.[a]

Items of returns and costs	Onsite farmers	Monona County	Offsite public	Watershed total
Section 1: Predevelopment (1947) resource-use situation				
1. Gross crop values	19,750	0	0	19,750
2. Total normal farm expense	8,717	0	0	8,717
3. Flood damage to bridge	0	385	0	385
4. Gully damages	137	0	0	137
5. Flood damage to crops	2,803	0	0	2,803
6. Offsite flood damage	0	0	140	140
7. Total costs (add items 2-6)	11,657	385	140	12,182
8. Net returns (item 1 less item 7)	8,093	–385	–140	7,568
Section 2: Optimal development, Program C				
9. Gross crop values (I)	+12,171	0	0	÷12,171
10. Normal variable farm expense (C)	+4,833	+93	+26	+4,952
11. Flood damage to bridge (C)	0	–273	0	–273
12. Gully damages (C)	–60	0	0	–60
13. Flood damage to crops (C)	–2,803	0	0	–2,803
14. Offsite flood damage increase (C)	+125[b]	0	0	+125
15. Offsite flood damage decrease (C)	0	0	–77[c]	–77
16. Investment and maintenance (C)	+627	+9	+3	+639
17. Total benefits (add +I, and –C items)	15,034	273	77	15,384
18. Total costs (add –I, and +C items)	5,585	102	29	5,716
19. Net benefits (item 17 less 18)	9,449	171	48	9,668
20. Net per-unit cost (item 19/item 18)	1.69	1.69	1.69	1.69

[a] Program installation costs are in 1947 prices; remaining items are in projected long-term prices.
[b] Increase caused by diversion of onsite overflow with a levee decreasing onsite crop damage by $1,141.
[c] Decrease attributed to upland treatment measures.

a and b were presumed to accrue solely to farm operating units on which land use might be changed and those of type c to any farm unit or public entity damaged under predevelopment circumstances.

Qualifications of Development Planning

In addition to the planning horizon and discount rates previously noted, several qualifying assumptions influenced the nature of development programs for the Nepper Watershed. The assumptions pertained to (1) the sharing of any costs incurred to install and continue programs, on the basis that no farmer or public participant suffer uncompensated damages resulting from measures benefiting other participants, (2) appropriate estimates of projected commodity prices, production costs and related watershed damages and (3) the limited number of feasible land-use changes and structural improvements evaluated for costs and benefits, with the evaluations determining which land-treatment or structural measures would be considered as alternative development activities.

DISTRIBUTION OF COSTS

In appraising land-treatment and structural measures for economic feasibility (establishing whether benefit present values would exceed outlay present values), combining measures in feasible programs and indicating by whom costs would be covered, the following principles were adopted:

1. If measures were either of a single- or multipurpose, single-participant character — that is, yielding benefits to a single participant—all listed costs associated with such measures were charged to the

single participant, regardless of where within the watershed the measure would be applied.

2. If measures were of either a single- or multi-purpose, multiparticipant character—that is, yielding benefits to more than one participant—listed associated costs were allocated among beneficiaries in proportion to present values of gross benefits received, again regardless of the site of installation.

In proportionally assessing beneficiaries for resources needed to install and maintain development measures, it was assumed that the participants (a) would be indifferent as to the nature of multiple benefits, (b) at the maximum, would willingly contribute resources equivalent in value to total benefits expected and (c) would insist that any quantity of total or incremental benefit be obtained at minimum cost. Assessments associated with complex measures were thus implied to be costs willingly borne by beneficiaries in obtaining a "bundle" of benefits.[13]

3. In meeting the general criterion for economic feasibility (that present values of aggregate benefits exceed present values of aggregate outlays) measures also were required to satisfy the criterion that cost allocations to any participant not exceed benefit present values. But with allocations made proportional to benefits, any measure feasible in the aggregate would necessarily not be infeasible for any participant and would be equally profitable (yield equivalent positive rates of return) to all beneficiaries. Conversely, any measure infeasible in the aggregate would be necessarily infeasible and equally unprofitable (yield equivalent negative rates of return) for all beneficiaries. In both cases it was assumed that nonbenefiting interests would be indifferent to the measures, with those suffering damages or realizing other additional costs made so through equivalent compensations.

ESTIMATED PRICES, COSTS AND DAMAGE[14]

Gross farm incomes from land-use systems feasible on various soils of the Nepper Watershed were computed using projected Iowa seasonal average prices of \$1.41 per bushel of corn, \$0.74 per bushel of oats and \$15.70 per ton of baled brome-alfalfa hay. These estimates represent projections over an extended period under assumptions of relatively high national employment, a gradual improvement in international relations, continued population growth and a stable general price level. These assumptions underlie a projected all-product national index of 235 (1910-14 = 100) for prices received by farmers. Opportunities for marketing the grains and forages through livestock were not considered in determining the relative profitability of land-use systems feasible on each field.

Annual farm costs of production were similarly based on a prices-paid index of 265 (1910-14 = 100) applicable to expected outlays for equipment, seed, labor, fuel, repairs and fertilizer. Annual per-acre production costs, exclusive of fertilizing expense and harvesting expense variable with yields, were computed as \$16.23 for corn, \$13.28 for oats and from \$6.63 to \$10.30 for brome-alfalfa hay, depending on the number of successive hay crops in given rotations (table A-2 in Appendix A). These data were assumed to be applicable to all soil and field conditions found in the Nepper Watershed.

Calculations of fertilizing expense added \$12.90 per hundredweight of nitrogen applied and \$7.50 per hundredweight of available phosphorous applied at a uniform spreading cost of \$1.38 per acre. Hauling of corn and oats was charged at \$0.05 per bushel, with baling, hauling and storing of hay aggregated at \$2.72 per ton.

Costs of installing level terraces designed to retain 2 inches of runoff were estimated as they prevailed in 1947. A cost of \$0.04 per linear foot based on locally contracted bulldozer construction was assumed representative for all slopes that might be terraced. Terracing costs per acre thus depended on linear footage requirements varying with field slopes (table A-3 in Appendix A).

The effect of vegetated terrace backslopes in voiding productive areas on field slopes greater than 15 percent was considered by reducing budgeted gross farm returns and variable costs in proportion to the percentage of terraced areas necessarily occupied by the permanent sod. The expense of maintaining terraces, other than the costs of owning special implements for farming terraces, was computed with reference to estimated rates of channel siltation. Results for various land-use systems and field conditions are given in tables A-4 and A-5 of Appendix A.

Structural installation costs — including planning, construction and required rights-of-way — were also dated to 1947. They represented actual costs of installing a series of structures the following year under the Little Sioux Flood Control Program. Detailed design and cost data for individual structures are presented in Appendix A, tables A-6, A-7 and A-8.

Additional valuation problems were associated with reductions in gully and flood damage. As indicated by the description of predevelopment conditions (and by Appendixes B and C), all such damages were evaluated initially as average annual amounts resulting from continuation of the 1947 predevelopment land-use systems through 1997. Damages were then related to specified hydrologic variables (item 1, table 4) which could be modified either by changes in land use or by water-control structures. Damages estimated per unit value of the hydrologic variables observed under predevelopment (item 8, table 4) were conversely taken as benefits obtained per unit reduction in the relevant variables. For example, gully-control benefits of land treatment were estimated as reductions in gully damage per unit reduction of the runoff indexes from predevelopment values, while gully-control benefits of structures were directly the reduction in damage per unit of peak flow reduction attributable to structures.

[13] The interrelation of the problems of determining the economic feasibility of measures and of allocating costs on these criteria is illustrated by tables D-2 and D-3 of Appendix D. The two problems must be resolved jointly with reference to possible differences in participant planning horizons and/or discount rates—two variables which influence both the absolute and proportionate present values of gross benefits, costs and net benefits.

[14] Estimates of average future prices of farm commodities and production factors given in this section, as well as specific conditions on which the estimates are based, were taken from the following pamphlet prescribed for use of federal agencies engaged in watershed and river-basin studies: United States Department of Agriculture, Agricultural Marketing Service and Agricultural Research Service. Agricultural price and cost projections for use in making benefit and cost analyses of land and water resource projects. Washington, D. C. Sept. 1957.

TABLE 6. SELECTION OF ALTERNATIVE LAND-TREATMENT ACTIVITIES FOR 27 FIELDS WITHIN THE NEPPER WATERSHED.

Conditions for selection as watershed-treatment activities	Number of systems Added	Deleted	Remaining
1. Entire range of feasible systems	1,359	0	1,359
2. Annual erosion less than 5 tons per acre	0	928	431
3. Corn relatively frequent	0	246	185
4. Maximum on-farm returns per acre	0	152	33
5. Maximum on-farm returns to capital	19	0	52
6. Minimized sheet erosion	23	0	75
7. Net benefits (over predevelopment)	0	6	69
8. Maximum net benefits	0	38	31
9. Maximum net benefit per unit cost	16	0	47
10. Alternative watershed-treatment activities	0	0	47

LAND-TREATMENT DELIMITATION

Land treatment of any field was defined as any transition to other feasible land-use systems from the system prevailing in 1947, the benchmark of all the benefit-cost evaluations. But to isolate the entire range of alternative economic land-treatment measures competing for development resources in 1947 would have required a detailed benefit-cost analysis of all land-use systems agronomically feasible within the Nepper Watershed. By concentrating on fields within farms as land-treatment units, measures thought to represent a reasonable range of treatment possibilities were delimited as shown in table 6 and described in the following paragraphs.

Land-use systems considered feasible on each field identified in fig. 2 were those combinations of rotations, conservation practices and fertilizer treatments derived from the following assumptions made with respect to agronomic feasibility on the particular soil-slope conditions in fig. 1:

Feasible rotations. Seven cropping methods or crop rotations—ranging from continuous corn to continuous meadow—were considered feasible on all watershed fields. These were designated as CCCC, CCCO, CO_c, CCOM, COMM, COMMMM and MMMM.[15]

Conservation practices. All field slopes exceeding 2 percent could be contoured. Terracing also was included as an element of land-use systems and was considered feasible on all field slopes exceeding 3 percent, except for the Napier 3-5 percent slopes adjacent to drainageways where seepage might occur. Terraceable areas are stippled in fig. 2. Only level terraces of 2-inch runoff-retention capacity were considered.

Fertilizer treatment. It was assumed that all fields (a) could not be treated with commercial fertilizer, (b) could be treated with moderate applications of nitrogen and phosphorous or (c) could be treated with heavy applications, except that the latter would be unnecessary on successive meadow. Recommended rates of application would vary with soil-slope conditions, legume intensity as indicated by rotations and, to some degree, with tillage practices.

Associated yields and fertilizer inputs. Yields of corn, oats and brome-alfalfa hay expected under the various agronomically feasible systems were derived from estimates prepared for each of the 11 watershed soil types mapped in fig. 1. Such estimates are given in Appendix A, table A-1 for the predominant soil only. The estimates reflect timely farming operations, the use of adapted varieties, average weather and a maximum 10-year transitional period between yield levels of alternative systems. Supporting sources included local assessors' estimates, census records, tillage trials at the Western Iowa Experimental Farm, cooperative field trials with farmers and the 1950 Monona County Soil Survey. Recommended rates of nitrogen and/or phosphorus application also are given in table A-1 for the predominant soil.

RESULTS OF THE DELIMITING PROCESS

When all assumptions concerning feasible rotations, practices and fertilizer treatments were applied to every watershed field on the basis of contained soils, 1,359 land-use systems were feasible and initially considered, as shown in the first line of table 6.

To reduce the number of feasible land-use systems in the analysis, the first criterion applied to every farm field was that any system (except the predevelopment system) would be eliminated from further consideration if it would result in annual sheet erosion in excess of 5 tons per acre. As indicated in table 6, 928 systems were eliminated by this criterion.

Additional criteria then applied included a relative frequency of corn subject to the above 5-ton erosion-control standard, maximum farm returns per acre, maximum farm returns per dollar of total production cost and minimum erosion losses. As shown in table 6, the latter criterion left 75 land-treatment measures (about three per field) to be given detailed benefit-cost study from a watershed viewpoint. Six of these were eliminated as economically infeasible. Two added conditions were then arbitrarily imposed in selecting the land-treatment measures finally considered. These conditions were that the measures considered for each field would necessarily have to yield (1) maximum net benefits and/or (2) a maximum ratio of benefits per unit outlay.[16] Column 3 in table 6 indicates the number of systems remaining for evaluation as each criterion for elimination was applied. Forty-seven new systems (from 1 to 5 per field), *plus* the 27 predevelopment systems (1 per field) were retained for eventual planning consideration. Details of successively enforcing the series of elimination criteria are given for one field in Appendix D.

Aggregate benefits, costs, rates of return and fields associated with each of the 47 land-treatment measures are listed in table 9. The 27 corresponding fields were then defined as land-resource subclasses of the

[15] C = corn, O = oats, O_c = oats with clover catch crop, and M = brome-alfalfa meadow or pasture.

[16] In table 6, the final conditions were applied to 69 systems providing net benefits. Field units 2-1 and 7-4 (the floodplain) were excepted; the former to permit further comparison of the three measures appraised in Appendix D, tables D-2 and D-3, and the latter to compare five alternative floodplain land-use adjustments with possible continued flooding.

total watershed productive area of 442 acres susceptible to treatment. In this sense, they represented restrictions on land resources available for obtaining development benefits.

The specific nature of treatments is indicated by columns 4 and 5 in table 9. As shown in table 9 and fig. 2, for example, a CCOM rotation with no conservation and fertilization practices was the system prevailing in 1947 on field 1-1. The conditions listed in table 6 reduced the range of feasible systems given planning consideration to a single alternative—a shift to a continuous corn cropping system involving terracing and heavy applications of nitrogen and phosphorous. Gross benefits of $191 would have accrued jointly to farm 1 and the offsite area, as the field is located only within sector 0.[17] Proportionate sharing of $60 in increased costs thus would have yielded net return rates of $2.18 for farm 1 and the downstream public interest. Data in table 9 for field unit 2-1, contributing to four classes of watershed damages, are drawn from table D-4 in Appendix D.

Analysis of Structural Improvements

Six major structural improvements were considered as alternatives to land-use changes for controlling excess runoff contributing to gully and flood damage. These included four gully-control structures in the main drainage, a single structure having the same function in the southwest drainage, a structure to replace the frequently damaged Monona County bridge and three structures, including a levee system, designed to control floodplain crop damage.

Detailed design specifications utilized in estimating inputs and outputs of each structure or structure-combination are given in Appendix A, table A-6. Requirements for labor and materials in actual construction are included in contract-constuction costs, with land requirements given as site areas. Table A-7 lists all resource requirements in terms of capitalized cost, with some of the facilities listed in table A-6 redefined as measure-groups. The basis for grouping certain of the facilities listed singly in table A-6 was their apparent interdependence in flood control, in gully control or in both.

Benefits of structures were determined on the basis of their effectiveness in modifying the hydrologic variables with which predevelopment damages were associated. Gully-control benefits would have resulted from any reductions in peak discharge rates associated with land destruction in the main or southwest drainageways. An exception was the full-flow road chute designed as measure I which, so far as its gully-control features were concerned, would merely have stabilized the head of the main gully. As only onsite flood-control functions of structures were considered, corresponding benefits would have resulted either from seasonal control of runoff volumes affecting the Monona County bridge or from seasonal control of overflow flooding bottomland crops.

In Appendix A, table A-8, design data for each facility of table A-6 were converted into a form applicable to independent measures. In table A-9, these specifications are then given on a constant average or incremental unit basis; data required for analyzing other scales of installation were not available. Table 7 illustrates the derivation of annual benefits per installation increment for each structural measure with regard to its single- or multipurpose functions.

Structural measures were evaluated for economic feasibility, as shown in table 8. The feasibility criteria were the same as those applied with respect to land-

TABLE 7. INCREMENTAL BENEFITS OF STRUCTURAL IMPROVEMENTS DISTRIBUTED BY PURPOSES.

Major purposes	Units	I Upper road chute	II Main drainage group	III Levee system	IV Southwest drainage group
Installation increment	earth fill	1,000 cu.yds.	1,000 cu. yds.	1 foot height	1,000 cu. yds.
Incremental hydrologic control, by purposes[a]					
Gully control; by drainages	cu. ft. sec.	same	7.00	...	5.00
Flood control at county bridge	ac. ft.	1.78	...	...	...
Flood control for floodplain	ac. ft.		1.22	5.57	1.48
Damage per control unit, by purposes					
Gully control; by drainages	dollars	3.31[b]	0.47[c]	....	0.49[d]
Flood control at county bridge	dollars	20.51[e]	...	....	...
Flood control for floodplain	dollars		86.59[f]	86.59[f]	86.59[f]
Incremental benefits, by purposes[g]					
Gully control; by drainages	dollars	3.31	3.30	...	2.50
Flood control at county bridge	dollars	36.56	...	...	...
Flood control for floodplain	dollars		105.26	481.36	128.11
All purposes	dollars	39.87	108.56	481.36	130.61

[a] From table A-9 in Appendix A.
[b] Equivalent to 34 percent of gully damage in the main drainage ($101 in table 4) divided by the 10.50 increments installed in 1948 (table A-8 in Appendix A).
[c] Gully damage in the main drainage ($101 in table 4 and point A, fig. B-3 in Appendix B) divided by 215 cubic feet per second (point A, fig. B-1 in Appendix B).
[d] Gully damage in the southwest drainage ($36 in table 4) divided by 72 cubic feet per second, the peak discharge value corresponding to a runoff index of 47 in 1947.
[e] From table 4.
[f] Equivalent to damage per unit overflow of $86.59 in table 4.
[g] Computed as products of units of hydrologic control and damage averted per control unit.

TABLE 8. INCREMENTAL BENEFITS AND COSTS OF STRUCTURAL IMPROVEMENTS DISTRIBUTED BY PARTICIPANTS.

Installation increments and participants	I Upper road chute	II Main drainage group	III Levee system	IV Southwest drainage group
Installation increment	1,000 cu. yds.	1,000 cu. yds.	1 ft. height	1,000 cu. yds.
Benefits distributed by participants (dollars)				
Onsite farmers	3.31	103.56	481.36	130.61
Monona County	36.56	0.00	0.00	0.00
Total[a]	39.87	108.56	481.36	130.61
Distributed installation outlays (dollars)[b]				
Onsite farmers	105.48	996.26	1,314.75	1,116.70
Monona County	1,630.22	0.00	0.00	0.00
Total	1,735.70	996.26	1,314.75	1,116.70
Distributed equivalent annual costs (dollars)[c]				
Onsite farmers	5.27	55.10	106.79[d]	61.71
Monona County	58.09	0.00	0.00	0.00
Total	63.36	55.10	106.79	61.71
Annual net benefits distributed by participants (dollars)				
Onsite farmers	–1.96	53.46	374.57	68.90
Monona County	–21.53	0.00	0.00	0.00
Total	–23.49	53.46	374.57	68.90
Benefits per unit cost	0.65	1.97	3.50	1.11

[a] From table 7.
[b] Totals from table A-9 in Appendix A. Installation costs of the road chute were distributed in proportion to benefit present values, with a private discount rate of 5 percent and a Monona County rate of 2½ percent.
[c] Includes amortized installation outlays and required maintenance estimated in table A-9.
[d] Also includes $31.48 in increased offsite flood damage associated with onsite levee construction, which the benefiting onsite farmer would willingly pay as compensation to offsite parties damaged.

[17] Annual on-farm benefits of increased crop values would have been $189 and offsite flood-control benefits about $2.

TABLE 9. BENEFITS AND COSTS OF ALTERNATIVE LAND-TREATMENT ACTIVITIES AND STRUCTURAL ACTIVITIES FOR THE NEPPER WATERSHED.

Field units	Program disposal code	Land supply (acres)	Initial system (coded)	Watershed land-treatment activities: Alternative systems (coded)	Program code	Unit costs (dollars)	Unit net benefits (dollars)	Net benefit ÷ costs (dollars)
(see fig. 2)	(P_j)	(P_0)		(See fig. 2)	(P_j)	(a_j)	(c_j)	(d_j)
1-1	j=51	4.3	400	122	j=1	60.23	131.35	2.18
2-1	52	6.0	100	322	2	61.02	321.23	5.26
				122	3	129.65	409.51	3.15
				700	4	9.60	280.95	29.26
2-2	53	10.5	100	522	5	111.92	534.74	4.77
2-3	54	2.4	100	420	6	6.27	96.82	15.44
				222	7	36.40	117.88	3.23
3-1	55	30.4	300	422	8	489.12	616.33	1.26
				322	9	324.91	570.35	1.75
3-2	56	11.7	300	522	10	150.95	455.75	3.01
				422	11	191.07	524.61	2.74
4-1	57	16.6	700	522	12	237.43	59.40	0.25
4-2	58	7.6	700	522	13	116.41	27.45	0.23
4-3	59	13.9	700	522	14	173.16	77.07	0.44
				521	15	130.21	57.89	0.44
4-4	60	4.5	100	422	16	55.06	192.50	3.49
				521	17	8.25	184.44	22.35
4-5	61	5.6	100	522	18	40.58	260.41	6.41
5-1	62	3.3	100	321	19	21.45	23.04	1.07
				421	20	29.30	25.26	0.86
5-2	63	12.4	700	421	21	159.33	43.87	0.27
				422	22	236.04	53.03	0.22
5-3	64	13.3	300	420	23	36.85	91.71	2.48
				422	24	167.41	219.16	1.30
5-4	65	19.8	200	100	25	18.81	130.87	6.95
					26	334.02	654.39	1.95
6-1	66	12.8	400	121	27	134.94	338.75	2.51
				122	28	182.06	417.20	2.29
6-2	67	27.6	400	420	29	38.54	335.18	8.69
				421	30	187.10	494.08	2.64
6-3	68	15.5	400	521	31	84.39	274.33	3.25
				422	32	214.16	413.42	1.93
6-4	69	4.4	600	700	33	7.46	49.74	6.66
				122	34	59.40	15.92	0.26
6-5	70	19.0	600	522	35	180.08	382.93	2.12
6-6	71	17.1	400	421	36	121.14	333.13	2.74
6-7	72	43.9	400	122	37	656.20	1,445.22	2.20
6-8	73	8.2	400	122	38	124.46	278.83	2.24
				322	39	51.44	113.69	2.21
7-1	74	20.8	700	122	40	449.68	673.05	1.49
7-2	75	36.6	400	420	41	46.51	319.80	6.87
7-3	76	22.5	200	402	42	214.87	298.57	1.38
7-4	77	41.6	200	102	43	701.79	180.25	0.25
				402	44	370.66	389.03	1.04
				502	45	329.47	588.98	1.78
				602	46	320.32	741.65	2.31
				701	47	70.30	1,344.89	19.10

Structural measures	Program disposal code	Earth-fill height or supply (1,000 cu. yds.)	Watershed structural-treatment activities: Program code	Land inputs, by field units: 6-7 (acres)	7-3 (acres)	7-4 (acres)	Unit costs (dollars)	Net benefit (dollars)	Net benefit ÷ costs (dollars)
(see table 8)	(P_j)	(P_0)	(P_j)				(a_j)	(c_j)	(d_j)
II .... (main group)	j=78	40.85	j=48	0	0.051	0	55.10	53.46	0.97
III .... (levees)	79	6 ft.	49	0	0.175	0.175	106.79	374.57	3.50
IV .... (southwest group)	80	14.40	50	0.184	0	0	61.71	68.90	1.11

treatment measures. That is, aggregate benefits per installation unit had to exceed costs per unit, and benefits to individual beneficiaries had to exceed assigned costs, with costs assigned proportionately with benefits among beneficiaries and with compensated damages included as costs. All structural measures that met these criteria, regardless of the magnitude of their benefit-cost ratios or net benefits, were accepted as alternatives to land-treatment activities for obtaining watershed development benefits. As indicated in table 8, all structural measures except the road chute (measure I) were economically feasible when benefits and costs to farmers and Monona County were capitalized over a 50-year period at 5 and 2½ percent, respectively.

Planning data for the three structural measures yielding net benefits are given in the lower section of table 9. These data are comparable to those given previously for land-treatment measures. Restrictions on size of structures effectively limited capacities of structural measures for water control and consequent flood or gully damage-reduction benefits. The given limits on structure size were taken as earth-fill volumes actually installed in the 1948 Little Sioux Program for measures II and IV and as levee bank height for measure III. These are indicated by the final item of table A-8 in Appendix A. Design and cost data presented in table A-9 include estimated land or site-area requirements per unit of earth fill or bank height. The site requirements were transferred to table 9 as land inputs of alternatives 48, 49 and 50.

LINEAR PROGRAMMING AS A PLANNING TECHNIQUE

In view of the objective of combining watershed-treatment measures to maximize discounted net benefits, the planning problem in 1947 in the Nepper

Watershed was reduced to the following question: How could the 47 land-treatment measures and the 3 structural measures listed in table 9 have been so combined in 1947 and continued over a 50-year (1947-97) project period? This problem was solved by linear programming techniques.

Activity Unit Levels and Basic Assumptions[18]

Because the "activity-at-unit-level" concept is fundamental to linear programming, unit levels of the land-treatment and structural activities considered for the Nepper Watershed were defined as follows:

1. The unit level of any land-treatment measure designated in table 9 as P_1 through P_{47} was taken as the given measure applied over 100 percent of the relevant field area. Areas are tabulated in the P_0, or land supply, column. The benefit-cost data of the columns labeled a_j, c_j and d_j thus applied to entire field areas.[19]

2. The unit levels of the structural measures listed in table 9 as P_{48} through P_{50} were taken as installation increments indicated under P_0. The unit levels of measures II and IV, for instance, were 1,000 cubic yards of earth fill, and the unit level of measure III was 1 foot of levee bank height. Constant per-unit benefit-cost data for structures are given in table 8. A unit-level net loss of $23.49 for measure I in table 8 explains its absence from table 9. Additional design and cost data on structures, including land inputs from fields 6-7, 7-3 and 7-4, are given in Appendix A, table A-9.

Linearity. The major assumption of linear programming is that inputs and outputs related to alternative activities are proportional to (or a linear function of) activity levels. As applied to land treatment in the Nepper Watershed, the assumption meant that if treatment of 100 percent of a field containing 20 acres would have provided an annual benefit of $50 at a cost of $20, treatment of 50 percent, or 10 acres, would have provided an annual benefit of $25 at a cost of $10. It follows that the average and marginal benefit in both cases would have been constant at $2.50 per dollar of cost and at $2.50 per acre treated.

Applied to a structural measure such as P_{48} in table 9, the linearity assumption specified that for each added 1,000 cubic yards of earth fill, measure II would occupy an added area of 0.051 acre in field 7-3 otherwise utilizable for crop production; program costs would be increased by $55.10, gross benefits by $108.56 and net benefits by $53.46. These data would be reduced by 50 percent to obtain the effects of a 500-cubic yard increment of earth fill.

The linearity assumption added implications for proportional cost-sharing arrangements. In table 9, the unit-level annual costs of activity P_3 were given as $129.65 and net benefits as $409.51. Total benefits amounted to $539.16. Table D-3 in Appendix D indicates the distribution of unit-level benefits and costs of the activity between farmer-beneficiaries and Monona County. If the activity had been undertaken on only 3 acres of field 2-1, and not over the total area of 6 acres, all absolute annual and present-value amounts in table D-3 would have been reduced correspondingly by 50 percent. The terrace installation outlay (item 14) charged to benefiting farmers would have been reduced to $52.235 from $104.47 and that charge to Monona County reduced to $5.575 from $11.15. The percentage benefit distributions of item 12 and the net benefit-cost ratios of item 17 would have remained unchanged, maintaining proportionality.

Divisibility. Divisibility referred to the possibility of continuously increasing or decreasing the level of treatment activities. That is, a land-treatment activity level could have ranged continuously from 0 to 100 percent, rather than only by selected discrete levels of 0, 25, 50 or 100 percent.

Similarly for structures, an optimal combination of all activities might have suggested that levees (activity P_{49} in table 9) be built to a height of 4.75 feet, a height estimated from table 7 to annually divert (4.75) (5.57) = 26.45 acre-feet of floodwater originating on watershed uplands away from the floodplain and into the Maple River. From tables 8 and 9, corresponding total annual benefits would have been (4.75) ($481.36) = $2,286.46; annual costs (4.75) ($106.79) = $507.25; and net benefits $1,779.21. The required installation outlay borne entirely by farm 7, the sole beneficiary, would have totaled (4.75) ($1,-314.75) = $6,245.06 (from table 8). In practice, however, the height of the levee would likely have been increased to 5 feet.

In the absence of information to the contrary, each unit of earth fill in the dams and each foot of height of the levee were assumed to divert equal volumes of flood runoff. This indicates a weakness of linear programming when applied to structures designed on the basis of hydrologic events. In most instances, the lower portion of a dam or levee prevents a greater proportion of total potential damage over a long period than does the upper portion of the dam or levee. This occurs because of the greater frequency of storms of lesser severity.

Additivity. This could be termed an assumption of activity independence, in that the total input-output effects of combining certain activities would be obtained by summing effects attributable to each activity if conducted alone at the specified combination level. Thus, fertilizing the upper portions of a sloping field was assumed not to enhance yields on untreated portions of the field. Also, although terracing steeper slopes would have decreased per-acre erosion rates over lower unterraced slopes as well as terraced areas, through an effective reduction in slope length, the effect was ignored.

Finiteness. This required use of the unique-activity concept to specify a limited number of treatment

[18] For a detailed discussion of the basic assumptions of linear programming and their mathematical and economic significance, see: Robert Dorfman. Application of linear programming to the theory of the firm. University of California Press, Berkeley, Calif. 1951. pp. 18-25, 77-85.

[19] By dividing the columns a_j and c_j by the respective acreages under P_0 unit levels of land treatment could also have been defined in per-acre terms. The text interpretation was adopted to avoid manipulation of extremely small per-acre amounts of associated costs and benefits, particularly offsite benefits.

possibilities within a treatment continuum for each watershed field and the total watershed area. Although the land-treatment continuum for each field included many alternative shifts from the system followed in 1947, only those systems designated as activities P_1 through P_{47} were considered for programming.

Applied to inputs, finiteness specified that the quantities of at least some resources required to carry out the 50 land and structural treatment measures would be restricted. Otherwise, the scope of development projects would be unlimited[20] and the programming method superfluous.

Activity Restrictions

These referred mainly to limits on the intensity of land-treatment and structural activities imposed by fixed quantities of land, labor and capital resources plus maximum structure capacities imposed by engineering considerations.

Land. The unit-level definition of land treatment given previously indicated the land limitations to be the respective areas of each field possibly treated. That is, no land-treatment activity could be undertaken at more than its unit level—or on more than an entire field. Also, intensities of combined land treatment or nontreatment of the same field, measured as a percentage of the entire field area, could total no more than 100 percent. Nor could respective area percentages involved in treating or not treating some portions of fields and utilizing other portions as structure sites total more than 100 percent. Twenty-seven land-supply limitations were consequently denoted by P_{51} through P_{77} in column 2 of table 9, with watershed and farm location noted in column 1 and field areas in column 3. When such land-supply limitations are considered, it follows that net program benefits would be limited eventually by each watershed field being treated for maximum returns per acre.

Labor. Although some land-treatment activities which appeared promising in the Nepper Watershed in 1947 would have required more inputs of farm labor and some less, labor was presumed to be nonlimiting. That is, assumed adoption of labor-intensive treatments on each field was found to, on balance, require no more labor inputs than were currently not being utilized on each farm. The elimination of labor as a programming restriction was based upon 1947 labor-use estimates as computed from the per-acre requirements of table A-2 in Appendix A and the corresponding land-use pattern of fig. 2.

Maximum structure size. These restrictions were designated as P_{78} through P_{80} in column 2 of table 9. They specified that the total earth-fill volume of structures combined as the main drainage group could not exceed 40,850 cubic yards; the levees protecting the watershed floodplain from upland runoff could not exceed a height of 6 feet, and the total earth-fill volume of the measure termed the southwest drainage group could not exceed 14,400 cubic yards. The limits were equivalent to volumes or heights of the structures actually installed in the 1948 Little Sioux Program. They were assumed to approximate water-control capacities required for complete elimination of gully damage, as well as flood damage on the watershed floodplain, ignoring for the moment any reductions credited to treatment of upland fields.

Required capital outlays. All treatment activities were restricted by the present value in 1947 of immediate and recurring outlays necessary to initiate and continue land-use changes or to install and maintain structures over the project period. These amounts are given in table 9 for each activity at its unit level under the column headed a_j. They were computed as annual equivalents of capitalized cost.[21]

If program costs were of interest only in computing discounted net benefits and assigning costs among beneficiaries, rather than also in influencing planning decisions, the treatment activities P_1 through P_{50} of table 9 could have been combined subject only to the land-area and structure-capacity restrictions P_{51} through P_{80}. Except where field areas would also serve as structure sites (fields 6-7, 7-3 and 7-4), land treatment would be feasible on all fields, and the particular activity exclusively promoted on each field could have been taken as that yielding maximum net benefits per acre. The programming problem would have then been confined to structure sites and the relevant noncapital limitations. Such an approach, however, would have bypassed the problem of allocating limited capital outlays.

To demonstrate project formulation under conditions of both limited and unlimited capital, activities were combined with reference to their ratios of annual net benefits per dollar of capitalized cost converted into its annual equivalent.[22] In table 9, such ratios for each activity considered independently are tabulated in the final column as the d_j values. Even when capital is considered a continuous variable, however, the maximum capital outlay of interest was that outlay at which discounted program benefits could not be further increased, or the outlay at which discounted marginal benefits would be equivalent to discounted marginal expenditures.

Partial and General Aspects of Solutions

The problem of combining watershed-treatment measures to maximize aggregate net benefits subject to the specified restrictions had two major facets. The first concerned optimal allocations of development resources between or among competing land-treatment and/or structural measures for the same watershed field or treatment site. The utility of linear programming in dealing with this question is demonstrated in Appendix E.

[20] This follows from the linearity feature of programming, which indicates that if an activity would yield net benefits at its unit level, net benefits could be increased indefinitely by increasing the activity level.

[21] Computation of a_3 = \$129.65 is illustrated in Appendix D, table D-3, item 15.

[22] Adding or substituting activities in descending order of their opportunity net benefits to capital was a variation of programming developed by Wilfred Candler. See: A modified simplex solution for linear programming with variable capital restrictions. Jour. Farm Econ. 38:940-955. 1956.

The second facet involved the extension of principles useful in dealing with the first to the simultaneous allocation of resources among competing activities within and among fields and, hence, within and among farms or throughout the watershed. In terms of the programming principles illustrated in Appendix E and the benefit-cost data of table 9, an optimal intensity of watershed land treatment would be indicated by optimal levels of activities P_1 through P_{47}. Optimal structure capacities would be indicated by optimal levels of P_{48} through P_{50}. Because the unit-level benefit-cost data of the columns a_j, c_j and d_j of table 9 were based on detailed input-output evaluations relating to systems of land use, crop yields, erosion control, flood control and gully control, a specification of activity levels maximizing net benefits would call for simultaneously the patterns of farm and watershed land use, combinations of program purposes and interparticipant distributions of benefits and costs that would be consistent with optimal development programs.

ALTERNATIVE DEVELOPMENT PROGRAMS FOR THE NEPPER WATERSHED

Results of the programming analysis are presented as three types of watershed programs based on capital availability: (1) programs of very limited scope because of severe capital restrictions; (2) programs of expanded scope with increased, but still limited, outlays and (3) a program limited only by the availability of noncapital resources or by technological restrictions.

TYPE A: CRITICAL AND LIMITED PROGRAMS

In ordinary terms of watershed protection, critical measures are frequently recommended as the land-use changes or structural improvements most effective in alleviating a single critical physical damage problem. In this study the critical nature of treatment activities was measured by the magnitude of the marginal rates of return in providing aggregate economic benefits. Two subtypes of critical programs discussed are (1) treatment of upland areas to increase crop production and/or reduce consequent flood or gully damage and (2) land-use adjustments on the Nepper Watershed floodplain to increase net crop values under conditions where flood volumes were not completely eliminated.

UPLAND TREATMENT

Under conditions of severely limited capital, activity P_4 in table 9 would appear to have had first priority in a 1947 development program for the Nepper Watershed. Its marginal net returns per unit of expenditure were $29.26, a rate higher than for any other watershed treatment measure or structure. The activity involved a steeply sloping field cropped to continuous corn—field 2-1 in fig. 2. No terracing or other conservation measures were being practiced; consequently, runoff and erosion from this field were serious.

Referring to Appendix D, table D-2, it was estimated that shifting land use on field 2-1 from continuous corn to permanent meadow would have reduced average annual overflow by 1.5 acre-feet (see item 4, Section B, column 700, table D-2). This reduction would have increased estimated annual net returns on the watershed floodplain by about $130, an amount computed as the product of the 1.5 acre-foot reduction and $86.59, the latter being the unit value of such reductions (from table 4, item 8).

Again referring to table D-2, the same change in land use would have increased gross returns on the field itself by $101 (item 1) and reduced production costs by $26 (item 2). Moreover, Monona County would have benefited from a 1.5 acre-foot reduction in average annual runoff to the extent of about $31 saved on costs of bridge maintenance (item 5). Gully-control benefits of $1.47 (item 3) divided among farms 2, 3, 4 and 6 would have been minor.

The sum of itemized annual benefits, $290.55, would have been obtained for a discounted expenditure of $185.76 (item 9). On the basis of proportional benefits and discount rates appropriate for the farmer-beneficiaries and Monona County, the latter amount was converted into an annual equivalent cost of $9.60 and distributed as shown in table D-4. The cost and return data for activity P_4 as the first feasible program, program A, are also given in table 10.

For an additional annual outlay of $8.25, P_{17} as the second marginal activity in table 10 would have returned $184.44 in annual net benefits, or $22.35 per unit outlay, and could also have been termed a critical activity. This activity would have involved adoption of a COMM-terrace fertilizer system on field 4-4 (4.5 acres), which was also in continuous corn in 1947.

FLOODPLAIN USE ADJUSTMENTS

A study of methods of adjustment on the floodplain field 7-4 (41.6 acres) illustrates both some advantages and some pitfalls in the use of linear programming. Solutions obtained through linear programming, as with any mathematical procedure, can be no more accurate than the information on which they are based. Nearly all of this study is based on estimates. Some of these are fairly reliable, but many are based on scant information. Data on flooding probabilities and the effect of flooding on different crops are in the latter category.

Using the best information available on returns from different land-use practices on the floodplain, however, it appears from fig. C-2 in Appendix C that, with the predevelopment CCCO-F_0 cropping system, net income was —$6.50 per acre. While income under the predevelopment (zero) level of flood control was probably low, it is doubtful the land was actually being farmed at a loss.

Under the assumptions given in table C-5 in Appendix C pertaining to the relative damage to different crops from flooding, it is apparent from fig. C-2 that the most profitable use for the floodplain field with no flood control would have been permanent meadow (point A on the MMMM-F_1 curve), which is shown to yield a net income of about $26 per acre. In actual practice it is likely that if this area were too subject to flooding to be used for corn, it would have been

TABLE 10. ALTERNATIVE DEVELOPMENT PROGRAMS FOR THE NEPPER WATERSHED, BASED ON BENEFIT-COST APPRAISALS OF ALTERNATIVE ACTIVITIES AND DERIVED THROUGH LINEAR PROGRAMMING.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Program formulation			Marginal activities			Cumulative (program) activities			
Steps or programs	Activity added (code)	Activity deleted (code)	Added level (units)	Cost	Net benefits	Net ÷ cost	Cost	Net benefits	Net ÷ cost	Total benefits
	(P_j)[a]	(P_j)[a]				(6)/(5)	Σ(5)	Σ(6)	(9)/(8)	(8)+(9)
1(A)	4	52	1.00	$ 9.60	$ 280.95	$29.26	$ 9.60	$ 280.95	$29.26	$ 290.55
2	17	60	1.00	8.25	184.44	22.35	17.85	465.39	26.07	483.24
3-17	..		..	2,573.00	5,963.00	2.31	2,591.00	6,428.00	2.48	9,019.00
18	9	55	1.00	324.91	570.35	1.75	2,916.00	6,998.00	2.40	9,914.00
19	26	25	1.00	315.21	523.52	1.66	3,231.00	7,522.00	2.33	10,753.00
20	40	74	1.00	449.68	670.60	1.49	3,681.00	8,193.00	2.23	11,874.00
21(B) ...	35	70	0.14[b]	25.92	38.00	1.46	3,706.00	8,231.00	2.22	11,937.00
21-33 ...				236.03	35.29	0.10	5,363.00	9,644.00	1.80	15,007.00
34	13	58	1.00	116.35	11.65	0.10	5,480.00	9,656.00	1.76	15,136.00
35(C) ...	12	57	1.00	237.25	11.73	0.05	5,716.00	9,668.00	1.69	15,384.00

[a] Activities coded $P_j = 1, 2, \ldots 50$ denote "real" land-treatment or structural measures, while $P_j = 51, 52, \ldots 81$ denote disposal vectors for restrictions.
[b] Activity P_{35} was brought in at only 14 percent at step 21 to limit program B to a cost of $3,706 as described in the text.

used for pasture rather than for meadow. Returns probably would have been about the same under either system.

Again assuming some empirical validity in the estimates, the floodplain field 7-4 can be taken to illustrate advantages of linear programming in guiding floodplain management decisions. If flooding were uncontrolled, it appears that the best procedure would have been to shift from corn to meadow or pasture. The shift would then rank as the third treatment activity (P_{47} in table 9) given priority, because with average annual overflow reduced only 7.40 percent by upland treatment (or to 29.96 acre-feet from 32.36 acre-feet), no other floodplain cropping system would have been more profitable than improved pasture or permanent meadow. Figure C-2 indicates that a reduction in the average annual overflow volume to 9 acre-feet would have been necessary to justify a shift to heavily fertilized continuous corn rather than to pasture or meadow.

Type B: Intermediate Optimal Programs

Although they are not described for each farm or field, these programs were related to annual outlays ranging from $9.60 for program A to a maximum justified annual outlay of $5,716 for program C (step 35 in table 10). Optimal land-use conditions, associated damage reductions and degrees of hydrologic control corresponding with net benefit maximization are shown graphically for the entire relevant outlay range.

OPTIMAL LAND USE

The relation of Nepper Watershed cover conditions and adoption of conservation practices to maximize discounted net benefits are shown in fig. 3. The watershed area in corn and oats would have declined and that in meadow would have increased as severely limited development capital was allocated optimally, as in programs of Type A. At higher capital availabilities, however, optimal cover conditions would depend upon the degree to which capital-using conservation practices or water-control measures entered into solutions. The programming analysis (see program B, fig. 3) indicated that, if an annual outlay of $3,706 had been allocated to maximize aggregate net benefits at $8,231, the watershed area in corn could have been increased to 64 percent from the 53 percent

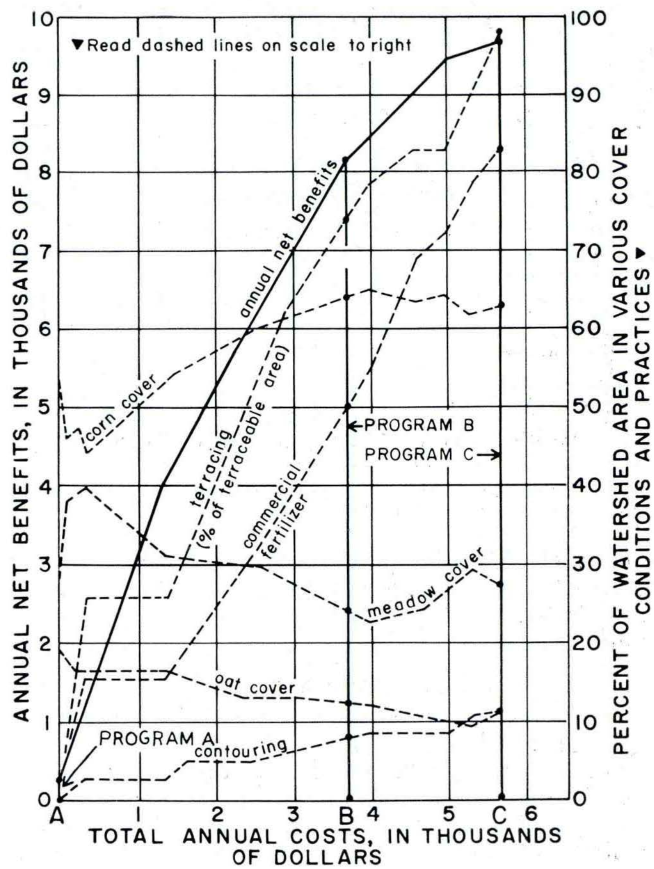

Fig. 3. Watershed cover conditions and land-use practices consistent with optimal development programs.

noted under predevelopment. The area in oats would have been decreased to about 12 percent from 19 percent under predevelopment, and meadow would have been decreased to 24 percent from 28 percent. Part of the increase in corn would have been profitable by construction of a 4-foot levee to protect the watershed floodplain from overflow volumes only partly reduced by upland treatment.

As successively greater outlays were assumed to have been available, further adjustments in the acreage of corn would have been associated chiefly with increased application of fertilizer and additional terraces. In general, alternate increases and decreases in corn, oats and meadow percentages betwen annual outlays of about $3,706 and the maximum justified

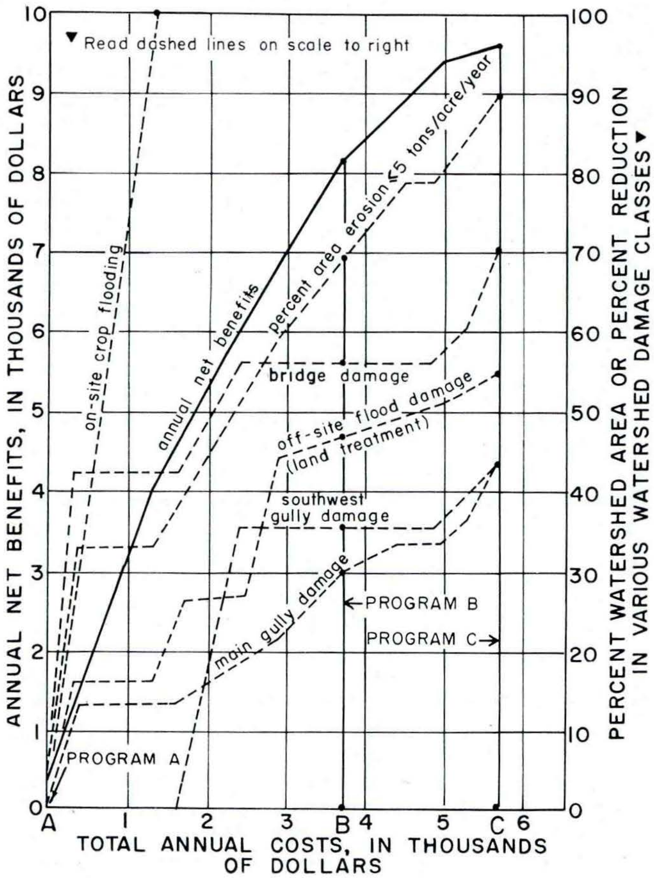

Fig. 4. Reductions in various classes of watershed damages consistent with optimal development programs.

outlay of $5,716 in fig. 3 would have been explained by treatments yielding maximum returns to land being substituted for those yielding maximum returns to development capital.

OPTIMAL DAMAGE REDUCTION

While fig. 3 describes the physical character of optimal programs in terms of watershed land-use patterns, fig. 4 indicates the relation of watershed development to the reduction of specific forms of damage. The diagram is useful also in recording which watershed fields or sectors would have been most economically treated at various capital levels. The fact that all curves other than that denoting "southwest gully damage" rise from a zero outlay reflects the multipurpose nature of the critical upland treatment activities in program A and indicates that they would necessarily have involved fields located within sector MFBO. In fig. 2, sector MFBO is a source-area for all damages other than gully damage in the southwest drainage.

Figure 4 also establishes the dependence of critical treatment activities on probable benefits derived through control of onsite crop flooding. Floodplain crop damage would have been entirely eliminated with optimal allocation of a $1,340 program outlay. About $982 of this amount ($1,340 – $350)[23] would have financed construction and maintenance of levees 4 feet in height, as well as a simultaneous shift in floodplain land use to continuous corn.

[23] The latter amount ($350) was approximated in fig. 4 as the outlay corresponding to the point at which control of main gully damages would first reach a temporary maximum, because levee construction would provide no gully-control benefits.

Type C: Optimal Development With Capital Nonlimiting

If planning in 1947 in the Nepper Watershed could have proceeded without regard to the cost of undertaking the various land-treatment and structural activities of table 9, all activities that would have added more to program benefits than to program costs could have been undertaken, and net benefits would have been maximized thereby. Such a program, program C, would have produced total annual benefits of $15,384 for a comparable outlay of $5,716. Thus, it would have netted a maximum of $9,668 in benefits distributed among the seven watershed farmers, Monona County and the offsite area. An annual outlay of $5,716 would have represented a maximum justifiable expenditure on watershed development, meaning that a greater outlay would have reduced aggregate net benefits to below $9,668.

The relation of program C to programs A and B is shown by the benefit-cost functions of fig. 5. The upper vertical axis of the diagram measures total and net benefits as functions of program costs. Average and marginal benefit-cost ratios can be read on the lower vertical scale. Program A, which was limited to the conversion to permanent pasture of a single field representing a major source-area of watershed damages, would practically coincide with the vertical

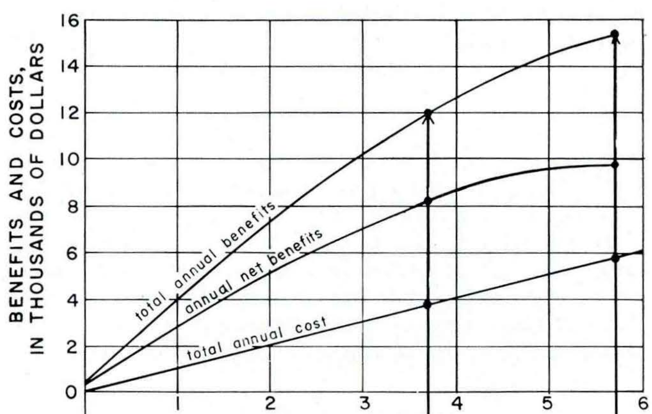

Fig. 5. Benefit-cost aspects of alternative optimal development programs for the Nepper Watershed.

axis of fig. 5, since it would have involved only $9.60 in annual costs (see also row 1, table 10).

As expenditures greater than $9.60 were being considered, it was possible to expand development by including treatments with benefit-cost ratios lower than the 29.26 ratio for the single activity of program A. For example, program B would have involved 20 treatment activities in various sectors of the watershed and would have returned total benefits of $11,937 at a cost of $3,706, thus netting $8,231. Figure 5 and table 10 show that the corresponding average or cumulative net benefit-cost ratio of program B would have been 2.22. Its marginal ratio, for P_{35} as the last treatment added, would have been 1.46.

For program C, the case of planning with unlimited funds, development could have been expanded to include treatment of all watershed fields to maximize net benefits per acre and also to include any structural improvements required to eliminate any watershed damages not eliminated by land treatment. Figure 5 and table 10 indicate that program C would have had an average net benefit-cost ratio of 1.69 and a near-zero marginal ratio of 0.05.

LAND TREATMENT WITH CAPITAL NONLIMITING

The activities of table 9 representing optimal land use in the Nepper Watershed under program C are mapped in fig. 6. Of the systems shown, only P_{42} (402 on field 7-3) and P_{43} (102 on field 7-4) would have been adopted at less than their unit levels[24] or on less than 100 percent of the respective field areas of 22.5 and 41.6 acres. Approximately 3 percent of field 7-3 and 2 percent of field 7-4 would have been required for the site of levees about 4 feet in height (activity P_{49} at 3.97 feet).

As indicated for program C at an outlay of $5,716 in fig. 3, complete adoption of the land-use pattern of fig. 6 over that for 1947 would have increased the watershed area annually in corn to 63 percent from 53 percent. It would have decreased oats to about 10 percent from 20 percent and left the area in meadow essentially unchanged at 27 percent. Also, level terraces of 2-inch runoff-retention capacity per storm could have been installed and maintained profitably on nearly 98 percent of the terraceable watershed area. About 11 percent of the 480-acre watershed would have been contoured, and 83 percent would have received applications of commercial fertilizer.

[24] When terracing or contouring were not feasible on certain field portions, more than one system may be indicated. The benefit-cost data of table 9 were adjusted for these composite cases.

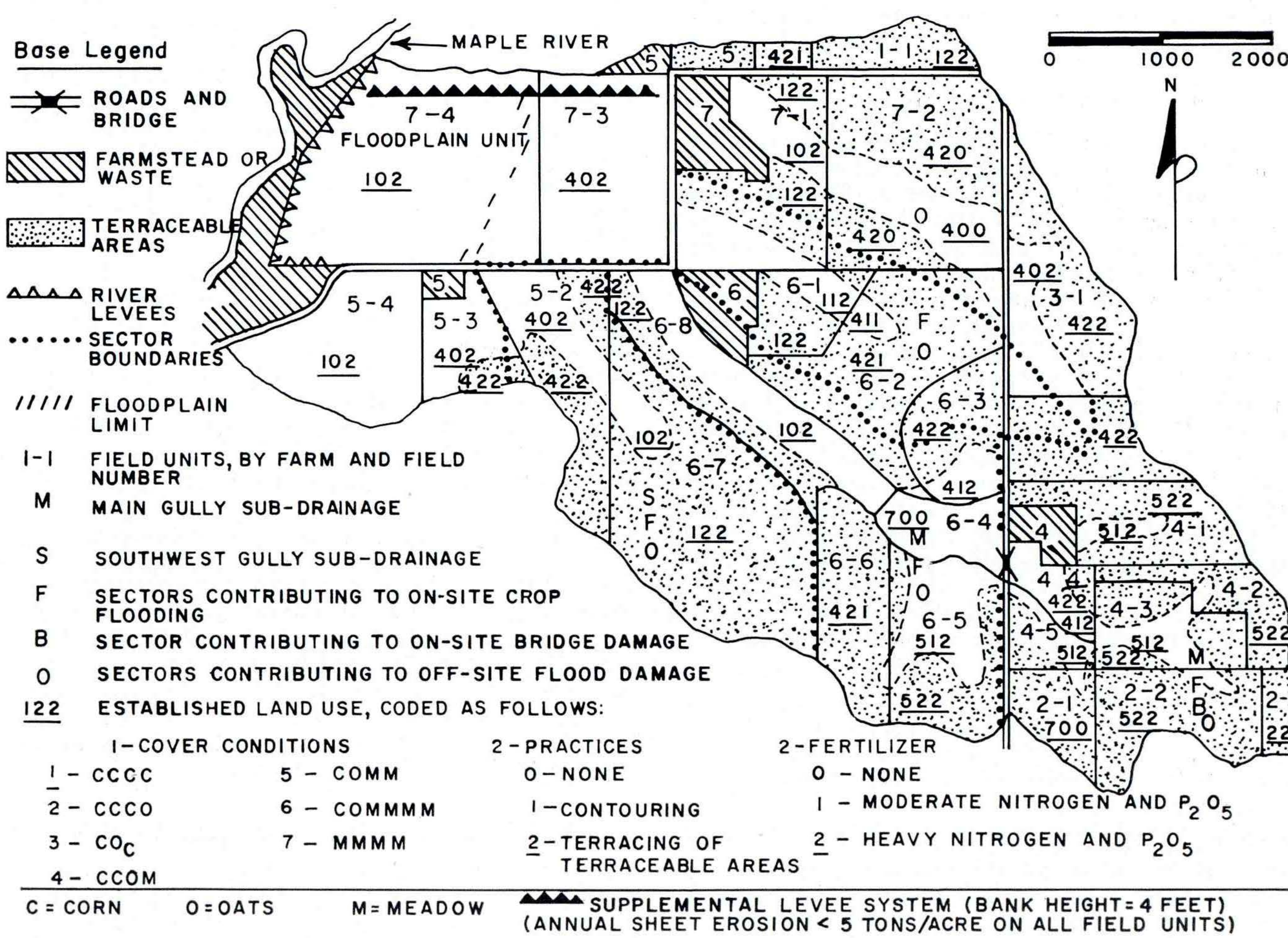

Fig. 6. Optimal development under program C for the Nepper Watershed; optimal land use and supplemental levee construction.

DAMAGE CONTROL WITH CAPITAL NONLIMITING

The described cover changes under program C, combined with the 36 miles of terraces on 288 cropland acres, contouring of 52 acres and fertilization of 400 acres, would have reduced predevelopment watershed damages in the proportions indicated at the $5,716 outlay in fig. 4. Sheet erosion would have been controlled on 90 percent of the watershed or on all cropland. Gully damage in both the main and southwest drainages would have been reduced by 43 percent. Flood damage to the Monona County bridge would have been reduced by 70 percent, and offsite flood damage would have been reduced 55 percent by onsite land treatment. About 24 percent of the flood-control benefits accruing to the onsite floodplain also could have been credited to upland cover changes and related conservation practices.

An initial outlay of $6,309 required to finance 36 miles or 288 acres of terrace construction and periodic re-establishment of 12 acres of permanent meadow would have represented 55 percent of the funds required to install program C (see table 11). On an annual basis, however, land-treatment activities would have been much more important, yielding 92 percent of aggregate benefits and involving 92 percent of all costs. Moreover, nearly 74 percent of annual program benefits (column 4, table 11) would have resulted from increased crop production on treated fields, aside from associated damage reductions there or elsewhere.

JUSTIFIED STRUCTURAL IMPROVEMENTS

The only structural component of program C, as formulated by programming the activities of table 9, was activity P_{49} at a program level of 3.97, designating levees (in fig. 6) built to a height of 3.97 feet. Although the main and southwest structural measures (activities P_{48} and P_{50}) were initially evaluated in table 8 as respectively providing $53.46 and $68.90 in net benefits per 1,000 cubic yards of earth fill, these benefits were largely of a flood-control nature, thereby assuming that flood damage had not been eliminated already by other activities. Consequently, with levees and effective upland treatments superseding the two remaining structural measures (P_{48} and P_{50}) as program elements, the latter two were re-evaluated, not counting any flood-control benefits eliminated by other means. On this basis, respective gully-control benefits of $3.30 and $2.50 per installed unit of measures II and IV (in table 7) were far less than corresponding unit costs of $55.10 and $61.71 (in table 8), rendering the measures infeasible as means for obtaining additional net benefits.[25]

Benefit-cost data for 4-foot levees—the only structural improvement required for economically complete development in the Nepper Watershed—are compared with data for land treatment in table 11. While involving roughly 45 percent of initial outlays, levee construction would have represented 8 percent of all annual benefits and costs. Despite their causing $125 in increased downstream damage to be charged to the benefiting onsite farmer (farm 7), the levees would have been a justified structural activity, ranking equally with land treatment at the margin. Whereas the major factor in zero marginal net benefits to land treatment with program C in effect would have been complete treatment of all fields to maximize net benefits per acre, zero marginal net benefits to added levee heights would have been attributable to onsite crop flooding damage having been completely eliminated.

DISTRIBUTIONS OF BENEFITS AND COSTS

Consistent with the criterion that capitalized activity and project costs be shared by participants in proportion to capitalized benefits, tables 12 and 13 indicate participant distributions of the benefits and costs of program C, with data other than initial installation outlays presented on an average annual equivalent basis.

To emphasize the principle of proportionate sharing of costs, tables 12 and 13 make no distinction between capitalized recurring expenses and initial installation outlays in arriving at total assignments among various beneficiaries, nor in describing internal features of program C. The ratio of net benefits to costs would thus have been equivalent at $1.69 for all participants in tables 12 and 13 and for the component measures shown in table 11. Marginal net benefits would have been correspondingly zero, indicating that under conditions of proportionate cost-sharing, net benefits of program C could not have been increased, either in the aggregate or for individual beneficiaries, by varying the land-use pattern from fig. 6 or by building structures other than levees limited to a height of 4 feet.

By using techniques illustrated in table D-3 in Appendix D, the data for program C, presented as annual equivalents in table 12, were resummarized as present values in table 14, applying a private discount rate of 5 percent and a public rate of 2½ percent over the 50-year (1947-97) project period. The relative distribution of benefits and costs would remain unchanged from that shown in table 12.

PROGRAM C RELATED TO PREDEVELOPMENT

In relation to the predevelopment resource-use situation of 1947, the over-all and interparticipant effects of program C involving a maximum justified annual expenditure of $5,716 beginning in 1947 are summarized in section 2 of table 5. The relative distribution of benefit classes and various cost items by land treatment and structural components of program C is given in the final column of table 11.

MAJOR LIMITATIONS OF THE STUDY

This study had numerous limitations as an attempt to outline and illustrate acceptable watershed planning procedures. Important among these was the use of single-valued estimates of the average and marginal

[25] Similar reasoning was applied in reappraising land-treatment measures installed in sectors denoted by F in fig. 6. Results indicated that flood-control benefits for onsite crops were primarily creditable to treatment of the steep sector MFBO, plus field unit 6-2 with an average slope of about 8 percent.

TABLE 11. INSTALLATION OUTLAYS, BENEFITS AND COSTS OF OPTIMAL DEVELOPMENT UNDER PROGRAM C IN THE NEPPER WATERSHED; DISTRIBUTED BY MAJOR COMPONENTS, IN DOLLARS UNLESS INDICATED OTHERWISE.

Benefit and cost items	Program components		Total program	Program percent
	Land treatment	Structures (levees)		
Initial installation outlays	6,309	5,200	11,509	....
Percent initial installation	55	45	100	....
Equivalent annual benefits				
Increased crop values	11,310	0	11,310	73.55
Gully control; main drainage	44	0	44	0.28
Gully control; southwest drainage	16	0	16	0.10
Flood control; onsite crops	2,523	1,141	3,664	23.80
Flood control; onsite bridge	273	0	273	1.77
Flood control; offsite	77	0[a]	77	0.50
Total gully control	60	0	60	0.38
Total flood control	2,873	1,141	4,014	26.07
Total annual benefits	14,243	1,141	15,384	100.00
Percent annual benefits	92	8	100	....
Equivalent annual costs				
Increased production expense	4,952	0	4,952	86.65
Increased flood damage; offsite	0	125[a]	125	2.18
Amortized installation	339	287	626	10.93
Levee maintenance	0	13	13	0.24
Total annual costs	5,291	425	5,716	100.00
Percent annual costs	92	8	100	....
Annual net benefits	8,952	716	9,668	....
Net benefits per unit cost	1.69	1.69	1.69	....
Marginal net benefits	0	0	0	....

[a] On the assumption that treatment activities be charged for (and compensate) possible increases in damage, increased offsite flood damage associated with diversion of onsite overflow into the Maple River by levees was included as an annual cost.

TABLE 12. INSTALLATION OUTLAYS, BENEFITS AND COSTS OF OPTIMAL DEVELOPMENT UNDER PROGRAM C IN THE NEPPER WATERSHED; DISTRIBUTED AMONG PRIVATE AND PUBLIC BENEFICIARIES, IN DOLLARS UNLESS INDICATED OTHERWISE.

Benefit-cost items	Onsite			Offsite public	Total public	Total program
	Private[a]	Public	Total			
Initial installation outlays	11,169	255	11,424	85	340	11,509
Percent initial installation	97	2	99	1	3	100
Equivalent annual benefits						
Increased crop values	11,310	0	11,310	0	0	11,310
Gully control; main drainage	44	0	44	0	0	44
Gully control; southwest drainage	16	0	16	0	0	16
Flood control; onsite crops	3,664	0	3,664	0	0	3,664
Flood control; onsite bridge	0	273	273	0	273	273
Flood control; offsite	0	0	0	77	77	77
Total gully control	60	0	60	0	0	60
Total flood control	3,664	273	3,937	77	350	4,014
Total annual benefits	15,034	273	15,307	77	350	15,384
Percent annual benefits	97.70	1.77	99.47	0.53	2.30	100.00
Equivalent annual costs						
Increased production expense	4,833	93	4,926	26	119	4,952
Increased flood damage; offsite	125	0	125	0	0	125
Amortized installation	614	9	623	3	12	626
Levee maintenance	13	0	13	0	0	13
Total annual costs	5,585	102	5,687	29	131	5,716
Percent annual costs	97.70	1.77	99.47	0.53	2.30	100.00
Annual net benefits	9,449	171	9,620	48	219	9,668
Net benefits per unit cost	1.69	1.69	1.69	1.69	1.69	1.69
Marginal net benefits	0	0	0	0	0	0

[a] Transferred from table 13.

TABLE 13. INSTALLATION OUTLAYS, BENEFITS AND COSTS OF OPTIMAL DEVELOPMENT UNDER PROGRAM C IN THE NEPPER WATERSHED; DISTRIBUTED AMONG PRIVATE BENEFICIARIES, IN DOLLARS UNLESS INDICATED OTHERWISE.

Benefit-cost items by watershed farms[a]	Farm identity							Total private[b]
	1	2	3	4	5	6	7	
Initial installation outlays	255	1,131	0	0	0	3,358	6,435	11,169
Percent initial installation	2.21	9.82	0	0	0	29.17	55.84	97.04
Equivalent annual benefits								
Increased crop values	189	524	1,562	822	1,678	4,570	1,965	11,310
Gully control, main drainage	0	2	1	12	0	29	0	44
Gully control; southwest drainage	0	0	0	0	10	6	0	16
Flood control; onsite crops	0	0	0	0	0	0	3,664[c]	3,664
Total gully control	0	2	1	12	10	35	0	60
Total flood control	0	0	0	0	0	0	3,664	3,664
Total annual benefits	189	526	1,563	834	1,688	4,605	5,629	15,034
Percent annual benefits	1.23	3.42	10.15	5.42	10.96	29.92	36.60	97.70
Equivalent annual costs								
Increased production expense	56	134	580	310	626	1,526	1,601	4,833
Increased flood damage; offsite	0	0	0	0	0	0	125	125
Amortized installation	14	62	0	0	0	184	354	614
Levee maintenance	0	0	0	0	0	0	13	13
Total annual costs	70	196	580	310	626	1,710	2,093	5,585
Percent annual costs	1.23	3.42	10.15	5.42	10.96	29.92	36.60	97.70
Annual net benefits	119	330	983	524	1,062	2,895	3,536	9,449
Net benefits per unit cost	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69
Marginal net benefits	0	0	0	0	0	0	0	0

[a] Farms numbered as in figs. 2 and 6.
[b] Transferred to the first column of table 12.
[c] Includes $2,803 in maximum protection for intensive floodplain use and $861 in permitted intensive use.

benefits from hydrologic control of flooding and gullying (table 4). In reality, these have multiple values, with respect to both given uses and all alternative uses determining potential damage on affected areas. In uniformly crediting land-treatment or structural activities with maximum benefits of reduced overflow on the floodplain, the floodplain was presumed to have been cropped to heavily fertilized continuous corn, the land-use system of fig. C-3 under which damage would have been greatest for any overflow volume. And with regard to this system alone, each reduction of 1 acre-foot in annual overflow was valued at $86.59

TABLE 14. CAPITALIZED BENEFITS AND COSTS OF OPTIMAL DEVELOPMENT UNDER PROGRAM C IN THE NEPPER WATERSHED; DISTRIBUTED AMONG PRIVATE AND PUBLIC BENEFICIARIES, IN DOLLARS UNLESS INDICATED OTHERWISE.

Benefit-cost items	Onsite Private	Onsite Public	Offsite public	Total program
Capitalized program benefits				
Increased crop values	206,463	0	0	206,463
Gully control; main drainage	803	0	0	803
Gully control; southwest drainage	292	0	0	292
Flood control; onsite crops	66,885	0	0	66,885
Flood control; onsite bridge	0	7,742	0	7,742
Flood control; offsite	0	0	2,183	2,183
Total gully control	1,095	0	0	1,095
Total flood control	66,885	7,742	2,183	76,810
Total capitalized benefits	274,443	7,742	2,183	284,368
Percent capitalized benefits	97.70	1.77	0.53	100.00
Capitalized program costs				
Initial installation outlays	11,169	255	85	11,509
Increased production expense	88,226	2,637	737	91,600
Increased flood damage; offsite	2,281	0	0	2,281
Structure (levee) maintenance	237	0	0	237
Total capitalized costs	101,913	2,892	822	105,627
Percent capitalized costs	97.70	1.77	0.53	100.00
Capitalized net benefits	172,530	4,850	1,361	178,741
Net benefits per unit cost	1.69	1.69	1.69	1.69
Marginal capitalized benefits	0	0	0	0

as estimated under the predevelopment conditions.

A second major weakness involved uncertainty aspects and was best shown by the basing of comparative runoff determinations on the 12 most erosive storms occurring at Castana, Iowa, over the period 1948-56 (table C-2 in Appendix C). There is neither assurance that antecedent moisture conditions prevailing at Castana at the time of each recorded storm were typical, nor assurance that the short flood-storm record in the Nepper Watershed even approximated the frequency distribution of flood-producing rainfall over an infinite period.

A third limitation concerns the criteria applied in delimiting the range of land-use changes selected for benefit-cost analysis. The criteria applied in table 6 with reference to each field and farm are perhaps still too objective. Some farmers are averse to erosion-control practices regardless of estimated benefits and, to some extent, regardless of liberal cost-sharing assistance. An example is terracing, which is often objected to because field operations may be more difficult.

In concentrating on the problems of determining optimal land-use patterns, the analysis did not consider those farm fields or parts of fields lying beyond the boundaries of the Nepper Watershed. Optimal land treatment undertaken on portions of farms within watershed boundaries is not independent of treatment possibilities for outlying areas, in that all farm fields compete for the limited resources available to the operator. The noncoincidence of farm and drainage boundaries poses a special problem in defining the areal scope of firm-oriented watershed planning. Delineations on a farm-firm basis may be inadequate from the hydrologic viewpoint and those on a watershed-firm basis inadequate from the farm viewpoint.

Another point meriting more careful consideration is income distribution. Watershed development projects doubtless can result in redistributions of income, either among watershed residents or between residents as a group compared with offsite interests. Particular redistributions desired can be effected by legislating the proportions in which development costs are shared.

No judgments were made for the Nepper Watershed as to what absolute or relative income distribution should prevail after development programs A, B or C were adopted. The condition was imposed, however, that programs maximizing net benefits in the aggregate could not thereby result in net losses, or absolute net income decreases, for any private or public participant. The condition was made operational in benefit-cost analyses and program formulation by interpreting such losses as costs to be compensated proportionately (in relation to benefits) by beneficiaries. With all program costs assigned proportionately, the judgment implied was that development programs would be intended neither to maintain nor to achieve given income distributions, but that prospective increases in income should be shared proportionately. The study merely illustrates how planners would abide by this one policy; alternative cost-sharing policies could be implemented quite easily within the same general planning framework.

RESEARCH CONCLUSIONS

Major research conclusions are summarized as follows:

1. The study focuses attention on the need for more precise information on the physical factors involved in watershed planning. This conclusion bears acutely on the factors affecting gully enlargement, on estimates of water yield under different land-use systems and on the effects of flooding on growing crops.

2. Despite the limitations of some of the physical estimates in absolute terms, relative differences of estimates suggest that two of the study's empirical findings merit special attention:
   a. Onsite land-treatment measures on the deep permeable soils of the Nepper Watershed apparently would have been quite effective in reducing sheet erosion, runoff and flood damage. These measures, such as terracing, contouring and fertilization, generally would have resulted in very favorable benefit-cost ratios, both for individual farmers concerned and for the watershed as a whole.
   b. Marginal net benefits of onsite land-treatment measures in the Nepper Watershed would have been great enough to obviate the need for installing many structural works of improvment. An important exception was a levee system.

3. The procedure of adding or substituting alternative watershed-treatment measures on the basis of maximum marginal net returns was very useful for indicating how aggregate net benefits from watershed development could have been maximized in the Nepper Watershed. This theoretical condition for maximizing a quantified objective would be quite practical for planning development in any watershed. This is because the condition automatically gives the most profitable measures first consideration, the somewhat less profitable measures secondary consideration and the clearly unprofitable measures no consideration as elements of a final program. The linear programming technique was merely the algebraic apparatus within which the condition was allowed to operate systematically.

4. The study suggests that organizations above the farm level are needed for watershed development, especially in connection with the equitable accumulation of capital required to initiate land-treatment measures or to install structural works, as well as to maintain programs at full efficiency. Although the Nepper analysis was not concerned with financial management problems as such, it did provide the detailed economic information required to solve such problems.

APPENDIX A: SUPPLEMENTAL INPUT-OUTPUT AND COST DATA

TABLE A-1. ANNUAL PER-ACRE PRODUCTION EFFECTS OF CONSERVATION PRACTICES AND FERTILIZATION WITH SELECTED ROTATIONS; MONONA SILT LOAM, 3-6 PERCENT SLOPE (NON-ERODED).

Rotations[a]	Practices	No fertilization Corn (bu.)	Oats (bu.)	Hay (tons)	F-1 fertilization Corn (bu.)	Oats (bu.)	Hay (tons)	F-2 fertilization Corn (bu.)	Oats (bu.)	Hay (tons)
CCCC or CCCO	None	38	32	..	60	35	..	65	40	..
	Fertilizing rate; lbs. N — lbs. P.				60-20	10-20	..	80-30	10-30	..
	Contouring	40	32	..	65	35	..	70	40	..
	Fertilizing rate; lbs. N — lbs. P.				60-20	10-20	..	80-30	10-30	..
	Terracing	40	32	..	65	35	..	70	40	..
	Fertilizing rate; lbs. N — lbs. P.				60-20	10-20	..	80-30	10-30	
CO_c	None	45	35	..	60	35	..	65	40	..
	Fertilizing rate; lbs. N — lbs. P.				30-20	0-20	..	60-30	0-30	..
	Contouring	48	35	..	65	35	..	70	40	..
	Fertilizing rate; lbs. N — lbs. P.				30-20	0-20	..	60-30	0-30	..
	Terracing	48	35	..	65	35	..	70	40	..
	Fertilizing rate; lbs. N — lbs. P.				30-20	0-20	..	60-30	0-30	
CCOM[b]	None	55	38	2.6	65	35	2.7	70	40	2.8
	Fertilizing rate; lbs. N — lbs. P.				30-20	0-20	0-20	45-30	0-30	0-30
	Contouring	58	38	2.6	58	38	2.6	70	35	2.7
	Fertilizing rate; lbs. N — lbs. P.				30-20	0-20	0-20	45-30	0-30	0-30
	Terracing	58	38	2.6	70	35	2.7	75	40	2.8
	Fertilizing rate; lbs. N — lbs. P.				30-20	0-20	0-20	45-30	0-30	0-30

[a] See footnote 15 for crop identification.
[b] Data for COMM, COMMMM and continuous meadow omitted.

TABLE A-2. ANNUAL PER-ACRE LABOR AND CAPITAL REQUIREMENTS FOR SELECTED CROP ROTATIONS FEASIBLE IN THE NEPPER WATERSHED.

Crops	Capital and labor inputs: Labor (man-hours)[a] No fertilizer	Fertilized	Capital[b] (dollars)	Percent frequency of crops: Corn (C)	Oats (O)	Meadow (M)
Single crops						
Corn	7.00	7.20	16.23			
Oats	5.00	5.30	13.28			
Meadow	11.62	11.92	6.63			
Rotations						
Continuous corn (CCCC)	7.00	7.20	16.23	100	0	0
Corn-corn-corn-oats (CCCO)	6.50	6.72	15.50	75	25	0
Corn-oats with clover catch crop (CO_c)	6.00	6.25	14.76	50	50	0
Corn-corn-oats-meadow (CCOM)	7.65	7.90	14.01	50	25	25
Corn-oats-meadow-meadow (COMM)	8.81	9.08	11.08	25	25	50
Corn-oats-meadow 4 years (COMMMM)	9.69	10.00	9.33	17	17	66
Continuous meadow (MMMM)	11.62	11.92	6.63	0	0	100

[a] Labor requirements are from: Arthur Mackie *et al.* Farm input-output data for budgeting and linear programming. Department of Economics and Sociology, Iowa State University, Ames. 1956. (Unpublished research.)
[b] Capital requirements were based on 1955 Iowa custom rates for field work adjusted for long-term prices. Fertilizing and harvesting expenses were not included.

TABLE A-3. DESIGN, CONSTRUCTION AND MAINTENANCE DATA FOR LEVEL TERRACES OF 2-INCH RUNOFF-RETENTION CAPACITY.

Construction and maintenance items	Units	Soil types by percent slope phases: Ida silt loam 4-8	9-15	16-25	Monona silt loam 3-6	7-9	10-14	15+
Design and construction								
Mean slope (S)	%/100	0.06	0.11	0.20	0.04	0.08	0.12	0.15
Vertical interval (V.I.)[a]	ft.	5.6	8.6	14.0	4.4	6.8	9.2	11.0
Horizontal interval (H.I.)[b]	ft.	93	78	70	110	85	76	73
Linear feet per acre[c]	ft.	468	558	600	396	513	573	596
Construction cost[d]	$/ac.	19	22	24	16	21	23	24
Maintenance								
Silt removal A[e]	tons	34	31	28	34	34	31	29
Amount replowed[f]	%	28	34	18	24	32	34	16
Silt removal B[f]	tons	na[g]	13.5	11.5	na	na	13.0	13.0
Capital for B[h]	$	na	0.76	0.41	na	na	0.76	0.36
Labor for B[i]	hrs.	na	0.37	0.19	na	na	0.37	0.17

[a] Vertical interval (V.I.) computed from $60S + 2$.
[b] Horizontal interval (H.I.) computed from (V.I.)/S.
[c] Feet per acre computed from 43,560/(H.I.).
[d] Construction cost computed from $0.04 x (linear feet per acre).
[e] From plowing operations following corn, oats and last year meadow.
[f] If additional plowing is done for terrace maintenance purposes.
[g] Indicates additional plowing is unnecessary regardless of land use.
[h] Computed from percent replowed and a variable plowing cost of $2.25 per acre.
[i] Computed from percent replowed and 1.1 man-hours of labor required for a complete plowing operation with a 2-14 inch moldboard plow. Man-hours of 1.1 are based on 0.9 acre per hour as the effective field working capacity for such a plow as estimated in the manual: Farm power and machinery management. Iowa State University Press, Ames, Iowa. 1956. p. 13.

TABLE A-4. TERRACE DEPRECIATION BY SOIL TYPES AND CROPPING CONDITIONS.

Silt loam soils	Percent slope	Rotations with terraces					
		CCCC	CCCO	CO_c	CCOM	COMM	COM_4
		Crude siltation rates (tons per acre per year)[a]					
Ida	4-8	22	18	11	8	3	2
	9-15	60	79	30	21	9	4
	16-25	118	97	59	41	17	9
Monona	3-6	13	11	6	4	2	1
	3-6 (e)	17	14	8	6	2	1
	7-9	23	19	12	8	4	2
	10-14	45	37	22	16	7	3
	15+	58	49	30	20	9	4
		Adjusted siltation rates (tons per acre per year)[b]					
Ida	9-15	29	43	0	0	(Zero for remaining soil types in table A-3)	
	16-25	90	70	31	13		
Monona	10-14	14	6	0	0		
	15+	29	20	0	0		
		Expected life without added maintenance (years)[c]					
Ida	9-15	10	6	..	..	(Infinite for remaining soil types in table A-3)	
	16-25	3	4	9	22		
Monona	10-14	21	49	..	..		
	15+	10	15	..	..		
		Annual depreciation charges (dollars)[d]					
Ida	9-15	2.20	3.67	0	0	(Zero for remaining soil types in table A-3)	
	16-25	8.00	6.00	2.78	1.09		
Monona	10-14	1.09	0.47	0	0		
	15+	2.40	1.60	0	0		

[a] Estimated from Browning's erosion factors, where the horizontal interval of terraces was considered as field length.
[b] Computed as crude siltation rates less silt removal incident to normal plowing, with negative adjusted rates considered nonpermissible.
[c] Channel capacity in tons per acre/adjusted siltation rates.
[d] Construction cost/expected life (see table A-3 for construction cost).

TABLE A-5. ANNUAL TERRACE MAINTENANCE REQUIREMENTS BY SOIL TYPES AND CROPPING CONDITIONS.

Silt loam soils	Percent slope	Number of added plowings for complete maintenance[a]				Per added plowing[b]		
						Silt	Requirements	
		CCCC	CCCO	CO_c	CCOM	removal	Capital	Labor
						(tons)	(dollars)	(man-hours)
Ida	9-15	2.18	3.55	0	0	13.5	0.76	0.37
	16-25	7.85	6.08	2.70	1.14	11.5	0.41	0.19
Monona	10-14	1.05	1.54	0	0	13.0	0.76	0.37
	15+	1.05	1.54	0	0	13.0	0.36	0.17
		Capital requirements for added maintenance (dollars per acre)[c]						
Ida	9-15	1.66	2.70	0	0	(Zero for all additional soils listed in table A-3)		
	16-25	3.20	2.50	1.11	0.47			
Monona	10-14	0.80	1.17	0	0			
	15+	0.38	0.55	0	0			
		Labor requirements for added maintenance (man-hours per acre)[d]						
Ida	9-15	0.80	1.31	0	0	(Zero for all additional terraceable soils listed in table A-3)		
	16-25	1.49	1.15	0.51	0.28			
Monona	10-14	0.39	0.39	0	0			
	15+	0.38	0.26	0	0			

[a] Computed by dividing adjusted siltation rates in table A-4 by corresponding silt-removal estimates given in column 7 of this table.
[b] Transferred from table A-3.
[c] Computed as products of capital required per added plowing and numbers of added plowings given in the first section.
[d] Computed as products of labor required per added plowing and numbers of added plowings given in the first section.

TABLE A-6. DETAILED DESIGN SPECIFICATIONS AND CONSTRUCTION OUTLAYS FOR INDIVIDUAL NEPPER WATERSHED STRUCTURES INSTALLED IN 1948.[a]

Specifications and construction outlays	Units	Main drainage					Southwest
		Chute spillway	Drop-inlet 1	Drop-inlet 2	Drop-spillway	Levees	drainage drop-inlet
Site area[b]	acres	1.79	6.20	1.95	0.14	2.10	2.65
Drainage area	acres	89	125	157	157	293[c]	57
Height or drop	feet	33	31	14	7	6	25
Detention capacity	ac. ft.	0	31	0	0	0	13
Maximum inflow[d]	cfs.	full-flow	440	full-flow	1,100	full-flow	165
Maximum outflow[d]	cfs.	full-flow	16	full-flow	660	full-flow	34
Peak flow reduction[d]	cfs.	0	424	0	440	0	131
Earth fill	cu. yds.	10,500	36,000	4,000	850	14,212	14,400
Construction outlay	dollars	15,261	18,565	9,000	14,600	4,929	10,600[e]

[a] Source of data other than site areas: Little Sioux Flood Control Office, Sioux City, Iowa.
[b] Site areas of structures other than levees were approximated as being proportional to earth-fill volume represented by drop-inlet 1, or by 0.17 acre per 1,000 cubic yards of earth-fill volume. The site area of levees was estimated with reference to 80 feet of total base width and 1,143 feet of length, measured from the location of the drop-spillway to the Maple River.
[c] Levees were assumed to drain all sectors designated by F and O in fig. 2. The area of the main drainage proper, however, was limited to the sectors designated by M in fig. 2.
[d] Peak flow data applicable to storms of 50-year recurrence intervals.
[e] Includes $419 in structure-related channel improvement.

TABLE A-7. CAPITALIZED COSTS OF NEPPER WATERSHED STRUCTURAL MEASURES AS INSTALLED IN 1948, IN DOLLARS.

Outlay items by measures	Main drainage			Southwest	Water-
	Chute-spillway	Drainage group	Levees	drainage group	shed total
Measure designations	I	II	III	IV	....
Installed units of measures[a]	10.50	40.85	6.00	14.40	....
Site acquisition costs[b]	370	1,713	2,121	3,188	7,392
Contract construction costs[c]	15,261	33,320	4,929	11,019	64,529
Planning at 17 percent of contract	2,594	5,664	838	1,873	10,969
Construction and planning	17,855	38,984	5,767	12,892	75,498
Total installation costs	18,225	40,697	7,888	16,080	82,890
Maintenance cost; present value[d]	103	400	360	141	1,004
Total costs; present value	18,328	41,097	8,248	16,221	83,894

[a] From table A-6. Units for measures I, II and IV are in 1,000 cubic yards of earth fill; units for measure III are feet of bank height.
[b] Estimated from site area requirements (table A-6) and the present value of maximum annual net income per acre, capitalized over 50 years at 5 percent.
[c] From table A-6.
[d] Maintenance costs for measures I, II and IV were estimated as being proportional to earth-fill volumes and were based on a $400 farmer contribution in 1948 toward continued maintenance of measure II. Maintenance costs for measure III were estimated as being equivalent to a similar farmer contribution of $360.

TABLE A-8. DESIGN DATA FOR NEPPER WATERSHED STRUCTURAL MEASURES AS INSTALLED IN 1948.[a]

Design specifications	Units	Main drainage: Road chute	Main drainage: Drainage group	Main drainage: Levees	Southwest drainage group
1. Measure designations	....	I	II	III	IV
2. Site area	acres	1.79	8.29	2.10	2.65
3. Drainage area	acres	88.95	157.53	293.14	48.00
4. Height or drop[b]	feet	33.00	52.00	6.00	25.00
5. Flood control;					
per storm[c]	ac. ft.	..	31.00	20.82	13.00
per season	ac. ft.	18.70	49.80	33.50	21.30
6. Flow reductions;					
10-year[d]	cfs.	0	286	0	98
7. Fill volumes;					
earth	cu. yds.	10,500	40,850	14,212	14,400
8. Installation increment	1.00	1,000 yds. earth	1,000 yds. earth	1 ft. height	1,000 yds. earth
9. Installed increments[e]	.	10.50	40.85	6.00	14.40

[a] Design data for each measure based on data for individual structural improvements are given in table A-6.
[b] Effective height refers to vertical drop for measures I, II and IV; and to levee bank height for measure III.
[c] Floodwater control refers to prevention of bridge undermining by the fullflow chute for measure I and detention capacity for other measures. Floodwater control per season was approximated by multiplying control per storm by 1.6; the ratio of about 70 acre-feet of average annual runoff (from the 293-acre area contributing to onsite crop flooding) to 44 acre-feet of runoff (the total detention capacity provided per storm by measures II and IV).
[d] Flow reductions were computed as the difference between average design inflow and outflow for storms of a 10-year recurrence interval.
[e] For measures I, II and IV refer to item 7; for measure III refer to item 4.

TABLE A-9. INCREMENTAL DESIGN AND COST DATA FOR NEPPER WATERSHED STRUCTURAL MEASURES INSTALLED IN 1948.[a]

Design specifications and cost items	Units	Main drainage: Road chute	Main drainage: Drainage group	Main drainage: Levees	Southwest drainage group
Designated measures	....	I	II	III	IV
Unit level of measures	....	1,000 yds. earth	1,000 yds. earth	1 ft. height	1,000 yds. earth
Flood control	ac. ft.	1.78	1.22	5.57	1.48
Flow reduction; 10-year[b]	cfs.	0	7.00	0	5.00
Site requirements; total acres		0.170	0.023	0.350	0.184
By field units[c]	4-f	0.170	0	0	0
	6-4	0	0.152	0	0
	7-3	0	0.051	0.175	0
	7-4	0	0	0.175	0
	6-7	0	0	0	0.184
Site acquisition[d]	dollars	35.23	41.94	353.59	221.43
Construction and planning	dollars	1,700.47	954.32	961.16	895.27
Total installation	dollars	1,735.70	996.26	1,314.75	1,116.70
Maintenance, present value	dollars	9.79	9.79	60.00	9.79
Total costs, present value	dollars	1,745.49	1,006.05	1,374.75	1,126.49

[a] Estimates obtained by recomputing items in tables A-7 and A-8 on a per-unit basis.
[b] Measures were designed for storms of 50-year recurrence, but 10-year recurrence interval reductions were utilized to estimate effectiveness of gully-control features.
[c] Refer to fig. 2 in text for field unit locations.
[d] Site acquisition costs were based on maximum net returns obtained by utilizing field units 7-3, 7-4 and 6-7 for crop production; and an actual payment of $370 in 1948 for necessary right-of-way from farmstead unit 4-f. No alternative use was assumed for field unit 6-4, because it included part of the area voided by the main gully prior to installation in 1948.

APPENDIX B: EVALUATING GULLY DAMAGE FROM RUNOFF RATES

Gully damage was evaluated as the annual equivalent of the present value (in 1947) of the maximum net income foregone during the 50-year period 1947-97 on fields or field portions likely destroyed within the main and southwest drainages. It was then charged as a production cost on all fields within the two drainages designated by M and S in fig. 2. By 1947, the main gully had destroyed about 5.8 acres and was advancing at an average rate of 0.133 acre per year. The southwest gully had destroyed 0.89 acre and was advancing at about 0.047 acre per year.

Projected rates of land destruction and consequent damages were estimated from the history of gully development and the drainage runoff characteristics influencing peak runoff rates coinciding with storms of a 10-year average recurrence expectancy.[26] Runoff characteristics considered included topography, vegetal cover, infiltration capacity and provision for surface storage of runoff. The three latter were allowed to vary by whichever land-use systems would have been established on different fields wholly or partly within drainage boundaries. Index values assigned to individual drainage characteristics on the basis of field slopes, crop rotations and the practices of contouring or terracing were aggregated by fields in arriving at average indexes weighted by both proportionate areas of fields included and respective land uses.

Figure B-1 indicates relations between the average index of runoff characteristics (termed Summation W) and peak discharge for the main drainage. Particular runoff index-peak flow relations were made dependent on local climatic conditions (as expressed by the rainfall factor), on drainage area and on the recurrence expectancy considered. Conversion of 10-

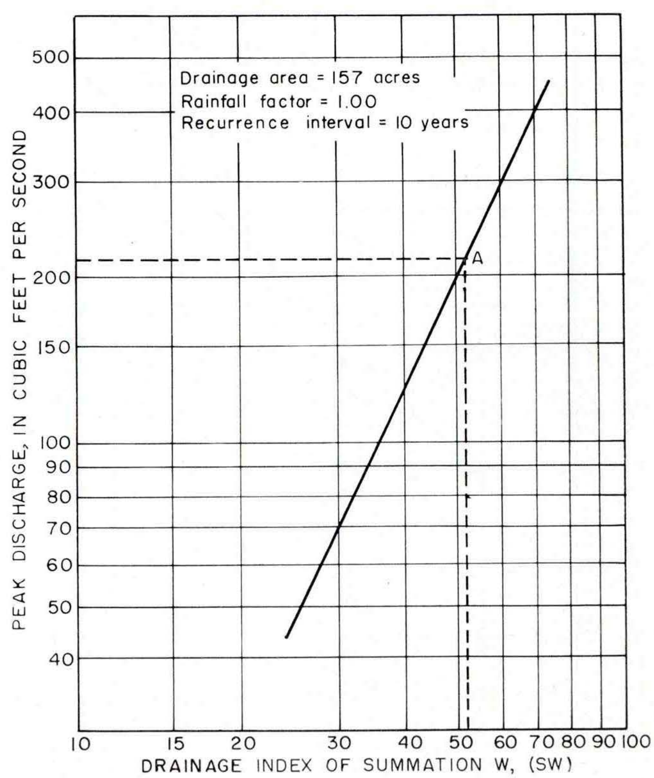

Fig. B-1. Main drainage peak discharge in relation to an index of runoff characteristics and storm recurrence.

[26] For details of this method for estimating runoff rates from watersheds see: R. K. Frevert, G. O. Schwab, T. W. Edminster and K. K. Barnes. Soil and water conservation engineering. John Wiley and Sons, Inc., New York. 1955. pp. 62, 436.

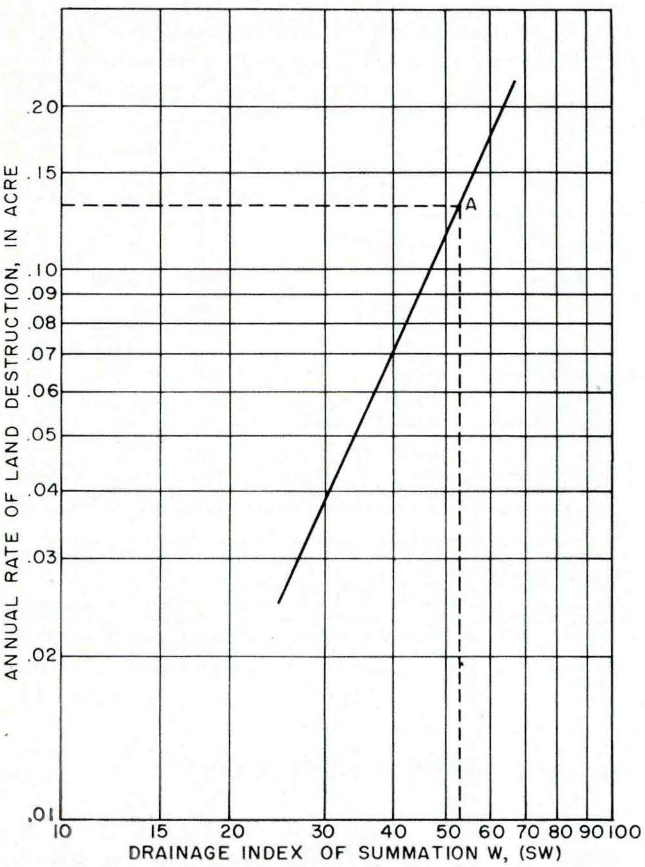

Fig. B-2. Average annual rates of land destruction in the main drainage in relation to an index of runoff characteristics.

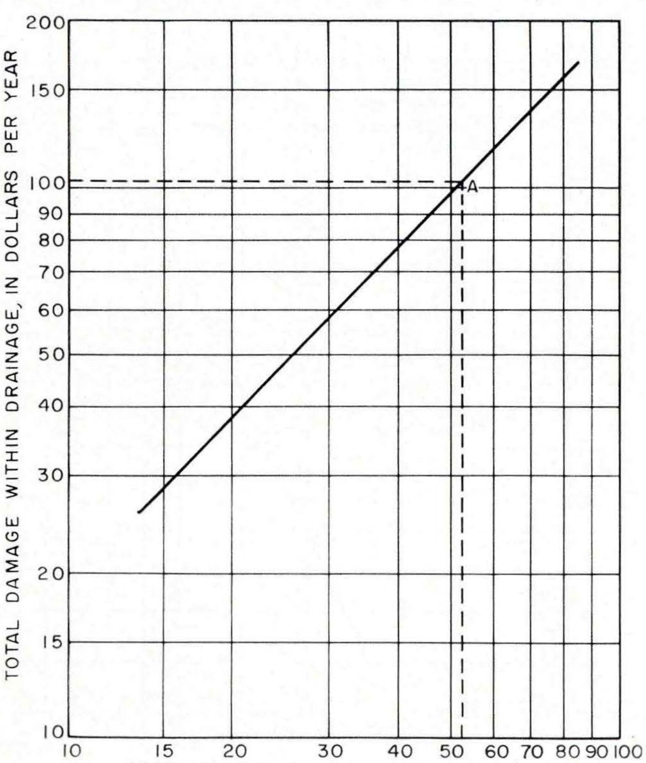

Fig. B-3. Average annual gully damage in the main drainage in relation to an index of runoff characteristics.

year recurrence peak flow into estimated annual rates of land destruction in the main drainage, with reference to the runoff index, is illustrated in fig. B-2.

Average annual equivalents of discounted gully damage, D, expected from various land-use patterns within the main drainage are plotted in fig. B-3 from rates of land destruction corresponding with various values of the Summation W index, assuming that affected areas would have been farmed for maximum net income. Lacking knowledge of precise dates at which the advancing main gully would reach potentially affected fields, the damage curve was derived from the formula

$$D = \sum_{i=1}^{m} \frac{a_i p_i N_i R_x r}{A_o (1 - d^n)} \left[\frac{(d^{n-1} - 1) - nd^n \; (d-1)}{(1-d)\;(d-1)} \right]; \qquad (1)$$

where a_i = total acreage of *ith* field wholly or partially within the drainage; $i=1, 2, \ldots m=18$,

p_i = proportionate acreage of *ith* field susceptible to damage,

N_i = maximum net income on *ith* field, with reference to profit-maximizing land-use systems, for $p_i \neq 0$,

R_x = projected rate of land destruction with reference to land use on contributing fields, estimated from fig. B-2,

A_o = total acreage within the drainage potentially susceptible to damage = 30.20 acres,

$d = 1/(1 + r)$; $r = 0.05$ = rate of discount,

$n = 50$ = planning period in years (1947-97),

[$312] = present value of $1 at the beginning of year 1, increasing by $1 per year for 49 more years.

Maximum average annual damage thus computed on affected fields was allocated among individual fields within the drainage relative to individual runoff indexes:

$$D_i = \frac{a_i \, p'_i \, w_i \, D}{A \; (SW)} \; ; \qquad (2)$$

where D_i = damage allocated to *ith* field within the drainage,

a_i = total acreage of *ith* field wholly or partly within the drainage; $i = 1, 2, \ldots m = 18$,

p'_i = proportionate acreage of *ith* field within the drainage,

w_i = runoff index for given land-use systems established on contributing fields,

A = total acreage within the drainage = 157 acres,

(SW) = weighted average runoff index for the drainage,

D = total annual damage, from equation 1 and fig. B-3.

For example, the land-use pattern prevailing within the main drainage in 1947 (shown in text fig. 2) yielded an average runoff index of 52. This index was associated with a 215-cubic feet per second peak 10-year flow (point A, fig. B-1) and a projected rate of land destruction of 0.133 acre per year (point A, fig. B-2). The annual equivalent of discounted damage estimated from this rate by equation 1 was given as $101 at point A in fig. B-3. Application of equation 1 in obtaining estimated average annual maximum damage with reference to 1947 land use and 1947 land use projected through a 50-year period is illustrated in table B-1, while table B-2 prorates the damage back to contributing fields or over the total drainage area. The same procedure was used to estimate the pre-development annual rate of land destruction of 0.047 acre and average annual damage of $36 in the 57-acre southwest drainage. Farm-by-farm allocations of gully damage are included in table C-7, Appendix C.

These methods of predicting gully damage are only approximate, the factual basis for the prediction being the history of gully development as determined by aerial photographs or interviews. This assumes that the average annual rate of land destruction does not change with time if cropping practices are constant. The assumption that the rate of gully development is directly related to a single hydrologic variable can also be questioned. Very little research has been completed on determining quantitative relationships between variables involved in gully development. Geophysical research of this type is expensive and time-consuming but is needed for improved benefit-cost analysis of gully control.

TABLE B-1. PROJECTED AVERAGE ANNUAL GULLY DAMAGE IN THE MAIN DRAINAGE WITH PREDEVELOPMENT LAND-USE CONTINUED 50 YEARS FROM 1947.

Field ident.[a]	Total area	Susceptible area[b]	Susceptible area[c]	Susceptible system Ident.[d]	Susceptible system Net per acre per year	Area lost per year[e]	Annual damage increase[f]	Average annual damage[g]
(code)	(acres)	(acres)	(percent)	(code)	(dollars)	(acres)	(dollars)	(dollars)
2-1 . . .	6.0	1.0	3.31	122	47.37	0.00440	0.208	3.562
2-2	10.5	0.4	1.32	522	27.97	0.00176	0.049	0.841
3-2 . . .	11.7	0.2	0.66	422	34.06	0.00088	0.029	0.512
4-1 . . .	16.6	1.5	4.96	522	29.72	0.00660	0.196	3.353
4-3 . . .	13.9	4.4	14.56	522	34.32	0.01936	0.664	11.357
4-4 . . .	4.5	2.8	9.27	422	42.33	0.01233	0.521	8.921
4-5 . . .	5.6	2.3	7.61	522	35.97	0.01012	0.364	6,222
4-f	2.9	0.5	1.65	[h]	0.00	0.00219	0.000	0.000
6-3 . . .	15.5	2.3	7.61	422	40.24	0.01012	0.407	6.961
6-4 . . .	6.2	5.2	17.21	122	62.70	0.02289	1.435	24.533
6-5 . . .	19.0	3.5	11.58	522	31.28	0.01540	0.481	8.234
6-6	17.1	1.5	4.96	421	38.04	0.00660	0.251	4.291
6-8 . . .	12.2	4.6	15.30	122	64.69	0.02035	1.316	22.503
Totals	141.7	30.2	100.00			0.13300	5.925	101.295

[a] Field codes from fig. 2 in text.
[b] Included Napier soil units of 3-5 percent slope within affected fields.
[c] Percent of total susceptible area of 30.2 acres.
[d] Systems identified in fig. 2; net incomes are in projected long-term prices.
[e] Column 4 x 0.133 acre per year from fig. B-2.
[f] Column 6 x column 7 (rounded to 3 places).
[g] Column 8 x $312 x 0.05478 (amortization factor for 5 percent and 50 years). See equation 1.
[h] Nonincome use assumed for farmstead.

TABLE B-2. AVERAGE ANNUAL GULLY DAMAGE IN THE MAIN DRAINAGE ALLOCATED AMONG CONTRIBUTING FIELDS WITH RESPECT TO LAND USES.

Field ident.[a]	Field area[a] Total	Field area[a] Proportionate	Established land use Ident.[b]	Established land use Runoff index[c]	Weighted index	Allocated damage
(code)	(acres)	(%/100)	(code)	(Wi)	(2)x(3)x(5)	(dollars)
2-1	6.0	1.00	100	65.2	391.20	4.81[d]
2-2	10.5	1.00	100	68.6	720.30	8.88
2-3	2.4	1.00	100	55.6	133.44	1.64
3-2	11.7	1.00	500	58.6	685.62	8.44
4-1	16.6	1.00	700	55.2	916.32	11.29
4-2	7.6	1.00	700	46.6	354.16	4.36
4-3	13.9	1.00	700	45.8	636.62	7.84
4-4	4.5	1.00	100	63.2	284.40	3.50
4-5	5.6	1.00	100	63.2	353.92	4.36
4-f	2.9	1.00	100[e]	49.6	143.84	1.77
6-2	27.6	0.18	400	51.3	254.44	3.13
6-3	15.5	0.27	400	56.3	235.33	2.90
6-4	6.2	1.00	600	34.1	208.01	2.56
6-5	19.0	1.00	600	50.4	969.01	12.02
6-6	17.1	1.00	400	47.4	801.54	9.98
6-8	12.2	1.00	400	46.5	567.30	6.99
6-f	4.8	1.00	100[e]	40.0	192.00	2.36
8-r	29.0	0.25	100[e]	50.0	362.50	4.46
Total or means . .	213.10	157.50[f]		52.2[g]	8,218.95	101.29

[a] Field codes, and approximate proportionate acreages can be noted from fig. 2.
[b] Established land use in 1947 from fig. 2.
[c] Runoff indexes are from the reference in note 1 of this appendix.
[d] Total damage from equation 1 and table B-1 allocated by weighted indexes.
[e] The equivalent of continuous corn and no practices was assumed on farmsteads and roads.
[f] Total main drainage area in acres is cross-product sum of columns 2 and 3.
[g] Weighted average index is total of column 6 divided by 157.50 acres.

APPENDIX C: EVALUATING FLOOD DAMAGE FROM RUNOFF VOLUMES

In associating flood damage with land use, runoff volumes were estimated directly from runoff percentages applicable to various cover conditions, conservation practices and degrees of terracing. Runoff resulting from various cropping conditions and conservation practices (other than terracing) was determined from relative values observed for the 12 most erosive storms occurring at the Western Iowa Experimental Farm at Castana from 1948 to 1956. Runoff estimates relative to degree of field slope were based on 1933-38 studies at the Upper Mississippi Valley Conservation Experiment Station at LaCrosse, Wisconsin, and estimates relative to slope length were based on 1933-42 data obtained at the Missouri Valley Loess Conservation Experiment Station at Clarinda, Iowa. Coefficients thus derived from the Castana storm record and the experiments cited were adjusted to a local basis by using the record of 14 flood-producing storms which occurred in the Nepper Watershed from April to September during the period 1950-54. Coefficients applicable to land-use systems in effect on individual field units were then utilized to estimate average annual runoff volumes and related flood damages.

Damaging effects of excess runoff as a detrimental output associated with land-use systems were evaluated as the separate forms of potential flood damage in the Nepper Watershed. These included damage to crops on the watershed floodplain (field 7-4 in fig. 2), damage at the Monona County bridge site and offsite or downstream damages on the Maple River floodplain. With regard to hydrologic relations between watershed sectors, these distinct problems and available runoff data, the hydrologic variable directly causing onsite crop flooding was assumed to be overflow volume. Overflow was determined as the excess of storm runoff from all fields within sectors denoted by F in fig. 2 over the capacity of an unimproved drainageway to divert about 5.72 acre-feet of storm runoff into the Maple River. Total runoff from all fields situated above the Monona County bridge was the variable related to bridge damage, while net watershed runoff (total watershed runoff less floodplain overflow) was related to offsite flood damage. In the absence of a more adequate long-term record, the 1950-54 flood-storm record for the Nepper Watershed (table C-1) was used for computing average annual flood damage of all types. Runoff estimates required in all evaluations utilized the relation

$$R_i = (a_i k_i P)/12 \quad ; \tag{3}$$

where R_i = runoff in acre-feet from *ith* field,

a_i = acreage of *ith* watershed source-area, including fields, farmsteads and roads; $i = 1, 2, \ldots 32$ contributing areas,

k_i = proportion of rainfall appearing as runoff, as determined from cover conditions, conservation practices, basic soil-slope features, watershed area and rainfall intensity,

P = rainfall in inches.

TABLE C-1. ADJUSTMENT OF EXPERIMENTAL PLOT RUNOFF OBSERVATIONS TO RUNOFF OBSERVED FROM THE NEPPER WATERSHED FLOOD-STORM RECORD FOR 1950-54.

Nepper Watershed storm record: Date	Rainfall	Watershed runoff[a]	Floodplain overflow[a]	Net offsite runoff
	(in.)	(ac. ft)	(ac. ft.)	(ac. ft)
6/18/50	1.67	21.70	6.14	15.56
8/ 4/50	1.43	17.18	3.77	13.41
4/30/51	1.47	27.82	9.37	18.45
5/ 1/51	1.20	19.12	4.79	14.33
6/ 1/51	1.40	18.15	4.28	13.87
6/17/51	5.62	101.00	47.88	53.12
6/20/51	2.00	26.85	8.86	17.99
6/23/51	1.02	20.73	5.64	15.09
8/15/51	0.97	18.80	4.62	14.18
6/26/52	2.82	26.85	8.86	17.99
7/ 6/52	2.16	18.15	4.28	13.87
6/24/53	3.62	32.01	11.57	20.44
5/27/54	3.87	50.71	21.48	29.23
6/20/54	2.06	29.43	10.22	19.21
Average per storm:				
April 1—May 31	2.18	32.53	11.87	20.66
June 1—Sept. 30	2.25	30.07	10.56	19.51
Seasonal	2.23	30.60	10.84	19.76
Average per year:				
April 1—May 31	1.31	19.53	6.95	12.41
June 1—Sept. 30	4.95	66.17	25.41	42.95
Seasonal	6.26	85.70	32.36	55.36
Average percent runoff:	*Watershed record*	*Period weight*	*Plot record*[b]	*Watershed weight*
April 1—May 31	37.30	1.09	17.40	2.14
June 1—Sept. 30	33.34	0.96	17.40	1.91
Seasonal	34.16	1.00	17.40	1.96

[a] Watershed runoff was assumed to originate from the entire 480-acre watershed area under 1950-54 land-use conditions, while floodplain overflow was assumed to originate under similar land use from the 293-acre sector contributing to onsite crop flood damage.

[b] Simulated runoff percentages approximated from 1950-54 watershed land-use conditions and 1948-56 plot runoff studies at the Western Iowa Experimental Farm (see table C-2 for plot results).

Relative values of k_i associated with different cover conditions, practices, slope degree and slope length were based on 1948-56 soil and water loss studies at the Western Iowa Experimental Farm at Castana. Results are summarized in table C-2. Relative values for land-use systems feasible in the watershed were derived as shown in tables C-2 to C-4. A runoff coefficient of 42.94 percent, observed for continuous corn on 12-percent slope Ida silt loam plots 72.6 feet in length with no special tillage practices, was arbitrarily established as a base. Relative values between early and later stages of the growing season and adjustment of the Castana plot relationships to a local basis are given in table C-3, where aggregate percentages derived by applying plot relationships to actual land-use systems for 1950-54 on each watershed field were compared with percentages derived from stage records of individual storms. Average values of k_i for individual fields, with any given feasible land-use system assumed in effect, were then determined from

$$k_i = (0.4295)\,(1.96) F_r F_c F_t F_s F_f F_p \quad ; \tag{4}$$

where $100\,k_i$ = average percentage runoff with regard to soil-slope conditions, land use and period of growing season; $i = 1, 2, \ldots 32$ watershed source-areas,

0.4295 = proportionate runoff from continuous corn,

1.96 = uniform adjustment of observed experimental runoff at Castana to a Nepper Watershed basis; from table C-1,

F_r = runoff relative to rotations; from table C-4,

TABLE C-2. EFFECT, IN INCHES, OF COVER CONDITIONS AND CONSERVATION PRACTICES ON RUNOFF FOR THE 12 MOST EROSIVE STORMS AT THE WESTERN IOWA EXPERIMENTAL FARM AT CASTANA, 1948-56.[a]

Castana storm record		Runoff in a CO_c rotation				Runoff in a COMM rotation			
Date	Rainfall	Corn no practices	Corn contoured	Corn listed	Oats disked	Corn listed	Corn disked	Meadow year 1	Meadow year 2
7/25/48	1.97	0.36	0.46	0.37	0.33	0.29	0.24	0.34	0.21
7/29/48	2.07	0.57	0.36	0.31	0.16	0.24	0.13	0.19	0.08
8/10/48	1.90	0.86	0.70	0.74	0.30	0.48	0.25	0.27	0.18
8/26/48	1.51	0.72	0.43	0.68	0.13	0.46	0.15	0.10	0.04
6/15/50	0.97	0.68	0.36	0.02	0.42	0.39	0.08	0.03	0.52
6/17/51	3.11	1.58	1.58	0.88	1.48	0.25	0.44	0.09	0.51
7/ 3/51	0.89	0.45	0.27	0.16	0.23	0.14	0.05	0.08	0.24
7/ 6/52	2.95	1.01	0.96	0.64	0.23	0.11	0.00	0.00	0.00
6/19/54	1.68	0.74	0.88	0.37	0.87	0.11	0.89	0.10	0.04
6/21/54	1.91	0.49	0.83	0.39	0.77	0.13	0.59	0.00	0.00
5/10/56	1.73	0.41	0.45	0.00	0.39	0.00	0.47	0.20	0.00
7/11/56	2.06	0.43	0.43	0.48	0.48	0.33	0.43	0.42	0.07
All storms	22.75	8.30	7.71	5.04	5.79	3.03	3.72	1.82	1.89
Average per storm (inches)	1.90	0.82	0.78	0.49	0.62	0.26	0.33	0.16	0.20
Average per storm (percent)	. . .	42.94[b]	41.44	25.87[b]	32.66	13.74[b]	17.51	8.36	10.65

[a] Data from: W. E. Larson and F. W. Schaller. Spacing of level terraces in western Iowa. Agr. Engr. 39:20-23. 1958.

[b] Interpolate percent for corn with no practices in COMM as follows: $\frac{13.74 \times 42.94}{25.87} = 22.80$ percent.

F_c = runoff relative to conservation practices; from table C-4,

F_t = proportion of field terraceable; this factor was applicable only if terracing was included as a conservation practice in F_c,

F_s = runoff relative to degree of field slope; from table C-4,

F_f = runoff relative to field length; from table C-4,

F_p = runoff relative to period of growing season; from table C-1.

TABLE C-3. ANNUAL FLOOD-PRODUCING RUNOFF IN RELATION TO CROPPING CONDITIONS.[a]

Cropping conditions[b]	Percent runoff[c]	Relative frequency of conditions by rotations (percent)						
		CCCC	CCCO	CO_c	CCOM	COMM	COM_4	MMMM
1	42.94	100	75	0	0	0	0	0
2	22.80[d]	0	0	50	50	25	17	0
3	32.66	0	25	50	0	0	0	0
4	17.51	0	0	0	25	25	17	0
5	8.36	0	0	0	25	25	17	0
6	8.36[e]	0	0	0	0	25	49	100
Rotation runoff percentages	. . . .	42.94	40.37	27.73	17.86	14.25	12.37	8.36

[a] Data are based on 1948-56 soil and water loss studies at the Western Iowa Experimental Farm, as reported in table C-2.

[b] Cropping conditions are identified as follows:
1. Continuous corn or corn in rotations excluding legumes
2. Corn in rotations including legumes
3. Oats in rotations excluding legumes
4. Oats in rotations including legumes
5. First-year meadow
6. Successive meadow

[c] Mean percent flood runoff applies to seasonal or annual flood-producing rainfall. Flood-runoff percentages of rainfall apply to the 12 most erosive storms tabulated in table C-2. Percentages for each cropping condition were weighted by maximum hourly rainfall intensities of each observed erosive storm.

[d] Interpolated from corn in COMM contour listed (13.74), corn in CO_c planted with slopes (42.94) and corn in CO_c contour listed (25.87), as indicated in table C-2.

[e] Observed as **10.65** percent but not regarded as significantly higher than first-year meadow.

With average annual flood damage to crops dependent on source-area land use, average annual overflow volumes, the time distribution of overflow within the growing season, the effect of different depths of flooding on crops at different growing stages, floodplain land use (or crops actually grown) are projected prices of crops and related inputs, the procedure for evaluating such damage consisted of first estimating probable runoff for the period April 1 to May 31 as follows:

$$R_e = \sum_{i=1}^{23} (a_i p_i k_i P_e)/12 \quad ; \qquad (5a)$$

where R_e = average annual flood runoff between April 1 and May 31, in acre-feet,

a_i = acreage of *ith* watershed field located

TABLE C-4. FLOOD-PRODUCING RUNOFF IN RELATION TO LAND USE, FIELD SLOPE AND SLOPE LENGTH.

Cover conditions	CCCC	CCCO	CO^c	CCOM	COMM	COM_4	MMMM
Percent runoff[a]	42.94	42.37	27.73	17.86	14.25	12.37	8.36
Relative to CCCC	1.00	0.94	0.64	0.41	0.33	0.28	0.19
Conservation practices with CCCC				None	Contouring		Terracing
Percent runoff[a]				42.94	41.44		0.00
Relative to no practices				1.00	0.96		0.00
Percent slope of plots			3	8	13		18
Percent runoff on plots[b]			32.10	32.40	36.40		41.50
Field slope percent limits:							
Lower		0	0.6	4.6	10.6		15.6
Upper		0.5	4.5	10.5	15.5		15.6+
Runoff relative to 13%		0 00	0.88	0.89	1.00		1.14
Plot slope length in feet		36	72	157	315		630
Percent runoff on plots[c]		21.20	18.20	16.00	13.90		12.10
Field slope length limits:							
Lower		0	56	116	237		478
Upper		55	115	336	472		473+
Runoff relative to 72 feet		1.15	1.00	0.99	0.76		0.66

[a] Runoff percentages for cover conditions and conservation practices other than terracing are from tables D-2 and D-3. Runoff is assumed to be zero upon installation of level terraces designed to retain up to 2 inches of runoff per storm.

[b] Runoff percentages for degree of field slope are from: United States Department of Agriculture, Soil Conservation Service. Investigations in erosion control and the reclamation of eroded land at the Upper Mississippi Valley Conservation Experiment Station near La Crosse, Wisconsin. 1933-43. Tech. Bul. 973. U. S. Govt. Print. Off., Washington, D. C. 1949. p. 28. Data given were observed on Fayette silt loam plots 72.6 feet in length planted to grain with slopes shown.

[c] Runoff percentages for slope length are from: United States Department of Agriculture, Soil Conservation Service. Investigations in erosion control and the reclamation of eroded land at the Missouri Valley Loess Conservation Experiment Station near Clarinda, Iowa. 1933-42. Tech. Bul. 959. U. S. Govt. Print. Off., Washington, D. C. 1948. pp. 47-52. Data given are for Marshall silt loam plots of 9 percent slope. Plots less than 157 feet in length were surface-planted to corn with slopes; remaining plots were lister-planted to corn with slopes.

wholly or partially within sectors designated by F in fig. 2,

p_i = proportionate acreage of each field located within the 293-acre contributing area F,

k_i = proportionate runoff determined from equation 4, with the period factor F_p selected as 1.09 from table C-1,

P_e = 1.31 inches average annual flood-producing rainfall between April 1 and May 31; from table C-1.

Probable overflow before June 1 was then approximated from:

$$O_e = R_e - \sum_{i=1}^{23} (3.16 a_i p_i)/293 = R_e - 3.16; \quad (6a)$$

where O_e = overflow in acre-feet,

R_e = average runoff, from equation 5a,

3.16 = average diversionary capacity in acre-feet of the unimproved drainageway before June 1; = (capacity per storm of 5.27 acre-feet) x (relative annual frequency of flood-producing storms prior to June 1). The latter was noted from table C-1 as three storms during the 5-year 1950-54 record, or as 0.60. Remaining terms are explained under equation 5a.

Estimates of the acreage annually flooded to various depths between April 1 and May 31 were obtained from the overflow-flood depth relations of fig. C-1, constructed from hypothetical applications of estimated 1950-54 overflow quantities given in table C-1 to the Nepper Watershed floodplain. Table C-5 indicates the effects of inundations of the specified depths on crop yields or production costs during this period, including effects for the three crops most likely grown on the floodplain. The effects per flooded acre are expressed as income losses in table C-6 and then combined with areas likely flooded to specified depths in arriving at total damage of \$551 for early stages of growth if the floodplain were cropped to heavily fertilized continuous corn and the contributory area were utilized as in 1947.

A similar procedure was applied to damage evaluation for the later stage of growth, presumed to run from June 1 through Sept. 30. Probable runoff for this period was estimated from:

$$R_m = \sum_{i=1}^{23} (a_i p_i k_i P_m)/12 \quad ; \qquad (5b)$$

TABLE C-5. EFFECT OF FLOODING ON NEPPER WATERSHED CROPS; BY PERIODS AND FLOOD DEPTHS.

Flood depth in inches	Seasonal periods: April 1—May 31 Corn	Oats	Hay	June 1—Sept. 30 Corn	Oats	Hay
	(Percent reduction in yield from unflooded yield)					
0- 6	(replanting	62.5	8.5	25.0	17.5	4.0
6-12	plus	62.5	8.5	50.0	17.5	4.0
over 12	20 bu.)[a]	62.5	16.5	100.0	87.5	17.0

[a] The estimate for corn in the first period is a standard 20-bushel-per-acre reduction in yield from the yield of unflooded corn plus the cost of repeating the seeding operation. Estimates for remaining crops and periods are in percent of nonflooded yield per flood of given depths.

TABLE C-6. MAXIMUM AVERAGE ANNUAL FLOOD DAMAGE TO CROPS UNDER PREDEVELOPMENT LAND USE ON CONTRIBUTING FIELDS; BY PERIODS AND DEPTHS.

Items	Units or depths	Flood periods: April 1-May 31	June 1-Sept. 30	Season
Sector runoff[a]	acre-feet	10.11	37.00	47.11
Ditch diversion[b]	acre-feet	3.16	11.59	14.75
Sector overflow[c]	acre-feet	6.95	25.41	32.36
		Floodplain area flooded by overflow (acres)[c]		
Flood depths	inches			
	0-6	6.44	2.39	8.83
	6-12	6.43	2.87	9.30
	0-12	12.87	5.26	18.13
	over 12	3.94	21.84	25.78
	Total	16.91	27.10	43.91
Flood depths	inches			
		Maximum damage per flooded acre (dollars)[d]		
	0-6	32.75	24.50	30.40
	6-12	32.75	49.00	37.70
	0-12	32.75	9.14	34.40
	over 12	32.75	93.95	84.60
Flood depths	inches	*Total damage (dollars)*		
	0-6	210.87	58.76	269.64
	6-12	210.87	140.78	351.65
	0-12	421.75	199.54	621.29
	over 12	129.08	2,052.38	2,181.46
	Total	550.83	2,251.92	2,802.75
Damage per acre of floodplain		\$32.60	\$82.80	\$67.40[e]
Damage per acre-foot of overflow		\$79.10	\$88.50	\$86.59

[a] Computed from average annual runoff originating on all field units located within sectors designated by F in fig. 2.
[b] Based on ditch diversion of 5.27 acre-feet per storm and the relative annual frequency of flood-producing storms by periods: 0.60 before June 1; 2.20 after May 31; and 2.70 for the season (from table C-1).
[c] Runoff less diversion; acreages flooded other than totals determined from rating curves based on floodplain topography.
[d] Assumes floodplain land use of continuous corn heavily fertilized, where without flooding, annual per-acre gross returns are \$100.18, total costs \$34.69 and net returns \$65.49 (net returns given in fig. C-1).
[e] Total seasonal damage of \$67.40 per flooded acre for 32-acre-feet of seasonal overflow is shown as point A on curve CCCC-F_2 in fig. C-2.

where R_m = average annual flood runoff between June 1 and Sept. 30, in acre-feet,

k_i = proportionate runoff determined from equation 4, with the period factor F_p selected as 0.96 from table C-1,

P_m = 4.95 inches = average annual flood-producing rainfall between June 1 and Sept. 30, from table C-1; remaining terms are explained under equation 5a.

Overflow after May 31 was then determined from:

$$O_m = R_m - \sum_{i=1}^{23} (11.59 a_i p_i)/293 \quad ; \qquad (6b)$$

where O_m = overflow in acre-feet,

R_m = average runoff, from equation 5a,

11.59 = average diversionary capacity in acre-feet of the unimproved drainageway after June 1; = (capacity per storm of 5.27 acre-feet) x (relative annual frequency of flood-producing storms after May 31). The latter was noted from table C-1 as 11 storms during the 5-year 1950-54 record, or as 2.20. Remaining items are explained under equation 5a.

The overflow-flood depth curves of fig. C-1 were utilized again in estimating areas of the floodplain annually flooded to specified depths after May 31. Effects on corn, oats and hay during this major period of the flood season are given also in table C-5. Damages per flooded acre with the floodplain in heavily fertilized continuous corn, combined with estimates of areas flooded to various depths, gave estimated annual damages of \$2,252 after May 31, as shown in table C-6. Maximum average annual crop flood dam-

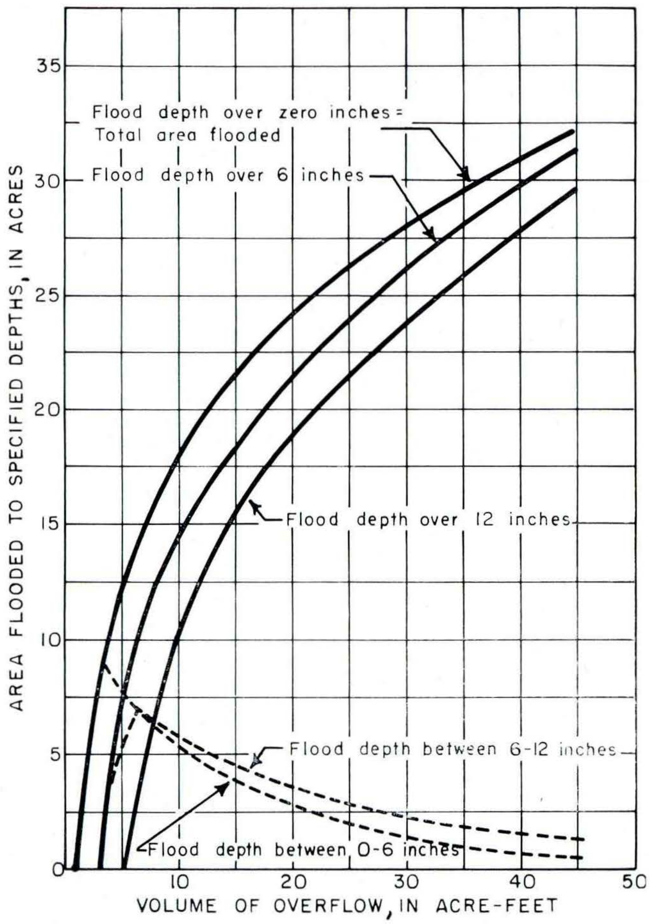

Fig. C-1. Overflow-flood depth curves for the Nepper Watershed floodplain.

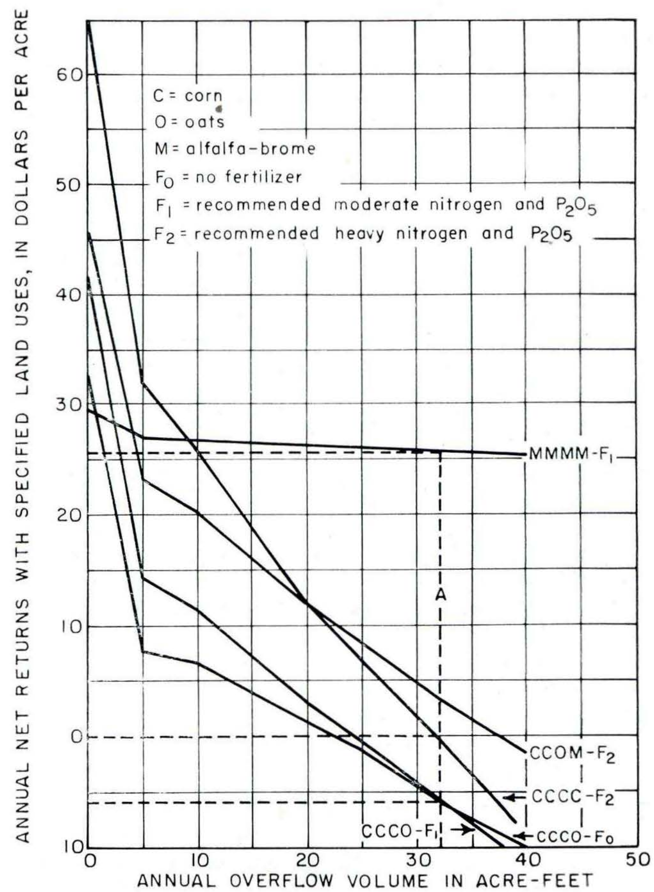

Fig. C-2. Net returns on the Nepper Watershed floodplain in relation to annual overflow and alternative land use.

age of \$2,803 for the entire season was then given as that probable between April 1 and Sept. 30, assuming the floodplain to be farmed for maximum net income (without flooding) and the 293-acre contributory area utilized as in 1947.

Total seasonal damage was allocated among individual fields comprising the contributory area in proportion to overflow quantities initially estimated from equations 6a and 6b. From table C-6, damage allocable per acre-foot of seasonal overflow under the specified land-use conditions was given as \$86.59, while average annual damage per acre of floodplain, assuming its entire 41.6-acre area to be in fertilized continuous corn, was \$67.40.

The calculation of average annual flood damage under predevelopment and alternative watershed land-use systems is illustrated in figs. C-2 and C-3. With reference only to annual overflow from the 293-acre source-area F (possibly resulting from many established land-use patterns), fig. C-2 indicates the decline in floodplain net returns for five selected floodplain land-use systems. All rotations including corn were shown to be more profitable than continuous meadow if overflow onto the floodplain could be eliminated. Otherwise, continuous meadow was most profitable at relatively small volumes of expected annual overflow, substituting for continuous corn at about 9 acre-feet. For any given volume of overflow, damage per floodplain acre was estimated as the loss in net income from the net income obtainable under nonflooded or fully protected conditions. Figure C-3 was thus derived from fig. C-2; it illustrates direct approximation of damage under alternative floodplain uses and various annual overflow volumes. Point A on curve CCCC-F_2 represents the \$67-per-acre damage estimate given in table C-6.

Annual damage to the Monona County bridge attributable to excess runoff from the 89-acre southeast sector MFBO in fig. 2 was also approximated from the 1950-54 flood-storm record, but in conjunction with projected annual damages of \$385 observed under predevelopment conditions. The annual runoff resulting in bridge damage was derived on a seasonal (April 1–Sept. 30) basis, being given by

$$R_b = \sum_{i=1}^{11} (a_i p_i k_i P_s)/12 \quad ; \tag{7}$$

where R_b = seasonal runoff in acre-feet,

a_i = acreage of *ith* watershed field located wholly or partially within the sector MFBO on fig. 2,

p_i = proportionate acreage of field located within the 89-acre contributing area,

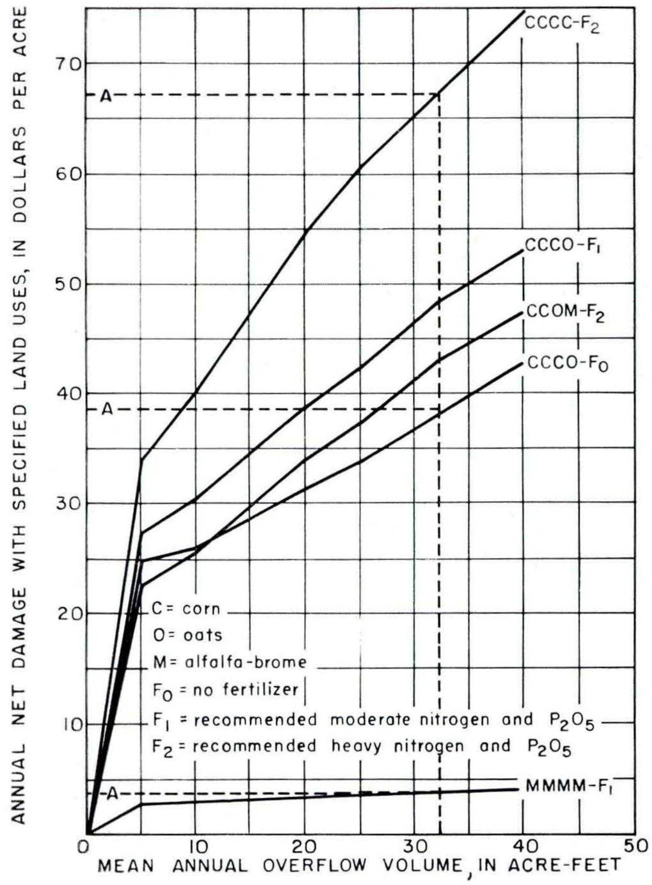

Fig. C-3. Flood damage to crops on the Nepper Watershed floodplain in relation to annual overflow and alternative land uses.

k_i = proportionate runoff, determined from equation 4, with the period factor P_f selected as 1.00 from table C-1,

$P_s = P_e + P_m = 6.26$ inches = average annual flood-producing rainfall between April 1 and Sept. 30; from table C-1.

With predevelopment damage of $385 representing the single observed estimate related to runoff, annual damage was assumed to be proportional to the annual runoff corresponding with predevelopment land use:

$$D_b = (R_b D_b') / R_b' \quad ; \qquad (8)$$

where D_b = average annual damage in dollars corresponding to runoff of R_b acre-feet determined from equation 7,

D_b' = annual damage of $385 observed under predevelopment land-use conditions,

TABLE C-7. PREDEVELOPMENT ANNUAL DAMAGES ALLOCATED AMONG FARMS AND THE ROAD SYSTEM.

Farm no.	Gully damage indexes: Main	Gully damage indexes: Southwest	Flood damage runoff volumes: Onsite bridge	Flood damage runoff volumes: Onsite crops	Flood damage runoff volumes: Offsite
(see fig. 2)	(index)	(index)	(acre-feet)	(acre-feet)	(acre-feet)
1	0	0	0.00	0.00	0.85
2	65	0	6.13	5.28	1.22
3	58	0	2.83	1.98	10.72
4	52	0	6.59	4.18	3.29
5	0	40	0.00	0.32	5.86
6	47	48	0.00	15.60	11.69
7	0	0	0.00	0.04	11.58
Roads	50	0	3.16	4.96	10.15
Watershed	52	47	18.71	32.36	55.36
Predevelopment damages allocated (dollars)[a]					
1	0	0	0	0	2
2	15	0	126	457	3
3	8	0	58	171	27
4	33	0	136	362	8
5	0	7	0	28	15
6	41	29	0	1,352	30
7	0	0	0	3	29
Roads	4	0	65	430	26
Watershed	101	36	385	2,803	140

[a] Allocated damages for farms, roads and the watershed are computed as the product of corresponding hydrologic units in the upper section and predevelopment damages per hydrologic unit as estimated in table 4.

R_b' = 18.71 acre-feet = runoff computed for predevelopment conditions from equation 7.

Damage allocable to fields within the 89-acre contributory area on the basis of equation 8 was $385/18.71 = $20.51 per acre-foot of runoff, regardless of the quantity of runoff estimated under alternative land-use systems from equation 7.

The remaining problem of offsite or downstream flooding associated with watershed land use was evaluated in terms of net watershed runoff, represented by the excess of annual runoff from all sectors denoted by O (see fig. 2) over the portion of such runoff appearing as overflow on the floodplain. The procedure varied little from those already described. Farm-by-farm allocations of flood damage are given with corresponding gully damage allocations in table C-7.

Although the emphasis in this report was on techniques, the problem of securing reliable basic flood damage data should be emphasized. The data from the plot studies and the small watershed studies are reliable; however, extending plot data for a single soil type and uniform cover to areas many times larger involving different soils, slopes and cover has little experimental confirmation.

Since the capacity of the original drainageway and the exact nature of the hydrograph at the floodplain were not known, an arbitrary ¼ inch of runoff from each flood-producing storm was assumed to be carried in the drainageway. Runoff volumes over ¼ inch were assumed to flow onto the area where damage occurred. In the case of the Nepper Watershed, the natural topography and the river levees held water on the land. For this study the volumes of flood runoff were assumed to be cumulative, however, because some floodwater would evaporate or infiltrate, and the flood damage figures tend to be overstated.

APPENDIX D: ILLUSTRATED DELIMITATION OF LAND TREATMENT

The method of selecting for each field and land-treatment measures appraised in detail for benefits and costs and the appraisals as such are reviewed in this appendix for field unit 2-1 in fig. 2. The method was applied to all 27 fields, however, and followed from similar assumptions and requirements.[27]

Basic Features and Feasible Land Use

Totaling 6 acres in area, field 2-1 includes Ida soils of 4-8 percent slope (1.4 acres), Ida soils of 16-25 percent slope (1.7 acres), Monona soils of 10-14 percent slope (1.9 acres) and Napier soils of 3-5 percent slope (1.0 acre). Possible land uses indicated that, in addition to the entire range of feasible cropping conditions,[28] contouring and fertilizing were practicable on the entire area, and about 84 percent of the area was terraceable.[29] The average degree of field slope is 11.9 percent, and the slope length is 455 feet. Figure 2 shows that the entire field contributed to gully damage in the main drainage and to all classes of flood damage.

Sheet Erosion Control

Considering the requirement that sheet erosion be controlled, application of Browning's procedure for estimating annual erosion rates for 55 feasible land-use systems suggested that a predevelopment rate of 27 tons per acre could have been reduced to about 3 tons by terracing the field, without abandoning continuous corn cropping or applying fertilizer. Terracing also would have been essential for erosion control if a CCCO rotation were considered. Erosion could have been reduced to 5 tons with a CO_c rotation, however, if the change at the minimum had involved contouring plus fertilizing at moderate rates.[30] Contouring alone would have been sufficient under a CCOM rotation, while a change to either COMM, COMMMM or continuous meadow without supplementary practices also would have reduced erosion to the permissible 5-ton rate. The requirements that sheet erosion be controlled eliminated from planning consideration 19 of the 55 land-use systems agronomically feasible for field 2-1. Acceptable rates for the 36 remaining systems are shown in column 2 of table D-1.

Corn Frequency

Preference for corn as a cash crop, provided annual erosion rates would not exceed 5 tons per acre, was recognized by further limiting the range of erosion-controlling land-use systems to those involving only the three (or fewer) rotations in which corn would recur most frequently.[31] With terracing permitting continuous corn cropping on the field, as shown in table D-1, rotations limited by corn frequency included continuous corn, CCCO and CO_c. Imposing the requirement for relatively frequent corn reduced the range of 36 systems effective in erosion control analyzed further to 12. Budgetary data for the 12 systems are given in columns 3-6 of table D-1.

On-Farm Profit Maximization

To apply a restriction of this nature, the first 12 systems listed in table D-1 were examined for source-area returns and costs. For all fields, these amounts were computed without including related flood or gully damages. They were presumed to influence decisions of operators interested in holding erosion to permissible levels but not particularly interested in reducing associated gully and flood damage, although significant reductions in damage would doubtless be complementary with erosion control. Two general situations of capital availability on farm 2 (and all farms) were considered by first eliminating systems failing to yield either maximum net returns per acre (representative of nonlimiting capital) or maximum returns per unit of capital used (representing the most profitable land use with capital limited). The system on field 2-1 yielding maximum net returns of

[27] For assumptions of the study concerning feasible land use and successive conditions for selecting land-treatment activities, see the text section on Land-Treatment Delimitation.

[28] Including CCCC, CCCO, CO_{c1}, CCOM, CCO_{c1}, COMM, COMMMM and MMMM.

[29] Nonterraceable Napier soils occupy 16 percent of the field area.

[30] Estimated from separate recommendations for each soil to be about 27 pounds of available nitrogen and 25 pounds of available phosphorous per acre. See table A-1 for sample data pertaining to the predominant soil type in the Nepper Watershed.

[31] If CO_c and CCOM (equal corn frequency) would both control erosion, both were analyzed further.

TABLE D-1. ANNUAL PER-ACRE EROSION RATES AND ON-FARM RETURNS OF SELECTED EROSION-CONTROLLING LAND-USE SYSTEMS ON FIELD 2-1.

Erosion-controlling systems[a]	Computed erosion	Gross returns[b]	Total costs	Net returns	Net per-unit capital
(code)	(tons)	(dollars)	(dollars)	(dollars)	($/$)
120	3.26	30.93	20.72	10.20	0.49
121	2.52	69.80	31.61	38.19	1.20
122[c]	1.73	84.95	39.96	44.99	1.12
220	2.47	26.27	19.98	6.29	0.31
221	1.89	58.20	29.03	29.17	1.00
222	1.58	69.91	35.56	34.35	0.96
311	3.94	48.60	25.80	22.80	0.88
312	2.78	55.09	29.58	25.51	0.86
320	1.21	31.49	18.85	12.64	0.67
321	0.94	51.54	25.99	25.55	0.98
322[c]	0.63	58.06	28.50	29.56	1.03
700[c]	0.68	42.63	15.05	27.58	1.83
410	4.78				
411	3.68	(Computations for remaining systems obviated by infrequent corn)			
412	2.57				
420	1.16				
421	0.89				
422	0.63				
500	4.10				
501	3.15				
502	2.20				
510	2.05				
511	1.58				
512	1.10				
520	0.47				
521	0.37				
522	0.26				
600	2.05				
601	1.58				
602	1.10				
610	1.05				
611	0.79				
612	0.52				
620	0.26				
621	0.21				
622	0.16				

[a] See fig. 2 for land-use code explanations.
[b] Returns and costs were computed for the systems involving the three most corn-frequent rotations controlling erosion, excepting system 700 (continuous meadow).
[c] On-farm returns to land (column 5) are maximized by system 122 and returns to capital (column 6) by system 700; while maximum erosion control from corn-frequent systems is obtained from system 322 (column 2).

$45 per acre was (from column 5, table D-1) continuous corn terraced and heavily fertilized, while (from column 6) the system yielding maximum net returns to capital of $1.83 was permanent meadow.

Aggregate Net Benefit Maximization

Although on-farm benefits would be important in justifying watershed-treatment measures, the possibility remained that land-use systems other than those yielding maximum on-farm returns to land or capital would yield maximum watershed-wide or aggregate development returns through a greater reduction of land-use-associated damages. This possibility was recognized by including also for benefit-cost analysis the system in column 2 of table D-1 that minimized sheet erosion while satisfying the requirement for frequent corn. This was a CO_c rotation terraced and heavily fertilized.

Benefits and Costs of Land Treatment

Detailed evaluation of returns and costs of terraced and heavily fertilized continuous corn, a CO_c rotation fertilized and terraced, continuous meadow and the predevelopment continuous corn cropping system on field 2-1 are given in section A of table D-2. Gross crop values and direct production expense for the 6 acres were derived from the per-acre on-farm data of table D-1. Associated gully damage was based on damages of $0.01232 per unit of the corresponding runoff index weighted for field area, as given in table 4. The benchmark estimate of $4.81 in gully damage under predevelopment conditions was allocated to the field by the procedure illustrated in table B-2. Flood damage to onsite crops was estimated from the seasonal overflow volume originating from the field under each system shown, regardless of conditions on other contributing fields. Unit damages of $86.59 per acre-foot of seasonal overflow are given in table 4. Also from table 4, flood damage to the onsite county bridge was derived from unit damages of $20.51 per acre-foot of seasonal runoff; offsite flood damage was derived from $2.52 per acre-foot of allocable net watershed runoff.

Benefits and costs of shifting to alternative land-use systems from the predevelopment continuous corn system involving no conservation practices were computed as in section B, table D-2. Although mere adoption of terracing and fertilizing would have provided greater benefits in total (largely credited to an increased corn output), the two practices combined with a shift to a CO_c rotation and a shift to continuous meadow alone would have been somewhat more effective in damage control. Terracing alone, however, would have reduced average annual overflow volumes by 1.68 acre-feet and floodplain damage by about $146 annually. The 1.68 acre-feet of runoff retained by terraces also would have reduced annual damage to the county bridge by $34.64.

Increased annual production costs associated with terracing and fertilizing alone were estimated at $123 in table D-2, and installation of the required 2,890 feet of terraces at $115. These outlays were distributed among beneficiaries in table D-3 to establish whether the practices could be justified economically.

In presenting a complete appraisal of costs and benefits on both the annual-equivalent and present-value bases, table D-3 followed from the cost-sharing criterion that, on either basis, total costs would be shared proportionately with total benefits, so that contributed resources would yield the same rate of net return for all beneficiaries. On an annual basis in item 12 of section I, for example, about 94 percent of the benefits of terracing and fertilizing of field 2-1 would accrue to four watershed farmers[32] and the remaining 6 percent to Monona County. Increased production expenses on farm 2 thus were allocated to farmer-beneficiaries and Monona County in these proportions. On the present-value basis of section II, however, about 90 percent of the benefits would have gone to the farmers and 10 percent to Monona County. The required investment of $115 in terrace construction was assigned by these percentages but then spread over the project period by the respective amortization factors of item 3. Aggregated annual net benefits of $409 resulting from total identified benefits of $539 less costs of $129 thus assigned would have represented an annual net return for all beneficiaries of $3.16 per unit value of all contributed resources, including initial capital outlays.

In section II of table D-3, all annual amounts are

[32] Increases in gross crop values would be retained on farm 2; gully-control benefits would be distributed proportionately with predevelopment damages on farms 2, 3, 4 and 6; and flood-control benefits to onsite crops would be limited to farm 7.

TABLE D-2. COMPUTATION OF LAND-TREATMENT BENEFITS ON FIELD 2-1, IN DOLLARS UNLESS INDICATED OTHERWISE.

Items by land-use systems or land-treatment measures	Section A: Associated returns and costs for coded systems of land use[a]				Section B: Associated benefits and costs of systems[b]		
	122	322	700	100	122	322	700
Annual returns							
1. Gross value of crops produced	509.70	348.36	255.78	154.02	355.68	194.34	101.76
Annual costs							
2. Direct production expense	239.76	171.24	90.30	116.22	123.54	55.02	–25.92
3. Gully damage; main drainage	2.22	2.11	3.34	4.81	–2.59	–2.70	–1.47
4. Flood damage; onsite crops	1.54	0.00	17.29	147.79	–146.25	–147.79	–130.49
Seasonal overflow (acre-feet)	0.02	0.00	0.20	1.70	–1.68	–1.70	–1.50
5. Flood damage; onsite bridge	6.55	4.09	10.28	41.20	–34.64	–37.10	–30.91
Seasonal runoff (acre-feet)	0.32	0.20	0.50	2.00	–1.68	–1.80	–1.50
6. Flood damage; offsite	0.97	0.67	0.97	0.97	0.00	–0.33	0.00
Net runoff (acre-feet)	0.30	0.20	0.30	0.30	0.00	–0.10	–0.00
7. Total annual cost decreases	...	...	...	...	–183.44	–187.92	–188.79
8. Total annual benefits (Item 1 less item 7)	...	...	...	...	539.16	382.26	290.55
9. Initial installation outlay	...	...	...	...	115.62[c]	115.62[c]	185.76[d]

[a] See fig. 2 for explanation of land-use codes.
[b] Computed as respective columns in section A less the column headed 100 in section A, or as changes in items alternately induced by shifting from predevelopment continuous corn (system 100) to the three other systems selected as in table D-1.
[c] For installation of 2,890 linear feet of terraces at $0.04 per foot.
[d] Represents the present value (in 1947) of establishing and re-establishing permanent meadow at 4-year intervals for 50 years.

TABLE D-3. BENEFITS AND COSTS OF TERRACING AND FERTILIZATION OF FIELD 2-1 DISTRIBUTED AMONG PRIVATE AND PUBLIC PARTICIPANTS, IN DOLLARS UNLESS INDICATED OTHERWISE.

Annual or present value items	Section I. Annual equivalents			Section II. Present values		
	Onsite private	Onsite public	Watershed total	Onsite private	Onsite public	Watershed total
1. Rate of discount in percent per year	5.0	2.5	...			...
2. Present value of $1 per year for 50 years	...	...	...	18.25483	28.36074	...
3. Amortization of $1 over 50 years	0.05478	0.03526	...	...	...	...
Changes in returns						
4. Gross value of crops produced (from table D-2)[a]	355.68	0.00	355.68	6,492.87	0.00	6,492.87
Changes in costs						
5. Direct production expense (from table D-2)[a]	123.54	0.00	123.54	2,255.20	0.00	2,255.20
6. Gully damage; main drainage (from table D-2)	–2.59	0.00	–2.59	–47.28	0.00	–47.28
7. Flood damage; onsite crops (from table D-2)	–146.25	0.00	–146.25	–2,669.76	0.00	–2,669.76
8. Flood damage; onsite bridge (from table D-2)	0.00	–34.64	–34.64	0.00	–982.41	–982.41
9. Cost decreases	–148.84	–34.64	–183.48	–2,717.04	–982.41	–3,699.45
10. Cost increases	123.54	0.00	123.54	...	982.41	–10,192.32
Net benefits determination						
11. Total benefits (item 4 less item 9)	504.52	34.64	539.16	9,209.91	982.41	–10,192.32
12. Percent total benefits[b]	93.58	6.42	100.00	90.36	9.64	100.00
13. Allocated cost increases (item 12 x $123.54)	115.60	7.94	123.54	2,110.20	225.09	2,335.29
14. Installation outlay (item 3 x section II)[b]	5.72	0.39	6.11	104.47	11.15	115.62
15. Total costs (add items 13, 14)	121.32	8.33	129.65	2,214.67	236.24	2,450.91
16. Net benefits (item 11 less item 15)	383.20	26.31	409.51	6,995.24	746.17	7,741.41
17. Ratio of net benefits to costs	3.16	3.16	3.16	3.16	3.16	3.16

[a] Table D-2 references apply only to section I; section II is derived from section I, except as noted below.
[b] Items 12 and 14 in section II are computed independently of section I; remaining items in section II are computed as products of annual values and the present value factors of item 2 above.

converted to present values by the present-value factors (of item 2) corresponding to the discount rates of 5 and 2.5 percent. If adopted on field 2-1 in 1947, the practices of terracing and fertilizing would have returned $10,192 as the present value at that time of $539 in annual benefits received over the 50-year project period, with all immediate and recurring outlays valued comparably at $2,450. Net benefits of $7,741 again would have represented for all beneficiaries a return of $3.16 per unit value of contributed resources.

Appraisals of the three land-treatment alternatives for field 2-1 by the method of table D-3 are summarized in annual-equivalent form in table D-4. All measures would be economically justified in yielding net benefits, both in the aggregate and, because of proportionate cost-sharing, for all beneficiaries. Although all would have benefited farms 2, 3, 4, 6 and 7, as well as Monona County, only the second would have provided any measure of offsite flood control as an added public benefit. Farms 1 and 5 would have been neither benefited nor damaged, because both lay outside the main gully drainage and also would have been unaffected by flood runoff.

Higher rates of return with the adoption of a CO_c rotation or permanent meadow shown in table D-4 relate to requirements for operating capital. The latter would require (see table D-2) $90 in operating capital, or $26 less than the predevelopment system of continuous corn. High rates also implied that field 2-1 was a critical damage and treatment area. That is, initial inputs of scarce development resources allocated to establishment and continuation of permanent meadow on the field would be an effective means for maximizing net benefits in a watershed development program.

TABLE D-4. BENEFITS AND COSTS IN DOLLARS OF ALTERNATIVE LAND TREATMENTS ON FIELD 2-1.[a]

Land-treatment measures	Annual items	Onsite private	Total public	Watershed total
122-CCCC with	Total benefits	504.52	34.64	539.16[b]
terraces	Total costs	121.32	8.33	129.65
and heavy	Net benefits	383.20	26.31	409.51
fertilizer[c]	Net/costs	3.16	3.16	3.16
322-CO_c with	Total benefits	344.83	37.43	382.26[b]
terraces	Total costs	55.04	5.97	61.01
and heavy	Net benefits	289.79	31.46	321.25
fertilizer	Net/costs	5.26	5.26	5.26
700-MMMM	Total benefits	259.64	30.91	290.55[b]
with no	Total costs	8.58	1.02	9.60
terraces or	Net benefits	251.06	29.89	280.95
fertilizer	Net/costs	29.26	29.26	29.26

[a] From fig. 2 the base or benchmark system is taken as CCCC with no practices.
[b] From item 8, section B, table D-2.
[c] See table D-3 for detailed costs and benefits.

TABLE D-5. SELECTION OF ALTERNATIVE LAND-TREATMENT ACTIVITIES FOR FIELD 2-1 IN THE NEPPER WATERSHED.[a]

Conditions for selection as field-treatment activities	Number of systems: Added	Deleted	Remaining
1. Entire range of feasible systems	55	0	55
2. Annual erosion less than 5 tons per acre	0	19	36
3. Corn relatively frequent	0	24	12
4. Maximum on-farm returns per acre	0	10	2
5. Maximum on-farm returns to capital	0	0	2
6. Minimized sheet erosion	1	0	3
7. Net benefits (over predevelopment)	0	0	3
8. Maximum net benefits	0	1	2
9. Maximum net benefits per unit cost	1	0	3
10. Alternative field-treatment activities	0	0	3

[a] See table 6 in text for the comparable summary for all watershed fields.

To specify the complex of land-treatment measures possibly undertaken in 1947 on all cropland in the Nepper Watershed, the procedure explained in this appendix for field 2-1 was repeated for the 26 remaining fields scattered among the seven watershed farms. Results of successively imposing conditions for erosion control, corn frequency, on-farm profitability and watershed profitability are summarized in table D-5 for field 2-1 and for all fields in table 6 of the text.

APPENDIX E: GRAPHICS OF APPLIED PROGRAMMING

This appendix describes how linear programming was used to derive development programs for the Nepper Watershed that would have maximized net benefits subject to planning restrictions. Programming concepts are illustrated for two major allocative problems encountered in watershed planning and decision making: (1) determining optimal combinations of competitive land-treatment measures or activities and (2) determining optimal combinations of competitive land-treatment and structural measures or activities. Certain supplementary relationships also were brought out in solving these problems.

Combining Land-Treatment Activities

In table 9, two alternative land treatments (P_{19}, P_{20}) were given for field unit 5-1 located on the northern boundary of the Nepper Watershed (see fig. 2). These included a shift in 1947 from continuous corn with no conservation practices to either a CCOM or a CO_c rotation, with terraces installed over the entire field and commercial fertilizer applied at moderate rates in both cases. Corresponding benefit-cost data and resource interrelationships of the two treatment possibilities are shown in fig. E-1.[33] If the CO_c, rather than the CCOM, rotation had been adopted in 1947 over the entire 3.3 acres (adopted at its unit level), the available treatment area L_b would have been entirely utilized at B, the required outlay would have been C_b, or \$21.45, and resulting net benefits would have amounted to \$23.04. If the CCOM rotation were selected at its unit level, the land resource L_d ($= L_b$) would again have been fully utilized at D, the required outlay would have been C_d, or \$29.30, and net benefits would have amounted to \$25.26. Consequently, \$29.30 in capital available to finance a shift to either of the two rotations and their similar added practices would suggest selection of the CCOM rotation, providing a net benefit maximum of \$25.26. With only C_b or \$21.45 in capital available, however, exclusive selection of CO_c would be indicated. And if a capital outlay less than C_b were allocated, for example C_a, a maximum of \$15 in net benefits obtainable at A would have resulted from adopting the CO_c rotation and related practices on 65 percent of the field and leaving the remaining area in continuous corn. The diagram thus suggests that three land-use alternatives were actually posed to the farmer—two involving changed cropping methods with related practices and one involving no change.

Relations shown in fig. E-1 also facilitated decisions as to how available capital outlays ranging between C_b and C_d would be best allocated among competing treatments. The theoretical condition for such allocations specified that each of the CO_c and CCOM rotations be adopted on the field in proportions equating the (a) marginal rate at which CO_c substituted for CCOM with (b) the ratio of discounted net benefits from CO_c to those for CCOM. With respect to capital, the proportion of the field not shiftable to a CCOM rotation relative to CO_c was given as constant at \$21.45/\$29.30 = 0.73, or as C_b/C_d in fig. E-1. With respect to land, it was constant at 100/100 = 1.00, or L_b/L_d. Because only capital and land were considered to be limiting, the marginal rate of activity substitution ranged between 0.73 and 1.00. The CO_c/C-COM net benefit ratio was computed as \$23.04/\$25.26 = 0.90, indicating that a CCOM rotation adopted on only 90 percent of the field would have provided net benefits of \$23.04, equivalent to a 100-percent adoption of CO_c. This result is shown along the \$23 iso-net-benefit contour of fig. E-1, but the same net benefit substitution ratio applied on all such curves in the figure.

A land-treatment programming problem was then given as allocating a capital outlay of C_e (\$24.25) and the total field area between the two treatments (or to no treatment) to maximize net benefits. The maximum net benefit attainable if capital had been nonlimiting has already been noted as about \$25 at point D resulting from the CCOM rotation, a benefit amount limited by the entire field being so treated. The maximum net benefit possibly gained from an outlay of C_e, however, would be about \$24 (\$23.87), shown as the iso-net-benefit contour intersected at point E. Points to the right of E conceivably increasing net benefits with the outlay held at C_e, or obtaining the same

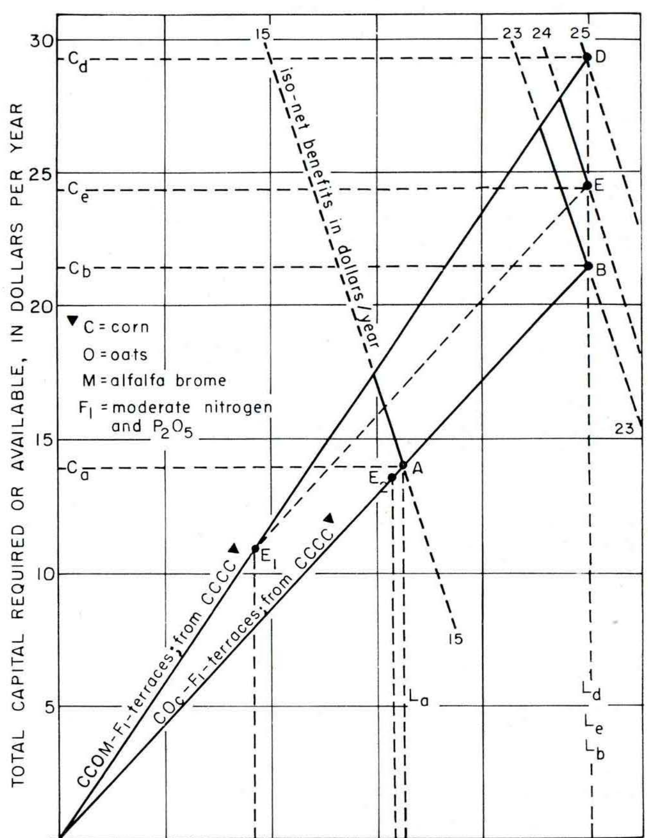

Fig. E-1. Determining optimal land treatment or combinations of land treatment with linear programming principles.

[33] The type of construction employed in figs. E-1 and E-2 is adapted from: Robert Dorfman. Mathematical, or "linear" programming; a non-mathematical exposition. Amer. Econ. Rev. 43:805. 1953.

benefit for a reduced outlay, implied treatment of more than 100 percent of the field area and were thus precluded by the land limitation. Also, points above E maintaining or increasing net benefits above \$24 with treatment of a smaller land area, or increasing benefits above \$24 while treating the entire field, were precluded by the C_e capital limitation. Point E was therefore optimal, in that any other percentage combination of the two rotational-practice treatments would fail to maximize net benefits subject to the stated resource restrictions, either by failing to use capital efficiently or by requiring more than C_e in capital.

With point E in fig. E-1 specifying total treatment by some combination of CO_c and CCOM, the particular combination could be determined geometrically[34] by extending E parallel to OB through OD at E_1, with OE_1/OD indicating a shift of about 37 percent of the field to the CCOM-F_1 terrace system and the remaining 63 percent to the CO_c-F_1 terrace system. Thus, the total area treated would have been 100 percent of the area feasibly treated; the total capital allocation of \$24.25 would have been utilized [$= 0.37\ (29.30) + 0.63\ (21.45)$], and net benefits would have been a maximum of \$23.87 [$= 0.37\ (25.26) + 0.63\ (23.04)$].

Combining Land Treatment and Structures

In its simplest form, this was also a problem of allocating optimally a given capital expenditure and land area, but with the land area alternatively treated, not treated or serving as structure sites. In table 9, a single land-treatment activity, P_{42}, considered for field 7-3 involved a change from an unfertilized CCCO rotation (noted in fig. 2) to a CCOM rotation heavily fertilized with nitrogen and phosphorous. But since 50 percent of the surface area required by the levee system (activity P_{49}) would necessarily have come out of the tillable area of the field, the field was nevertheless concerned in two treatment activities. Data for P_{42} in table 9 and OB in fig. E-2 indicate that, if the entire 22.5-acre area L_b had been shifted to a CCOM rotation and heavily fertilized, an annual capital outlay of C_b or \$215 would have been involved, and net benefits would have approximated \$300. Data for the levee (P_{49}) refer to height increments of 1 foot and are given in table 9 as a \$106 capital expenditure and \$374 in net benefits per foot of height. Ignoring the land area also occupied in field 7-4, the curve OD in fig. E-2 applied to levees and was scaled by various bank heights up to the 6-foot maximum permitted by the P_{79} size limitation. If the levees had been built to a maximum height of 6 feet, an annual capital expenditure of C_d, or \$640, would have been involved; net benefits would have been \$2,250, and 1.05 acres, or 4.67 percent (L_d), of field unit 7-3 would have been diverted from crop production.

With OD and OB representing alternative means of attaining given iso-net-benefit contours, fig. E-2 shows that land and capital resources most profitably would have been allocated exclusively to levee construction, subject only to the 6-foot height restriction. A capital outlay of C_a (\$284), for example, would have permitted a maximum of \$1,000 in net benefits at point A, while requiring a very small proportion (2 percent) of the available field area. The appropriate levee height is directly read at A at 2.67 feet. Similar conclusions would hold for any capital outlay not exceeding C_d (\$640).

Concerning capital outlays exceeding C_d in fig. E-2, net benefits would have been maximized by allocating the amount C_d to levee installation and utilizing the remaining capital and land area for the given rotational-fertilizing treatment. If a capital restriction of C_e (\$844) had been specified, the maximum net benefit permitted without the land or levee height restrictions being exceeded would have been \$2,534 at point E. With the levee capital allocation held at \$640 by the height limit, \$204 (\$844 — \$640) would remain for financing land treatment on the 95 percent of the field area (21.45 acres) remaining, permitting point E_2 to be reached along OB. Thus, the entire field would have been utilized either for levee installation (5 percent) or treated by the CCOM-F_2 system (95 percent); the available expenditure of \$844 would have been exhausted [$= 6\ (106.79) + 0.95\ (214.87)$], and net benefits would have been a maximum of \$2,534 [$= 6\ (374.57) + 0.95\ (298.57)$].

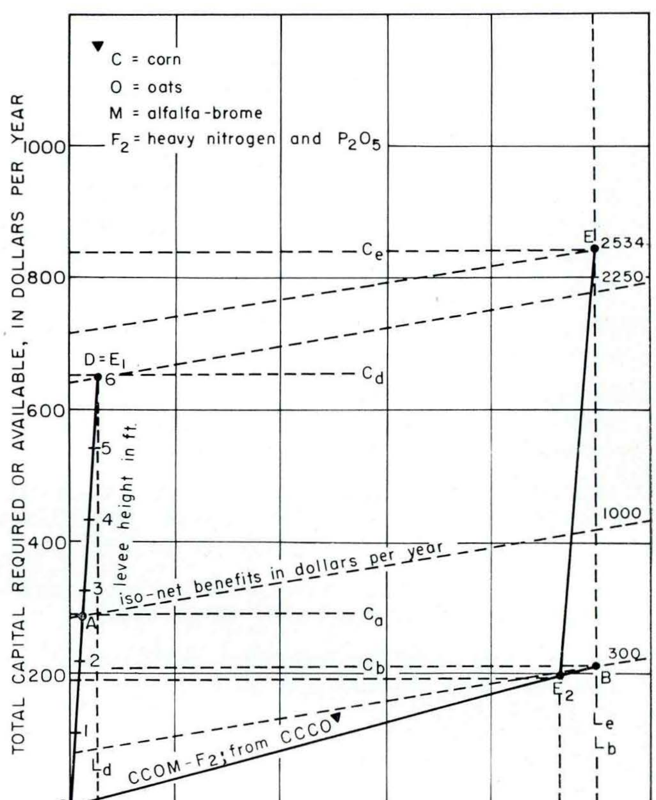

Fig. E-2. Determining optimal land treatment, structural treatment or combinations of land and structural treatment with linear programming principles.

[34] *Ibid.*

STATE LIBRARY OF IOWA
3 1723 02094 9970

SELECTED REFERENCES

American Society of Planning Officials. Planning problems of small watersheds. Amer. Soc. Planning Off. Conf. Proc. 1948:84-100.

Blackmore, J. A watershed development program for the TVA. Unpublished Ph.D. thesis. Harvard University Library, Cambridge, Mass. 1954.

Boles, J. N. Linear programming and farm management analysis. Jour. Farm. Econ. 37:1-24. 1955.

Candler, W. V. A modified simplex solution for linear programming with variable capital restrictions. Jour. Farm Econ. 38:940-955. 1956.

Dorfman, R. Applications of linear programming to the theory of the firm. University of California Press, Berkeley, Calif. 1951.

——— Mathematical or "linear" programming: a nonmathematical exposition. Amer. Econ. Rev. 43:-798-825. 1953.

Economics of watershed planning. G. S. Tolley and F. E. Riggs (Eds.) Proceedings of symposium on the economics of watershed planning. Knoxville, Tennessee, June 10-12, 1959. Iowa State University Press, Ames, Iowa. 1960.

Gertel K. Benefits and costs of land improvements. Unpublished M.S. thesis. Iowa State University Library, Ames, Iowa. 1949.

Heady, E. O. and Candler, W. V. Linear programming methods. Iowa State University Press, Ames, Iowa. 1958.

Heard, W. L. Putting the watershed plan to work. Jour. Soil and Water Cons. 7(1):22-27. 1952.

Herrick, V. C. and Raup, P. M. Organizational problems in developing the small watersheds of Minnesota. Minn. Agr. Exp. Sta. Bul. 437. 1957.

Huffman, R. E. Sharing the financial responsibility. U. S. Dept. Agr. Yearbook 1955:677-681.

Leopold, L. B. and Maddock, T. The flood control controversy: big dams, little dams and land management. Ronald Press, New York. 1954.

Morgan, R. J. The small watershed program. Law and Contemporary Problems 22(1):405-432. Duke University School of Law, Durham, N. C. 1957.

Muehlbeier, J. How do watersheds actually work? Land Improvement 2(1):16-17, 20-21. 1955.

———Organizing for watershed development. S. Dak. Agr. Exp. Sta. Bul. 133. 1957.

Otte, R. C. Local resource protection and development districts: statutory functions and powers as related to the Watershed Protection and Flood Prevention Act. U. S. Dept. Agr., Agr. Res. Serv. ARS 43-48. April 1957.

Pavelis, G. A. Economic planning within small agricultural watersheds. Unpublished Ph.D. thesis. Iowa State University Library, Ames, Iowa. 1958.

Reder, M. Studies in the theory of welfare economics. Columbia University Press, New York. 1947.

Renshaw, E. F. Toward responsible government: an economic appraisal of federal investment in water resources programs. Idyia Press, Chicago. 1957.

Sandals, K. M. and Adams, L. M. Progress in state legislation relating to the Watershed Protection and Flood Prevention Act, as amended. U. S. Dept. Agr., Soil Conservation Service. TP 135. 1958.

Steele, H. A. Economics of small watershed development. Agr. Econ. Res. 8(1):17-23. 1956.

——— and Regan, M. M. Organizational and administrative arrangements for an effective water policy. Jour. Farm Econ. 37:886-896. 1955.

Timmons, J. F. Economic framework for watershed development. Jour. Farm Econ. 36:1170-1183. 1954.

Tolley, G. S. Analytical techniques in relation to watershed development. Jour. Farm Econ. 40:653-655. 1958.

United Nations Food and Agriculture Organization. The challenge of our watersheds. Development Centre on Watershed Management for Asia and the Far East Conf. Proc. 1957.

U. S. Department of Agriculture Library. Small watersheds: a selected list of references. Library List No. 63. Washington, D. C. Oct. 1957.

Voelker, S. W. and Muehlbeier, J. Institutional arrangements for watershed programs. Jour. Farm Econ. 36:1184-1196. 1954.

Weinberger, M. L. and Otte, R. C. Economic evaluation of the small watershed program. Jour. Farm Econ. 39:1256-1270. 1957.

Western Agricultural Economics Research Council. Water resources and economic development of the West: small watershed development and rehabilitation and reorganization of irrigation projects. Committee on Economics of Water Resources Development Conf. Proc. 1957.