ECONOMIC PLANNING WITHIN

SMALL AGRICULTURAL WATERSHEDS

by

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SUMMARY

Economic planning within agricultural watersheds has become an accepted element of coordinated resource development on farms and within river basins. The 1936 and 1944 Flood Control Acts, the "pilot" watershed authorizations (1953), and the Watershed Protection and Flood Prevention Act (1954) has successively broadened watershed planning responsibilities of the Soil Conservation Service. Such basin-oriented public agencies as the Tennessee Valley Authority have modified their concern with major tributaries and structures toward greater recognition of the dependence of stream hydrology on upstream cover conditions and mechanical tillage practices. Also, States have enacted special statutes permitting independent local planning on a "Conservancy District" basis (Chapter 467C, Iowa Code, 1950) or to qualify these and other organizations for assistance under Federal laws.

The problems dealt with in this study are posed by the above merger of viewpoints. They include (1) application of multi-purpose concepts heretofore mainly used in river basin planning to the evaluation of development opportunities in much smaller drainages; (2) reconciliation of the planning objectives of farmers controlling watershed uplands with those of other private or public units affected by their use; and (3) formulation of optimal development programs for small watersheds. Programs devised in this study are keyed to the limited availability of resources, utilize benefit-cost appraisals in support of recommended development measures, and are based on techniques allowing project comparison for priority purposes.

The objectives are to treat these problems by simultaneously outlining a framework for evaluating development possibilities in small watersheds and utilizing the framework in devising a series of plans for a watershed in western Iowa. The importance of watershed hydrology to both benefit-cost relationships among alternative development activities and the physical nature of programs is stressed.

The analysis is concerned with both land use changes and structures. The former include basic shifts in crops grown or rotations followed, soil- and water-conserving tillage practices or fertilizer treatment, and terraces designed for retention of runoff. Structures examined either detain, divert, or permit free flow of runoff; these control features are directly related to benefits obtained by reduction of rates or volumes of runoff.

Given average prices estimated for a stated planning period, non-capital resources available for development purposes, and input-output relationships of various development activities, a series of optimal programs are formulated with reference to various amounts of expenditure involved in development, utilizing the "linear programming" technique. The method is used to (1) illustrate how all resources can best be allocated among competing activities as one might be varied in quantity; and (2) indicate the applicability of linear programming to principles of project formulation relying on conventional benefit-cost comparisons.

The study concerns the Nepper Watershed, a 480-acre drainage tributary to the Maple, Little Sioux, and Missouri rivers; and located in Monona County, Iowa. A hilly relief and loessial soils (ranging to 100 feet in depth) of this watershed offer a potential for serious sheet erosion, gully formation, and flood damage. Development possibilities are evaluated by determining specific relationships between each type of damage and physical variables modifiable by land treatment or waterflow-control structures.

Given the problems and development possibilities, planning in the Nepper Watershed involves (1) seven farm operating units, Monona County, and the off-site area as potential beneficiaries and a community of watershed interests; (2) predevelopment deviation from some community objective, or "planning norm," which cooperative development might achieve; (3) a range of land treatment and structural measures effective in achieving the community objective; and (4) a complex of land, labor, and capital resources available for development purposes.

Interests of farm units in watershed development are related directly to possibilities for obtaining the benefits of increased productivity; and to additional benefits from reduced sheet erosion, gully erosion, or flood damage to watershed crops. Interests of Monona County are in reducing the undue expense of maintaining a bridge periodically damaged by flood runoff. Reduction of downstream flood damages defines an additional public interest.

The "planning norm" to be achieved by optimal development in the Nepper Watershed is presumed to be a maximum discounted value of net returns from primary agricultural production (excluding livestock). All gully damage, flood damage, and damage-control outlays are charged as costs of this output. In these terms, optimal development programs are combinations of land treatment and structural activities producing maximum discounted net benefits, or increased discounted net returns for the watershed community of private and public interests.

The benchmark situation from which benefits and costs of each land treatment and structural activity are computed is selected as that pattern of land use and the consequent damages prevailing in the Nepper Watershed in 1947. The year 1947 is selected as the base date to facilitate formulation of optimal plans without reference to the going Little Sioux Program installed in 1948, appraise the Little Sioux Program with regard to possible alternatives as devised in this study, and utilize basic data both available to and contributed by the Little Sioux planning group.

A field-by-field summary of 1947 land use in the Nepper Watershed is shown by Figure 11, while column 1 of Table 1 indicates corresponding annual equivalents of discounted values for each item devised to estimate net production returns. All annual returns and costs are computed with reference to a 50-year (1947-97) economic horizon, with private values discounted at 5 percent and public values at 2 1/2 percent.

Benefits and costs of each land treatment activity are estimated as changes in returns and costs induced by shifting land use on each field from the system prevailing in 1947, the benchmark year. Benefits of increased productivity, for example, are estimated as the discounted values of increases in yields of corn, oats, or hay obtained by either adopting new rotations, practicing contour tillage, applying commercial

Table 1. Predevelopment (1947) resource use in the Nepper Watershed as affected by an optimal development program; average annual costs and returns[a]

	Return and cost items	Program in 1947	Optimal changes in 1947	Optimal 1947 program
		(dollars)	(dollars)	(dollars)
	Equivalent annual returns			
1.	Gross value of crops produced	19,750	11,310	31,060
2.	Permitted intensive use of floodplain	0	861	861
3.	Total annual returns	19,750	12,171	31,921
	Equivalent annual costs			
4.	Direct production expense on farms	8,717	4,952	13,669
5.	Gully damage; main drainage	101	-44	57
6.	Gully damage; southwest drainage	36	-16	20
7.	Flood damage; on-site crops	2,803	-2,803	0
8.	Flood damage; on-site bridge	385	-273	112
9.	Flood damage; off-site (land use)	140	-77	63
10.	Flood damage; off-site (levees)	0	125	125
11.	Total gully and flood damage	3,465	-3,088	377
12a.	Program installation; land treatment	0	339	339
12b.	Program installation; structures	0	287	287
13.	Program maintenance	0	13	13
14.	Total annual cost decreases[b]	0	-3,213	0
	Determination of net returns			
15.	Adjusted annual returns[b] (Item 3 less item 14)	19,750	15,384[c]	31,921
16.	Total annual cost (increases)[b]	12,182	5,716[c]	14,685
17.	Net value of crops produced[b] (Item 15 less item 16)	7,568	9,668[c]	17,236
18.	Net value per unit cost (Item 17/item 16)	0.62	1.69[c]	1.18
19.	Marginal net returns	29.26[d]	0	0

[a]Installation costs are in 1947 prices; remaining items are in projected long-term prices. Private values are discounted at 5 percent and public values at 2 1/2 percent.

[b]Items 14, 15, and 16 not additive by columns.

[c]Respectively total program benefits, total costs, net benefits, and ratio of net benefits to costs.

[d]Represents the highest ratio of net benefits to costs, obtained by shifting from predevelopment continuous corn to permanent meadow on a steep area contributing to gully and flood damage.

fertilizer, or installing terraces. Gully control benefits are the amount by which average annual gully damage (as projected from 1947 conditions) could be reduced by the same changes in land use; while flood control benefits are amounts by which annual flood damage to on-site crops, the County bridge, and off-site areas could likewise be reduced. Benefits from increased yields are credited to farms on which land use changes are made; other benefits are credited to public or private participants initially damaged. Costs of land treatment include any additional recurring expense of obtaining increased yields, and annual charges associated with the installation or maintenance of terraces and permanent pasture. These costs are allocated among beneficiaries in proportion to discounted values of total credited benefits, assuming costs would willingly be shared on a basis permitting equal rates of net return on resources contributed for program purposes.

Structural alternatives for reducing gully erosion and flood damage in 1947 were the facilities subsequently installed in the Little Sioux Program. All are appraised by estimating benefits and costs per defined unit of installed capacity. Interdependent structures are evaluated as groups. One structure (a chute-spillway) yields benefits less than the costs on a unit basis; it is eliminated as a development activity allowed to compete with the remaining structures and land treatment for development resources. Structure costs include immediate capital outlays for planning, construction, and rights-of-way; plus recurring maintenance expense and associated damages. As with land treatment, costs of each structural measure are 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 Nepper Watershed relate to land and capital; additional labor needed for some land treatment activities is found to be available on most farm units. Land resources are subclassified into the 27 fields scattered among the seven farm units. In total, fields represent the maximum cropland area susceptible of treatment for development purposes; individually they represent 27 unique classes of land for which inputs and outputs characterizing various treatment activities are determined. As shown in Figure 2, they range in number from one to eight per farm, with farmsteads and roads eliminated as treatment units.

Requirements of land treatment and structural activities for development and operating capital are indicated directly by their respective benefit-cost analyses. The requirements are estimated as total immediate and annual outlays required of farmers or public interests to initiate and continue each activity over the 50-year planning horizon (1947-97), with projected commodity prices, factor prices, and rates of discount equivalent to those underlying the cost and return data of Table 1.

As indicated above, programs are appraised through benefit-cost calculations and are devised by the technique of linear programming. With reference to 50 land treatment or structural activities and 31 restrictions defined, the technique is applied in specifying which of the land treatment or structural activities could have been undertaken (and at what intensity) in 1947 to maximize net benefits for the Nepper Watershed as a whole, without net losses being imposed on any of the seven on-site farmers, Monona County, or off-site interests. Results are presented for three general project types: (1) those of limited scope because of severe capital or other restrictions; (2) those of a somewhat expanded scope as increased but still limited outlays are allocated; and (3) those of a scope limited only by the availability of non-capital resources or by technological restrictions. Limited projects for the Nepper Watershed with 1947 as the planning date or base are discussed as including land treatment activities "critical" in providing net development benefits, whether promoted on upland or bottomland areas.

The "expanded scope" type is represented as a program devised by reallocating the annual expenditure of $3,706 estimated to be involved in the 1948 Little Sioux Program. Results indicate that, while actual adoption of land and structure treatment recommended in 1948 would have provided total annual benefits of $2,085 for the $3,706 outlay (or an annual loss of $1,621), an allocation of $3,706 based on preliminary benefit-cost analyses and the linear programming procedure would have yielded total annual benefits of $11,899 and net benefits of $8,193.

With no limit on program expenditure, a project of the third type would have produced total annual benefits of $15,384 for a comparable annual outlay of $5,716, and thus netted a maximum of $9,668 in annual benefits distributed among the seven watershed farmers, Monona County, and the immediate downstream area along the Maple River. Major elements of such a program in terms of increases in crop yields, enhanced use of the watershed floodplain, or decreases in land-use-associated gully or flood damage are given in column 2 of Table 1. Superimposing (adding) such changes on the program of 1947 (column 1) indicates (item 17) that the net annual value of agricultural output in the Nepper Watershed could have been increased by 128 percent; from $7,568 to $17,236.

The general relation of contrasting cost and return data of Table 1 to watershed land use can be noted by comparing Figure 11 with Figure 18, the former identifies predevelopment conditions and the latter conditions resulting from implementation of the optimal changes in Table 1.

Because of the fixed character of extensive structural improvements actually installed in the 1948 Little Sioux Program for the Nepper Watershed, the foregoing results of linear programming are hypothetical. Consequently, the study concludes with presenting the benefits of farmers shifting from current (1957) methods of land use to those comprising the above optimal program with expenditure unlimited, despite the effectiveness of the treatments in gully and flood control being partially ignored by reason of existing structures partially eliminating such damage.

Average annual benefits of $8,977 resulting from adjustments in 1957 land use are derived as $7,926 in the value of increased crop yields on uplands, added to $984 in complete floodplain protection and $67 in reduced off-site flood damage. The benefits require an added average annual outlay of $4,199; $3,866 in increased production expense on farms, and $333 as the amortized installation cost of 277 acres of additional terraces. Initial installation outlays for terraces range from $163 to $1,958 per farm and total $6,108. Annual net benefits range from $129 to $1,539 per farm, and approximate $35 for the downstream interest.

Although the program resulting from the described adjustments remains sub-optimal with respect to that possibly resulting from ideal planning in 1948, it can be recommended as maximum improvement over present conditions in the watershed. Its effect in this regard is that discounted net returns annually foregone by installation of unnecessary structures in 1948, a measure of the opportunity cost of uneconomic planning, can be reduced from a maximum of $7,364 (the cost if an adjustment program is not undertaken) to a minimum of $2,586, the reduction of $4,778 representing net benefits of an adjustment program carried out in 1957.

INTRODUCTION

Nature and Importance of Watershed Development

Hydrologically, watersheds (drainage basins) are defined[1] as geographic areas tributary to given streams or points on streams, and as such have long interested geographers, historians, and engineers. Viewing watersheds as regions within which concepts of economic efficiency might be applied is of fairly recent origin, however. In this study, the terms "watershed" and "watershed development" are given the following economic interpretations:

1. A watershed as defined hydrologically is also a center of economic activities and the basis of an aggregated economic decision-making unit or "watershed firm" made up of two or more private and/or public decision-making sub-units.[2] To the extent other (off-site) areas are measurably affected by intra-watershed decisions; that is, downstream private or public groups, the effective scope of watershed activities and decision-making is broadened to include off-site effects. Each on-site and off-site decision-making unit is a potential participant in watershed development.

2. Watershed development is a welfare-oriented economic reorganiza-

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[1] R. K. Linsley and J. B. Franzini. Elements of hydraulic engineering. N. Y., McGraw-Hill Book Co., Inc., 1955. p. 8.

[2] This concept of an aggregated firm is advanced in John F. Timmons. Economic framework for watershed development. Journal of Farm Economics. 36: 1170-1183. 1954. In the special case of one private or public unit controlling an entire watershed area and all related off-site areas, the single unit would be considered synonymous with a watershed firm.

tion in which welfare can be increased both by (a) a more efficient allocation of resources currently available to participants; or (b) an efficient allocation of 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 (or uncompensated) by reason of development programs being carried out.

Although the foregoing definitions may appear ambiguous in the context of water resources programs, they specify the locational and welfare frames of reference implicit in the statutory justification of projects. For example, the Flood Control Act of 1936[3] provides

> . . . that investigations and improvements of rivers and other waterways, including watersheds thereof, for flood control purposes are in the interest of general welfare; that the Federal government should participate in the improvement of navigable waters or their tributaries, including watersheds thereof, for flood control purposes if the benefits to whomsoever they may accrue are in excess of the estimated costs, and if the lives and social security of people are otherwise adversely affected.

Despite its concern with flood control, this policy statement has since guided the evaluation of diverse water projects and underlies a considerable body of principles devised to expedite the process.[4] Identifying all beneficiaries of flood control more often than not,

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[3]U. S. Code, 1951, Title 33, Sec. 70a. 1952.

[4]A review of viewpoints adopted and procedures employed by the U. S. Corps of Army Engineers, the Bureau of Reclamation, the Federal Power Commission, and the Department of Agriculture as the principal Federal agencies involved in project evaluation is given by the U. S. Federal Interagency River Basin Committee. Subcommittee on Benefits and Costs. Washington, D. C., U. S. Govt. Print. Off. 1950.

however, precludes confinement of flood damage surveys to drainage basins under study, particularly as the basins may merely represent lesser tributaries of such major systems as the Mississippi, Missouri, or Columbia. A similar complication applies to a basin's power potential, where benefits are dispersed over an area delimited by power networks rather than drainage divides. The difficulty of treating project areas as "closed economies" producing only locally salable goods and services has led to classification of benefits and costs as direct or indirect, primary or secondary, and tangible or intangible; exhaustive attempts are then made to trace project effects throughout the general economy. These efforts have been confused and inconsistent, so much so that review groups have recommended that only benefits and costs easily susceptible to monetary valuation and directly attributable to project activities be considered in determining whether benefits exceed costs. Vague effects induced in off-site areas and such intangibles as protection of human life would be reported but regarded only as supplemental data.[5]

An obvious implication of thus categorizing project effects is the narrow definition attached to economic justification. If direct costs exceeded direct benefits, projects would be deemed uneconomic on the above criterion, but a society (though its legislative or administrative agents) might nevertheless approve them on the basis of their supple-

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[5]U. S. Commission on Organization of the Executive Branch of the Government. Task Force on Water Resources and Power. Report on water resources and power. Vol. 2. Wash., D. C., U. S. Govt. Print. Off. 1955. p. 383.

mental considerations. Such decisions would appear to be inherently economic, inasmuch as selection of means (the projects) to serve a given end (welfare) is involved. Where non-monetary factors were believed unimportant, projects could be judged solely on their tangible merits and also approved as welfare-increasing if aggregate net benefits are presumed optimally allocated in consumption and are a proper welfare indicator.[6] It is projects of the latter character with which this study is concerned, particularly as planned for small drainages utilized mainly for agricultural purposes.

The analysis bears directly on public programs for erosion control, flood control, or other damage-reduction purposes in small watersheds. By May 31, 1958, about 153 small watershed "action" programs had either been installed or were being installed under Federal legislation alone. An additional 258 watersheds had been approved for planning and an additional 781 local organizations had applied for planning assistance of the Soil Conservation Service. The many programs being promoted by States and other public agencies frequently combine research activities

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[6] Aggregate net benefits refer to the sum of net benefits accruing to various project participants, whether the sum be positive, zero, or negative. Positive aggregate net benefits imply the possibility of increasing welfare through compensating burdens and bounties; whereby beneficiaries can be taxed up to the level of their net benefits to provide compensation for potential losers, with the welfare-increasing surplus regarded as the excess of maximum taxes over total compensation requirements. Zero aggregate net benefits imply equality between maximum tax collections and required compensation, or the absence of a welfare-increasing surplus; while negative aggregate net benefits preclude collection of sufficient taxes to provide compensation and thereby denote existence of a welfare-decreasing deficit. For further explanation of the welfare aspects of gains and losses coincident with economic reorganizations, see M. W. Reder. Studies in the theory of welfare economics. N. Y., Columbia University Press. 1947. pp. 13-17; also pp. 94-100.

with actual planning and installation.

Problems in Program Planning

Current planning activity commonly involves these objectives: (1) development programs consistent with a watershed norm of productive efficiency, usually defined or implied to be maximum benefits for given program costs; (2) an equitable sharing of costs by program beneficiaries; and (3) organizations within which programs can be effectively implemented and managed. Principal problems involved in achieving these objectives are as follows:

1. Determining physical relations between land use in various source-consequence[7] watershed sectors, and utilizing these relations in economic appraisal of alternative as well as existing land use patterns.

2. Reconciling conflicting interests of potential participants, either in the selection of improvement measures to be included in programs, or by distributing costs (including compensations) to meet possible objections to specific measures.

3. Devising analytical techniques appropriate for detailed economic evaluations of development possibilities and measures, and then combining the measures in programs to maximize aggregate watershed-

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[7]This concept refers to all the physical and economic effects of land management on one watershed sector for that same and/or other sectors. An example is the typical upland-bottomland relationship of runoff and flooding.

wide net benefits.[8]

Hypotheses and Objectives of the Study

A major hypothesis guiding subsequent analyses is that a multiple-purpose approach to both evaluation of existing watershed conditions and appraisal of development measures can specify the measures maximizing the aggregate net benefits of development. The approach accounts for physical relations of land use management within and among various watershed sectors, and includes such source-consequence relations in economic appraisals.

A secondary hypothesis is that the application of elementary welfare criteria, particularly by the compensation principle, can overcome the problem of making measures optimal in the aggregate also acceptable to all program participants.

A third hypothesis is that conventional benefit-cost estimates (as prepared by Federal agencies) combined with the allocative features of linear programming can serve in formulating and evaluating alternative

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[8] This kind of problem is illustrated by the division of funds between land treatment and gully control structures in 12 sub-watersheds of the Little Sioux River in western Iowa improved by 1953. Although the structures involved 94 percent of installation costs and 60 percent of annual costs, they produced only 29 percent of the total benefits, and returned only $0.89 on each dollar committed to the improvements. On the same basis, land treatment was estimated to return $3.00 in total benefit for each dollar committed. The data indicate, on the maximum net benefit criterion, that no funds should have been allotted to structural improvements. See Table 11 and the accompanying discussion for a detailed benefit-cost analysis of the Little Sioux Program.

programs subject to restrictions of a resource-supply or technological nature.

With regard to the foregoing problems and hypotheses, the objectives of this study are:

1. To outline a rational evaluation and planning framework for developing agricultural watersheds in which primary concern with directly measurable benefits and costs is justified. Procedural elements of this framework are (a) preliminary field investigations to verify the actual existence of hypothesized development possibilities; (b) delimitation of the range of land treatment or structural measures considered as alternatives for obtaining development benefits; and (c) formulation of development programs maximizing aggregate net benefits, subject to any competitive relations of alternative measures, cost-sharing criteria, and resource limitations.

2. To illustrate evaluation and planning within this framework for a representative project area, selected as a small watershed in western Iowa. Without denying their importance, organizational aspects of watershed development are only incidentally treated.[9]

Formulation of development programs yielding maximum aggregate net benefits is a planning and study objective consistent with usual concepts of productive efficiency, since a maximum of net benefits is a maximum increase in the present worth of goods and services resulting from productive activities. The norm to be achieved by optimal combina-

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[9] A good discussion of these aspects is given by John Muehlbeier. Organizing for watershed development. So. Dak. Agr. Exp. Sta. Circ. 133. January 1957.

tions of land and structural treatment in the problem watershed is accordingly specified as a maximum present value (at the assumed planning date) of net returns from primary agricultural production. The present value of all associated damages and/or damage control outlays, as well as normal production expense, are charged as costs of this net output.

Statement of the norm in these terms implies that optimal programs represent optimal changes from pre-development to post-development resource use, or optimal magnitudes of any component of developmental benefits and costs. This analysis thus includes as program benefits any (a) increases in gross crop income on farms, (b) decreases in normal farm production expense, and (c) decreases in any land-use-associated damage item. Program costs include (d) decreases in gross crop income on farms, (e) increases in normal farm production expense, (f) possible increases in associated damages, and (g) direct outlays for damage control. Benefits of types (a) and (b) accrue to farm operating units on which land use is changed, and those of type (c) to any farm unit or public body actually incurring damages as evaluated for pre-development circumstances. Farm units noted in (c) may or may not include particular units on which land use is changed or structural improvements installed. Costs of all listed types are distributed in accordance with criteria presented under the study's qualifications.

The Problem Area and Procedures

Empirical investigations concern the Nepper Watershed in Monona County, Iowa. This 480-acre watershed is only one of many similar drainages tributary to the Maple, Little Sioux, and Missouri rivers; its major physical features are described in Figures 1 and 2. Factors in selection of the Nepper Watershed for illustrated planning include reasonably adequate data on the hydrologic effects of particular land use systems, and that the watershed was partially improved in 1948 under the Little Sioux Flood Control Program. The latter combined with a 1949 evaluation of its economic effects and a 1956 restudy conducted on a "pilot" basis are thought to provide sufficient information for achieving this study's objectives.

The present approach differs from those of earlier research in the Nepper Watershed in its attempt to derive a series of alternative optimal programs through multi-purpose planning, rather than simply evaluate and compare predefined programs for their benefits and costs. Following review of current watershed development activities and their implications for research of this nature, the study's qualifications are stated and sources of special data noted. The Nepper analysis then proceeds by the following stages possibly extended to other watershed investigations:

1. Generalized description of the watershed as a hydrologic-economic unit of observation and study; such description including physical characteristics, major agricultural and related economic activities, and based on a subdivision scheme appropriate for detailed investigation and subsequent planning.

2. Statement of the hypotheses requiring detailed analysis of existing pattern of land use in relation to quantities of resources

currently used, and additional quantities possibly available for promoting development programs.

3. Input-output analyses of the range of land use systems deemed feasible on particular farms and operational units (fields within farms), with emphasis on the hydrologic variables influenced by land use and consequent problems of water use or control. Also analyzed at this point are capital improvements possibly installed in fields or drainageways, improvements designed to modify hydrologic variables through water detention, storage, or diversion.

4. Summarization of discounted returns and costs incident to existing land use and capital improvements, as accruing to all affected decision-making units being potential participants in development programs. This situation is regarded as the benchmark or predevelopment situation, with reference to which discounted program benefits and costs are evaluated. The predevelopment situation in the Nepper Watershed is specified as that prevailing in 1947, one year prior to partial installation of improvements recommended in the 1948 Little Sioux Flood Control Program.

5. Predevelopment appraisals to isolate the elements of returns and costs inconsistent with the norm of maximum discounted net returns, and subject to adjustment through land use changes or installation of additional capital improvements. Benefits and costs of both types of treatment measures are evaluated for all participants.

6. Economic appraisal (with reference to the same above norm) of any likely proposed programs emphasizing physical standards of damage

control. The recommended land use changes and installed structures of the 1948 Little Sioux Program in the Nepper Watershed are appraised on this basis.

7. Presuming non-achievement of the efficiency norm under programs proposed in 6, isolation of a complex of land use changes and structural improvements possibly included in an optimal watershed development plan--consistent with requirements for physical and economic feasibility and also serving other possible objectives of participants. Required hydrologic and economic data are drawn from stage 3 in estimating benefits and costs with reference to the predevelopment situation described in stage 4.

8. Selecting combinations of treatment activities maximizing aggregate net discounted benefits, or most closely approximating the norm of maximum discounted net returns on watershed resources. Such combinations are limited to those not resulting in uncompensated losses for any private or public participant. Alternative programs represented by justified combinations of treatment activities are formulated with reference to varying levels of expenditure involved in installing and maintaining activities over the stated project period. Alternative programs described in detail for the Nepper Watershed (and all participants) include (a) one comprised of only several activities "critical" in providing benefits for limited available outlays; (b) that resulting from a reallocation of the outlay involved in the 1948 Little Sioux Program; and (c) a program resulting from an optimal allocation of a maximum justified outlay. The latter includes all treatment activities

or activity combinations adding to discounted aggregate or participant net benefits. Programs of all three types are formulated by the methods of linear programming.

Because of the fixed character of uneconomic structures actually installed in the 1948 program planned in the Nepper Watershed, resulting programs of types (b) and (c) in stage 8 are largely hypothetical. The analysis consequently concludes with suggestions for presently (in 1957) minimizing the opportunity costs of prior uneconomic planning. Involved is an adjustment program of changes in current (1957) land use primarily providing benefits in the way of increased crop yields and/or reduced operating expense on watershed areas so treated.

RESEARCH-ACTION PROGRAMS OF WATERSHED DEVELOPMENT

Historical Background and Current Activities

Definite interest in upstream tributaries as cultural units for water management decision-making originated in 1911. Passage of the Weeks Forest Purchase Act (amended in 1924 by the Clarke-McNary Act) authorized Federal acquisition of forest lands for runoff control purposes.[1] A series of severe floods in the Miami Valley of Ohio in 1913 prompted 1914 enactment of the Ohio Conservancy Act[2] which, with successive amendments permits establishment of conservancy districts for preventing floods, modifying stream channels, reclaiming land through drainage, providing water supplies for irrigation, and other functions. To date Ohio has 15 active conservancy districts; most notable are the Miami Conservancy District (1914), the Muskingum Watershed Conservancy District (1933), and the Maumee Watershed Conservancy District (1950). Water-control plans for most of these recognize the importance of land management, but structures and channel improvement are emphasized as flood protection or water-supply measures.

Despite evidence of earlier attempts[3] to coordinate farm and water-

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[1]U. S. Code, 1951, Title 16. Secs. 513-519. 21. 1952.

[2]Ohio Revised Codes Annotated, 1954, Chap. 6101. 1954.

[3]U. S. Department of Interior. Soil Erosion Service. Tentative program for the control of erosion on the watershed of Coon Creek in southwest Wisconsin. Washington, D. C. Author 1933. (Republished. Madison, Wisc., Wisconsin State Soil Conservation Committee. July 1955).

shed management, specific responsibilities of the U. S. Department of Agriculture and the Soil Conservation Service in watershed planning were first clarified by the earlier cited Flood Control Act of 1936. This Act provided that Federal investigations of rivers and other waterways for flood control were the responsibility of the U. S. Corps of Army Engineers, while Federal investigations of watersheds and installation of runoff-retarding measures were assigned the U. S. Department of Agriculture. Although the Department has completed about 30 detailed surveys supporting upstream projects proposed under the 1936 Act, Congress in 1944 approved only 11 projects for construction, including the 2.8-million acre Little Sioux River Program in southwestern Minnesota and northwestern Iowa. Moreover, Congressional appropriations have subsequently been sufficient to cover only 20 percent of the Federal spending authorized for these projects, with legislative enthusiasm for the program sharply declining since 1944.

In 1951 the House Committee on Agriculture initiated hearings on the Missouri River Basin Agricultural Program,[4] a proposal for over-all development of basin resources over a period of 30 years. In addition to conservation of grassland, cropland, and forests, and irrigation and drainage improvements, the program recommended stabilization of small watercourses with 5,000 floodwater-retarding structures, 500 sediment-retention structures, 5,000 miles of minor floodways, and between 10,000

[4] U. S. Congress. House. Missouri River Basin agricultural program. 81st Cong., 1st sess., H. Doc. 373, Wash., D. C., U. S. Govt. Print. Off. 1949.

and 12,000 miles of channel improvement.[5] Joint application of land treatment and structural measures was argued to be essential for efficient use and safe disposal of water throughout the many sub-watersheds of the basin. An important effect of the hearings was renewed Congressional interest in upstream soil conservation and flood prevention, but focused on independent programs for areas much smaller than those surveyed under the 1936 Flood Control Act. The concensus of legislators at this time was that small watershed programs merited considerable public support; could be undertaken without prior construction of large main-stem facilities already planned; would coordinate on-farm conservation with river basin planning; and should be cooperatively installed and financed by local residents as well as all levels of government.[6] Initial small watershed legislation introduced in the House in 1952 was never submitted to a vote, however, being opposed by the Bureau of Reclamation and Corps of Engineers through the Committee on Public Works. The following year saw $5 million added to the 1954 fiscal budget of Soil Conservation Service for initial installation of about 60 "pilot" watershed programs in 33 states.[7] The pilot projects are admittedly experimental and demonstrational, being intended to cement Federal-State-

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[5] Ibid., p. 19; also pp. 112-113.

[6] U. S. Congress. House. Committee on Agriculture. Watershed protection. Hearings before a subcommittee on soil conservation and flood control of the committee on agriculture. 82d Cong. 1st sess., Miscellaneous hearings. Wash., D. C., U. S. Govt. Print. Off. 1951.

[7] An eventual $30 million are authorized for pilot projects. As of June 1, 1958, 58 of these projects were active, including those for Mule Creek (Mills County) and Honey Creek (Lucas County) in Iowa.

local relationships in program planning, test or illustrate the feasibility of combined land and structural improvement measures, and provide basic evaluation data for subsequent planning in surrounding regions.

The general authority for Federal-State-local participation in upstream projects is the Watershed Protection and Flood Prevention Act, passed in 1954.[8] As amended in 1956[9] it encourages upstream localities to prepare watershed improvement plans that combine elements of flood control with local agricultural, municipal, and industrial requirements for water, conservation utilization, and disposal. To qualify under this Act, single watersheds cannot exceed 250,000 acres in area, any proposed structure cannot exceed a total capacity of 25,000 acre-feet, or a flood storage capacity of 5,000 acre-feet. In addition, the local watershed organizations (groups having authority under State law to install, maintain, and operate works of improvement) must obtain necessary rights-of-way or easements, establish water rights, contract for actual construction, operate and maintain completed structures, and assure application of recommended conservation practices on at least 50 percent of the area drained by any flood control structure.

With regard to installation, the Federal government extends (through the Soil Conservation Service) technical planning assistance for both land treatment and structural improvements, and bears all construction

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[8] U. S. Congress. Senate. 83d. 2nd sess. Watershed protection and flood prevention act. Aug. 4, 1954. Public law 566. Wash., D. C., U. S. Govt. Print. Off. 1954.

[9] U. S. Statutes at Large. 70, Pt. 1, Chap. 1088. 1956.

costs allocable to flood control. Local organizations must bear all costs of municipal and industrial water supply, plus a proportionate share of remaining construction outlays deemed by the Secretary of Agriculture to be "equitable in consideration of the direct identifiable benefits applicable to agricultural phases of the conservation, development, utilization, and disposal of water."[10] Excepting certain measures bearing critically on flood prevention, Federal cost-sharing for land treatment is limited to that currently in force under the Agricultural Conservation Program, the Soil Bank, or other standing legislation.

Since its passage in 1954 and through May 31, 1958, the Secretary of Agriculture has received 874 applications covering 68 million acres in 47 states from local groups seeking assistance under the Watershed Protection and Flood Prevention Act. The Secretary has authorized planning for 351 of these projects and actual operations for 93 projects in 39 states, or for approximately 7 percent of the total acreage involved in all applications. The estimated Federal-local cost of installing projects approved for operations ranges from $26,440 for the Lake Placid Project in Florida to $5 1/2 million for the Upper Brushy Creek Watershed in Texas. Applications received from Iowa organizations total 18 for 383,000 acres in 21 counties. Nine Iowa projects have received planning approval. Actual operations are authorized for the Harmony Creek Watershed (Harrison County, 24 farms, 3,100 acres); the Rocky Branch Watershed (Jefferson County, 69 farms, 8,663 acres); and Simpson

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[10] U. S. Congress. Senate. 83d. 2nd sess. Watershed Protection and Flood Prevention Act. <u>op</u>. <u>cit</u>., Sec. 4.2.

Creek Watershed (Fremont County, 26 farms, 2,393 acres). Structural installation costs of the latter projects are estimated at $132,170 for Harmony Creek, $261,000 for Rocky Branch, and $126,343 for Simpson Creek.[11]

Alternative approaches to watershed planning are meanwhile being pursued by other Federal agencies and States, notably the Tennessee Valley Authority, Kansas, and Iowa. Although TVA enabling legislation emphasizes structural flood control, navigation, and power generation as controlling objectives of basin planning, the close dependence of stream behavior and reservoir siltation on land use has led the Authority to determine and encourage needed land use adjustments in small watersheds throughout the Tennessee Valley.[12] In cooperation with local Land Grant Colleges and farm operators, a number of TVA programs completed or currently underway attempt to determine effects of intensive farm planning on watershed hydrology as well as farm incomes. In the 1,060-acre Parker Branch Watershed[13] of North Carolina, for example, a research-action program is phased by a calibration period

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[11] Foregoing project data are from the U. S. Soil Conservation Service. Watershed Planning Branch. Information on status of watershed protection program under Public Law 566. Mimeo. memorandum. Washington, D. C. Author. June 1, 1958.

[12] For a comprehensive treatment of TVA small watershed activities see John Blackmore. A watershed development program for the TVA. Unpublished Ph.D. Thesis. Cambridge, Mass., Harvard University Library. 1954.

[13] Tennessee Valley Authority. Systematic farm planning in relation to water resources at Parker Branch Pilot Tributary Watershed. Knoxville, Tenn. Author. March 1956. pp. 2-3.

(1952-51), an action or first period is (1954-56) and an evaluation period (1956-62). Initial calibration involved studies of watershed hydrology under land use conditions then existing, detailed resource inventories combined with economic appraisal of alternative farm enterprises, and formulation of alternative plans satisfactory to 47 resident farm families. Hydrologic measurements continued through the action period when operators were assisted in carrying out recommended land use changes. The evaluation phase is intended to correlate hydrologic and economic results observed during the calibration and action phases.

A second illustration of TVA research activity is a 1954 land use-streamflow study conducted in the Turkey Creek Sub-watershed of the Beech River in Tennessee.[14] In this case hydrologists furnished seasonal estimates of peak runoff rates expected from the 5,120-acre area as land use observed in 1954 might shift to patterns whereby net farm income on 47 farms was alternatively maximized with regard to (1) those capital resources currently available; and (2) non-rationed capital. Estimated runoff rates would be reduced by 13 percent under (1) and by 26 percent under (2), with net income on all farms substantially increased over 1954 levels. A major objective of this study was determination of the extent to which the dual goals of net farm income maximization and runoff minimization might be complementary or competitive.

Watersheds being studied in Kansas include Sabetha Lake (Nemaha County, 39 farms, 6,400 acres) and Walnut Creek (Brown County, 450 farms,

[14] Tennessee Valley Authority. Division of Agricultural Relations. Annual report, 1954-55: 29-33. 1955.

73,600 acres).[15] At Sabetha Lake, rates of sediment deposition in a municipal reservoir and farm income are being correlated with land use; while in Walnut Creek, 120 conservation farm plans are being prepared and then analyzed for consistency with watershed planning objectives.[16]

Iowa investigations began with the Little Sioux Flood Control Surveys in 1939. In 1948, results of the surveys were applied in a program for the Nepper Watershed (Monona County, 7 farms, 480 acres) under authority of the 1936 and 1944 Federal Flood Control Acts. Gertel[17] evaluated the farmland treatment and gully-control phases of this program for economic effects on each watershed farm unit, Monona County, and downstream areas. He concluded that (1) single-agency planning is not conducive to adequate considerations of alternative watershed improvements; (2) landowner and tenant attitudes toward conservation importantly condition the feasibility of otherwise optimal programs; and (3) economic evaluation is more useful in planning optimal programs than in justifying a particular one before administrative or legislative bodies.[18]

[15] In addition, Kansas has six U. S. Dept. of Agriculture pilot projects and 11 other projects proposed under the Watershed Protection and Flood Prevention Act.

[16] Anon. Watershed studies in Kansas. Mimeo. report. Manhattan, Kansas. Kans. Agr. Exp. Sta. 1955.

[17] Karl Gertel. Benefits and costs of land improvements. Unpublished M. S. Thesis. Ames, Iowa, Iowa State College Library. 1949.

[18] _Ibid._, p. 98.

After several years of special engineering and agronomic research in small watersheds, the Iowa Agricultural Experiment Station in 1954 initiated a pilot study of the Nepper Watershed jointly involving the Iowa State College Departments of Agronomy, Agricultural Engineering, and Economics and Sociology.[19] While developing procedures for appraising such watershed problems as flooding and gullying, efforts were made to evaluate seven alternative patterns of watershed resource use with regard to their economic consequences for seven on-site farm units, Monona County, and downstream areas; and all these participants then jointly considered aggregated hypothetical decision-making unit or "watershed firm."[20] The six patterns other than that prevailing in 1947 were analyzed as alternative programs for watershed development having the object of increasing the present value of aggregate net returns from primary agricultural production throughout the watershed. Resulting flood or gully damages, as well as direct outlays associated with production, were estimated in computing net returns. Alternative programs were predefined in terms of broad assumptions concerning either capital availability, the intensity of land treatment, installation of structures, or combinations of land treatment and structures. Results indicated that, of the alternatives considered, present value aggregate net

[19]Iowa State College. Departments of Agronomy, Agricultural Engineering and Economics and Sociology. Integrated analysis of watershed development as applied in a pilot study of the Nepper Watershed. Mimeo. report. Ames, Iowa. Iowa Agr. Exp. Sta. June, 1956.

[20]Timmons, op. cit., p. 1171.

returns from agricultural production would be maximized with a program requiring no structures and permitting farm operators to maximize their net returns without capital limitations. Approximately 70 percent of the terraceable watershed cropland would be terraced, 90 percent of the cropland in continuous corn, and 100 percent of the cropland heavily fertilized. If land treatment were ineffective in reducing on-site road maintenance costs and off-site flood damages, however, Monona County and off-site areas would be indifferent to any program not involving economically feasible structures.

A current research activity of the Iowa Station concerns the Spring Valley Creek Watershed (Mills County, 46 farms, 5,319 acres). Objectives are: (1) to establish long-term field studies of the specific effects of various land use practices and fertility treatments on watershed runoff and erosion; (2) to prepare individual farm plans that incorporate management and resource capabilities with minimum requirements for watershed protection; and (3) to assist farmers and local organizations by extension efforts or other means to implement these plans on their own initiative.[21]

Concerning the latter objective, the Agricultural Law Center of the University of Iowa has reviewed Iowa statutes concerning the corporate, financial, and regulative powers of soil conservation districts or subdistricts, conservancy districts, and other special-purpose districts; particularly with reference to local organizations seeking Federal

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[21]Iowa State College. Departments of Agronomy, Agricultural Engineering, and Economics and Sociology. op. cit., p. 109.

assistance under the Watershed Protection and Flood Prevention Act.[22] Special studies of local taxing procedures, zoning ordinances, and leasing arrangements applicable to such programs as those contemplated in the Spring Valley Creek Watershed are also underway.

Planning Implications of Research-Action Programs

Planning objectives of efficiency and equity implied in the foregoing review have important implications as to how they can be suitably combined in appraising developmental measures for economic feasibility. Many watershed treatment measures are physically effective in damage control or in providing other direct benefits. Consequently, a presentation of qualifications in the Nepper Watershed analysis is preceded by (1) specification of the concept of economic feasibility possibly employed in small watershed planning; (2) discussion of the role of benefit-cost analysis in evaluating programs or separable program components on this concept; and (3) discussion of the dependence of feasibility on welfare aspects of cost-sharing arrangements, conflicting interests of participants, and compensation requirements. The added objective of adequate institutional arrangements is discussed only in its general relation to economic feasibility.

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[22] Patrick Riley. The adaptation of the Federal watershed act to Iowa. Typewritten report. Iowa City, Iowa. University of Iowa College of Law. June, 1956.

Feasibility in relation to an efficiency norm

Emphasis on direct benefits permits identification of an efficiency norm with a maximum present worth of goods and services produced within project areas over specified planning horizons, where present worth represents the excess of gross present values over the present value of all associated expenditure. In relation to a norm of maximum present worth, feasible watershed development specifically pertains to economic reorganizations which show promise of increasing aggregate present worth (that of all participants) without decreasing the present worth of income streams accruing to any individual participant.[23] If costs cannot exceed existing levels, aggregate present worth can be increased either by increasing gross present values and/or reducing costs. If increased costs are considered, aggregate present worth can be increased by any increases in gross present values exceeding cost increases. Both potentialities for obtaining present worth increases are relevant to watershed planning, particularly as such projects typically involve investment of substantial capital.

Benefit-cost analysis

The function of benefit-cost analysis in measure appraisal and project formulation follows from the equivalence of efficiency norms with

[23] This concept of feasibility only specifies a necessary condition for attainment or partial attainment of efficiency norms. The sufficient condition would be complete attainment or reorganizations increasing aggregate present worth by a maximum amount.

maximum present worth; it is to evaluate alternative proposals for their absolute and relative effectiveness in increasing aggregate present worth. With added gross values and/or outlay reductions comprising benefits, and gross value sacrifices and/or added outlays comprising costs, any program or separable program component evidencing aggregate benefits in excess of costs is economically feasible on the above definition provided no participant thereby incurs costs greater than realized benefits. Subject to this constraint and others imposed by limited resources being available for development purposes, any program that maximizes aggregate net benefits (or the increase in aggregate present worth) is optimal in the senses of (1) providing a maximum welfare-increasing surplus available for distribution among participants; and (2) being most consistent with the efficiency norm set up as a planning objective.

Feasibility and welfare

Since present values of development benefits or costs and possibly conflicting interests of individual participants are allowed to control planning decisions, the feasibility of improvement measures as appraised through benefit-cost analysis depends in some degree on the manner in which such costs are to be borne by individual participants; that is, recurring annual benefits and allocated outlays must be converted to aggregate present values with particular rates of discount appropriate for individual participants, rather than a single over-all rate. Discount rates and planning horizons varying among private or public participants can influence the relative profitability of alternative improvements and the final selection of those included in an optimal development program. Given the basis on which costs of each development measure are to be shared by beneficiaries, assignment of program costs can be made simultaneous with program formulation or the selection of measures most economically included.

Requirements for compensation, by limiting aggregate net benefits, also influence the feasibility and relative profitability of alternative measures and programs, both for individual participants taxed for compensation purposes and for the watershed community. Applied to watershed development, the compensation principle would specify that participants potentially suffering a reduction in present worth by reason of measures adopted by themselves or others that in the aggregate do provide net benefits, should be reimbursed to the extent of potential losses to leave them at least as well off as before the measures are undertaken. Recognizing that actual compensation payments to damaged parties are in effect program costs incurred by beneficiaries taxed for this purpose permits their being added to other costs in evaluating separate measures or alternative programs. By this means all programs or separable program components providing aggregate net benefits will also not be infeasible for any participants, because possible reductions in individual net worth are initially accounted for in benefit-cost analysis and compensated for in cost-sharing arrangements.

Institutional arrangements

With cost-sharing and compensation forming important elements of any feasible program undertaken, watershed development further involves devising institutional means by which programs can be centrally planned, financed, installed, maintained, or otherwise managed. Although management functions might be served through numerous bilateral agreements between various participants interested in promoting the same development measures, formal organizations have the advantages of being the agent of all on-site participants and possibly acquiring legal authority for negotiating with off-site parties, or assuring (by zoning, land use regulations, and assessment powers) the conduct of programs as initially planned.

Because many of the flooding, siltation, land damage, and water-supply problems to be overcome by development arise from the manner in which watershed uplands are farmed (as indicated by cropping and tillage practices), cost-sharing arrangements and institutional devices can reconcile planning objectives of farmers controlling uplands with those of other concerned participants. This is usually discussed with reference to such costly land improvements as terraces but is basically no less applicable to the simple practices of rotation adoption, contouring, and fertilization. Similar considerations determine the feasibility of structural improvements, whether installed for flood control, channel stabilization, irrigation water storage, or any other purpose.

Determining and promoting land use adjustments desirable from a watershed viewpoint is a major concern of research and action programs.

The fact that land use can result in damage diseconomies aside from being beneficial in yielding commodities suggests, therefore, that the multi-purpose concept heretofore guiding river basin development can be usefully applied in small watershed planning. This requires extending it from its usual use in the appraisal and design of structures to examining the feasibility of land use changes with regard to possible increases or decreases in basic productivity, and to associated beneficial or detrimental water-yield and erosion effects. With detailed benefit-cost relationships of land use changes and structures known, optimal combinations of these two types of watershed development activities can be selected with reference to resource capabilities of various participants.

Qualifications of the Nepper Analysis

Several types of qualifications limit the study. These principally pertain to (1) the viewpoints of analysis, economic horizons, discount rates, and price estimates considered appropriate by official water-resource policy review groups for watershed planning and adopted here; (2) criteria for the sharing of costs incurred in the installation and operation of projects; as possibly specified by statute, administrative decision, or welfare conditions; (3) the limited number of feasible land treatment measures given benefit-cost analysis as a basis for selecting those eventually considered as appropriate development activities; and (4) the restricted intensity of land treatment or water-control capacities of structures, as determined by requirements for limited land, labor, and capital resources; or effectiveness in reducing predetermined maximum damage.

Technical assumptions

Viewpoint of analysis. Evaluation and planning for the Nepper Watershed are based on the year 1947 representing predevelopment conditions. As noted earlier, land treatment was recommended and structures were planned and installed in the area the following year under the Little Sioux Flood Control Program. This study re-evaluates as multiple development possibilities the erosion, flooding, and gullying problems determined to exist in 1947. It then attempts to specify programs combining land treatment and structural controls to maximize net benefits for the watershed as a hypothetical decision-making unit, integrating interests of seven farm operating units, the local County, and the immediate downstream area. Alternative optimal programs are devised for any available outlay level; this permits reappraisal of the Little Sioux Program within the study's framework along with specification of programs representing optimal allocation of resource outlays greater or less than that called for in the Little Sioux Program.

Economic horizons. In estimating economic consequences of predevelopment conditions continuing indefinitely beyond the benchmark year 1947, a 50-year economic horizon is assumed for all participants; that is, projected predevelopment costs and returns as well as program costs and returns recurring beyond 1997 are ignored.[24] Structures and

[24]Major Federal water-resource agencies other than the Bureau of

terraces as major improvements are assumed to have zero salvage value in the cut-off year. Similarly, improvement installation costs allocated among benefiting private or public participants must be recovered with interest over the 50-year project life.

Rates of discount. Future returns and costs are discounted at 5 percent if accruing to private participants (farm units) and at 2 1/2 percent if accruing to public participants.[25] The annual equivalent method of presenting returns and costs associated with various economic activities is utilized in appraisal and summarization, however. The method yields results consistent with computation and comparison of present values if all present values are converted to annual values by amortization at appropriate rates of interest.

Price estimates.[26] Budgetary analyses of gross farm income from

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[24](Continued from page 29)
Reclamation limit project lives (particularly for repayment purposes) to 50 years, with the Bureau frequently amortizing installation costs over a 100-year period. The above assumption conforms with recommendations presented in the following publication: U. S. Department of Agriculture. Soil Conservation Service. Watershed protection handbook; policies, procedures, and instructions relating to the program authorized by the watershed protection and flood prevention act. Mimeo. report. Wash., D. C. Author. July 1957. p. 6-6.

[25]Rates considered effective in 1948 when the Little Sioux improvements were installed.

[26]Estimates given in this section of average future prices of farm commodities and production factors, as well as specific conditions on which the estimates are based, are taken from the following pamphlet recommended for use by Federal agencies engaged in watershed and river basin studies. U. S. Department of Agriculture. Agricultural Marketing Service. Agricultural price and cost projections for use in making benefit and cost analyses of land and water resource projects. Wash., D. C. Author. September 1957.

land use systems feasible on various soils and fields within farms assume long-term Iowa projected 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 employment, a gradual improvement in international relations, continued population growth, and a stable general price level; assumptions believed to underlie a projected all-product index of 235 (1910-14 = 100) for prices received by farmers. Opportunities for marketing the grains and forages through livestock are ignored in determining the relative profitability of land use systems feasible on each field.

Annual farm costs of production are similarly based on an 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 fertilization expense, harvesting expense variable with yields, and property taxes are computed at $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. The above data are uniformly applicable to all Nepper Watershed soil and field conditions. Calculations of fertilizing expense add $12.90 per cwt. of nitrogen applied and $7.50 per cwt. of available phosphorus applied to a uniform spreading cost of $1.38 per acre. Hauling of corn and oats is charged at $0.05 per bu.; and baling, hauling, and storing of hay at $2.72 per ton. Property taxes are estimated at $2.38 per acre.

Costs of installing level terraces designed to retain 2 inches of runoff, and structures as major improvements are estimated for 1948, the year of Little Sioux planning for the Nepper Watershed. A $0.04 per linear foot local contract cost of bulldozer terrace construction computed for field slopes of 12 percent is assumed representative of all terraceable areas; terracing costs per acre thus depend on total footage requirements varying with field slopes. An effect of vegetated terrace back slopes voiding productive areas on field slopes exceeding 15 percent is considered by reducing budgeted returns and variable costs in proportion to the percent of terraced areas necessarily occupied by permanent sod. Terrace maintenance expense other than the costs of owning special implements for farming terraces is computed with reference to estimated rates of channel siltation; results for various land use systems and field conditions are given subsequently.

Structural installation costs -- including planning, construction, and required rights-of-way -- are also dated to 1948, and essentially are either estimates available to or provided by the Little Sioux planning group. This study assumes proportionality between installation costs and structure size as represented in most cases by volumes of earth fill; also between recurring maintenance expense or associated damages and earth fill volume.

Additional conditions apply to unit reductions in gully and flood damage as price equivalents. All damages are initially evaluated as average annual amounts expected from continuation of 1947 predevelopment land use methods through 1997, then related to specified independent hydrologic variables modifiable either by changed land use or by water-control structures. Damages estimated per unit value of hydrologic variables observed under predevelopment are conversely taken as the program benefits obtained per unit reduction in the relevant hydrologic variables. Gully damage, for example, is evaluated as the maximum net discounted income foregone on areas likely destroyed over the period 1947-97 by owners of affected properties, and is related to runoff indexes in turn influencing expected rates of peak flow in drainage-ways. Gully control benefits of land treatment are estimated as reductions in otherwise expected gully damage per unit reduction of runoff indexes from predevelopment values; while corresponding benefits of structures are directly the reduction in damage per unit of peak flow reduction. Where gully or flood damages are estimated as net decreases in land values or crop income, the commodity prices and farm production costs utilized in general land use system budgeting underlie the computations.

Distribution of costs

In determining the economic feasibility of alternative land treatment and structural measures (establishing whether benefit present values exceed outlay present values), combining measures in feasible programs, and indicating by whom costs are to be covered, the following principles are employed:

1. If measures are either of a single- or multi-purpose, single-participant character; that is, yielding benefits either of types a and/or b and c on page 8 to a single participant, all listed costs of

types d through g associated with such measures are charged to the single participant, regardless of where the measure might be applied within the watershed.

2. If measures are either of a single- or multi-purpose, multi-participant character; that is, yielding benefits either of types a and/or b and c to more than one participant, listed associated costs are distributed to render total beneficiary allocations proportional to present values of gross benefits received, again regardless of the site of installation.

It may be noted that only for single-purpose, single-participant measures do charges clearly represent costs of providing a specific kind of benefit for a specific participant. Those of remaining character encountered in the analysis commonly produce distinct classes of benefits combined in fixed proportions and/or accruing in fixed proportions to more than one beneficiary, the feature of fixed proportions preventing calculation of partial average or marginal costs.[27]

In relation to the allocation question, no allocations of costs among multiple purposes are made. Agency allocations of joint costs among purposes are usually intended to approximate partial costs as a basis for assessing beneficiaries of particular purposes; namely, irrigation, power, and municipal water supply, reimbursable by

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[27]The theoretical impossibility of computing partial marginal and average costs, and average total costs of producing multiple products in fixed proportions is well presented by Erick Schneider. Pricing and equilibrium. N. Y. The Macmillan Co. 1952. p. 94. See also Sidney Weintraub. Price theory. N. Y. Pitman Publishing Corp. 1949. pp. 290-294.

law.[28] Because this study is concerned with illustrating program planning under conditions of complete reimbursement by beneficiaries, intermediate allocations based on the nature of benefits are unnecessary.[29] In proportionally assessing beneficiaries for resources needed to promote development measures, it is assumed that they (a) are 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. Assignments pertinent to complex measures are thus only implied to be costs willingly borne by beneficiaries in obtaining a "bundle" of benefits, not an indeterminate cost of providing benefits of a particular kind to individual beneficiaries.

Although cost allocations proportional to benefit present values have no rational justification in cases of rigid cost interdependence, their use in the study is based on the frequently repeated policy recommendation implying that such allocations most equitably consider

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[28]For a discussion of various techniques employed see Horace M. Gray. The allocation of joint costs in multiple-purpose hydroelectric projects. American Economic Review. 25: 224-235. June 1935. Also Martin G. Glaeser. Water resources. U. S. Congress. Joint Economic Committee. Papers submitted by panelists appearing before the subcommittee on fiscal policy. Nov. 18, 1957 to Nov. 27, 1957. 85th Cong., 1st sess., Wash., D. C., U. S. Govt. Print. Off. 1958. pp. 668-682.

[29]In 1954 the Federal Power Commission, the Corps of Engineers, and Bureau of Reclamation agreed to uniformly adopt the separable cost-remaining benefits procedure of joint cost allocation. With the technique defining respective separable costs of purposes as savings in total costs resulting from their elimination, its application here would reduce to an allocation directly proportional to benefits. Of the multipurpose measures evaluated, none could be adopted at reduced cost if any purposes were eliminated or, more properly, ignored.

interests of all beneficiaries, public or private. A recent statement follows:[30]

> Just as a sound national policy should provide for joint participation of Federal and non-Federal interests in the planning of water resources, by the same token it should provide for an equitable sharing of costs. As a general principle, the share of the costs to be borne by the beneficiaries should be proportionate to the benefits received. . . . . The principle of cost sharing should not be limited to projects constructed by the Federal Government. It should apply also to projects constructed by non-Federal interests.

3. In meeting the general feasibility criterion that aggregate benefit present values exceed aggregate outlay present values, measures must also meet the criterion under (2) that outlay allocations to any participant must not exceed benefit present values. But with allocations made proportional to benefits, any measure feasible in the aggregate is necessarily not infeasible for any participant, and will be equally profitable (yield equivalent positive rates of return) to all beneficiaries. Conversely, any measure infeasible in the aggregate is necessarily infeasible and will be equally unprofitable (yield equivalent negative rates of return) for all beneficiaries. In both cases it is assumed that non-benefiting participants are indifferent to the measures, with those possibly suffering damages or expected to realize other additional costs made indifferent through equivalent compensations.

4. Measures are combined in development programs with reference to their ratios of net capitalized benefits to total capitalized costs; the latter including initial installation outlays; and recurring operating-

[30] Presidential Advisory Committee on Water Resources Policy. Report on water resources policy. 84th Congress, 2d sess., H. Doc. 315, Wash., D. C., U. S. Govt. Print. Off. 1956. pp. 8-9.

maintenance expense and compensated increases in damage. Since the ratios are not observed to vary with measure intensity, they represent both average and marginal rates of net return on capitalized expenditures. With the ratios also denoting opportunity costs of not independently including feasible measures in programs, or possibly not substituting among measures, aggregate and individual net benefits are maximized by adding or substituting measures in descending order of benefit-cost ratios applicable to the additions or substitutions. The procedure permits formulation of alternative net benefit-maximizing programs keyed to the availability of resources and technological restrictions on planning. In addition it specifies the investment capital (as one element of capitalized cost) and other resources willingly contributed by identified beneficiaries, on the basis of requirements for promoting included measures at their optimal intensity.

An alternative criterion for ordering and combining measures yielding capitalized benefits greater than costs could be taken as the discount rate which equates the present value of annual gross benefits, less the recurring expenses noted above, to initial installation or investment costs. This ratio, variously termed the internal rate of return or marginal efficiency of capital, is seldom used in economic studies of river basin or in public resources development projects in general. Arguments are current for its adoption, however, mainly as a device for optimally allocating given installation budgets.[31] The

[31]For elaboration of suggested rankings by internal rates of return, see Julius Margolis. The discount rate and the benefit-costs justification of Federal irrigation investment. Technical Report No. 23. Stanford University. Department of Economics. November 1955. pp. 12-14.

procedure of crediting to capital project benefits net of recurring costs (for other input factors) is generally rationalized on the basis that the efficient use of the capital resource is of primary interest in making investment decisions.

The position of Federal agencies on the internal rate of return is that ". . . . Under this method comparison of respective operation and maintenance costs is incomplete, since they are deducted before computation of percentages."[32] And on the benefit-cost ratio[33]

> . . . . The ratio of benefits to costs reflects both benefit and cost values and is the recommended basis for comparison of projects. If the sum of all beneficial effects were compared with the sum of all adverse effects for a project, the ratio of the benefits to the costs would reflect the effectiveness with which all the resources involved were being used. The procedures recommended herein are based on [the] assumption that, in general, the economic resources involved in the project development over and above those accounted for in project benefits and project costs would be used with equal effectiveness with or without the project. Therefore, a ratio of project benefits to project costs constitutes the proper measure of the effectiveness of use of the Nation's resources insofar as the use of such resources for project purposes is concerned.

The ratio of net benefits to costs as an indicator of the relative profitability of alternative justified measures is retained in this study as another prevailing policy recommendation under which program formulation is to be illustrated.

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[31](Continued from page 37)
Also Roland N. McKean. Efficiency in government through systems analysis. N. Y., John Wiley and Sons, Inc. 1958. pp. 74-133.

[32]U. S. Federal Interagency River Basin Committee. _op. cit._, p. 14.

[33]_Ibid._, p. 14.

Limited scope of planning

Isolation of the entire range of economic land treatment and structural measures properly considered as alternative activities competing for development resources would require detailed benefit-cost analyses of every land use system agronomically feasible within the Nepper Watershed; and similar analyses of all engineeringly feasible water-control structures. With concentration on fields[34] within farms as basic land treatment units or possible structure sites, measures thought to represent a reasonable range of activities given detailed benefit-cost appraisal are delimited by conditions outlined below.

Land treatment measures. The first condition applied to land treatment is that reduction of sheet erosion to annual rates no greater than 5 tons per acre on each of 27 field units might be acceptable to farm operators concerned as a secondary watershed development objective if measures thus reducing erosion were not less profitable on a present value basis than continuation of predevelopment land use. This condition obviates detailed appraisal for planning purposes of all agronomically feasible land use systems (excepting that observed in 1947) for which annual sheet erosion rates would exceed 5 tons per acre.

With annual erosion rates reduced to 5 tons per acre, the land use systems appraised in detail for aggregate benefits and costs include (aside from 1947 systems for each field)--

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[34]Fields are defined as operating sub-areas of farms in 1947, where each sub-area was cropped exclusively either to corn, oats, or hay; or was in permanent pasture.

1. The system representing land treatment recommended in the Little Sioux Program for the Nepper Watershed, and/or
2. The system observed as current at the time (1957) of this study, and/or
3. The system likely adopted by a farm operator not faced with capital limitations and seeking to maximize net farm income while raising corn relatively frequently, and/or
4. The system likely adopted by a farm operator faced with capital limitations and seeking to maximize net farm income while raising corn relatively frequently, and/or
5. The system minimizing sheet erosion while allowing corn to be grown most frequently, without particular regard to farm returns and costs. This system is selected as tending to minimize adverse watershed-wide and off-site consequences of land use on each field while giving some regard to possible preferences for row crops.

For any of the systems given above to be considered as comprehensive land treatment measures, detailed appraisals must indicate an excess of aggregate benefits over aggregate outlays. Benefits and costs are computed as changes in farm and thence watershed accounts induced by shifting to any of the given systems from the system followed in 1947, the benchmark year. All investment and recurring costs are distributed in proportion to benefits received by any participant, with possible damages assumed compensated for.

The listed systems then selected for illustration of comprehensive planning must, in addition to yielding aggregate benefits greater than costs, either yield maximum net benefits per acre treated or maximum benefit per unit outlay (aggregate or individual). The final selections are to indicate the changing character of programs as successively greater outlays of capital and other required development resources are allocated to maximize net benefits for participants individually and as a watershed community.

Structural measures. Structural measures considered are limited to the types and locations deemed feasible by technicians planning the 1948 Little Sioux Program. Included for benefit-cost appraisal are a combination bridge and chute-spillway designed for road protection, three drop inlets for either gully and/or flood control, a channel-stabilizing drop-spillway, and a levee system protecting crops on the watershed floodplain. Those structures designed to function interdependently are so appraised as grouped measures; with measures other than the levee system appraised on a unit earth-volume basis (1,000 cubic yards) and the levee system appraised on a unit height (1 foot) basis.

Initial consideration of structural measures as development activities is governed by the same criteria applied to land treatment measures; aggregate benefits per installation unit must exceed aggregate costs, and individual benefits must not be less than assigned costs, with costs distributed proportionally with benefits among beneficiaries and compensated damages included as costs. All structural measures meeting these criteria, regardless of the magnitude of benefit-cost ratios or net benefits, are considered in program formulation along with the complex of land treatment measures selected as described in the preceding section.

Restricted measure intensity

In formulating programs consistent with the planning objective of maximizing net benefits, restrictions on land treatment intensity and water-control capacity of structures relate both to available resources and maximum damage averted.

Land. Land resources available for obtaining development benefits from land treatment are represented in general by the total watershed area susceptible of treatment, which includes the watershed area as hydrologically defined less the area occupied by roads and farmsteads. Particular classes of land susceptibly treated include 27 fields distributed among seven farm operating units. Net benefits in general are then limited by complete treatment of all fields and in particular by individual fields being treated to yield maximum net benefits per acre.

Land resources available for obtaining benefits from structures are represented by fields in which feasible structure sites are located, excepting the single combination bridge and chute spillway located on the County road.

Labor. It is presumed that additional inputs of farm labor involved in land use changes recommended by development programs are available as needed. This is based on observation of land use current in 1957 in conjunction with similar resource inventories for all farms in the watershed. In the absence of contrary evidence, the same conclusion applies to structure installation and maintenance.

Capitalized expenditures. Expenditures for both land treatment and structures are calculated as the capitalized cost of installing and continuing these activities over the 50-year project period. For land treatment such costs include initial outlays for terrace construction and permanent pasture establishment; plus recurring outlays for pasture re-establishment (at 4-year intervals), increases in annual farm operating expense, decreases in farm returns, and increases in either annual flood or gully damage possibly associated with treatment. Included for structures are the installation costs of planning, construction, and land acquisition; plus annual outlays for maintenance and compensated increased damages resulting from installation.

In combining land treatment and structural measures in programs maximizing net benefits it is assumed only that participants would be justified in making assigned outlays for installation, with corresponding benefits necessarily sufficient to cover recurring expenses as well as discharge initial capital outlays at the specified rates of interest. This implies capital rationing only if required funds were not available from lending agencies at the specified rates of interest.

Maximum damage-reduction benefits. These independently relate to land treatment and structures in that either are possibly (depending on location) effective in modifying hydrologic variables with which damages are associated. Since such benefits are limited to maximum average annual damage probable with continuation of predevelopment land use through the project period, no land treatment or structure is credited with damage-reduction benefits unless other measures more effective in yielding aggregate benefits do not in combination eliminiate damage entirely. This condition is enforced even if measures so re-evaluated yield specific damage-reduction benefits greater than other measures included in programs, on the basis that net benefits in the aggregate are to be maximized rather than benefits of a particular kind. Measures re-evaluated, however, are eliminated from further consideration only if remaining benefits are not in excess of capitalized cost; that is, benefits of other types may warrant inclusion of the measures despite an independent effectiveness in some forms of damage control being ignored.

Sources of Special Data

Land use patterns

Two historic patterns and one suggested pattern of watershed land use are compared with optimal patterns subsequently specified. Records of these defined patterns are cited as follows:

Pattern A. Established land use prior to installation of the Little Sioux Program in 1948. For the most part, this pattern is approximated from studies of Gertel;[35] required historical land use data are otherwise based on 1957 farm interviews conducted by the author. As noted previously, this historic pattern is taken as representative of the predevelopment land use situation from which benefits and costs incident to

[35] Gertel, op. cit., pp. 47-67.

land treatment or structures are computed.

Pattern B. Land use recommended in conjunction with structural measures installed in the Little Sioux Program. Recommendations for each field are available from Gertel's evaluation of that program.

Pattern C. Established land use current in 1957 with this study. Cover conditions for most of the watershed area are determined from records maintained since 1950 by the Iowa State College Department of Agricultural Engineering. Cover conditions, conservation practices, and fertilizer treatments observed from 1947-1957 established this historic pattern, with practices and fertilizer treatments noted in the aforementioned interviews. This pattern is included for later indicating the nature of adjustments in current land use required to achieve specified optimal patterns.

Land use systems and related hydrologic data

Combinations of crop rotations, conservation practices, and fertilizer treatments feasible for each of 11 watershed soil types, with corresponding estimates of harvested crop yields and recommended rates of fertilization, are those provided by the Iowa State College Department of Agronomy (see Table 27). Yields are representative of average weather conditions, adapted varieties, and average management where given land use systems have been established over a period of 10 years. Resulting rates of sheet erosion for each feasible system applied on each watershed field unit are calculated from "Browning factors."[36] In relation to

[36]Iowa State College. Department of Agronomy. Browning's erosion factors. Mimeo. report. Ames, Iowa. Author. February, 1957.

erosion, yield estimates are minimums associated with continued loss of topsoil at computed rates.

Gross crop returns and production costs for systems denoted by Patterns A through C above, and remaining feasible systems with annual erosion rates not over 5 tons per acre, are adjusted to long-term price levels discussed on page 30 from price levels available when system budgets were prepared for the 1954-56 pilot study. Estimates of crop flooding damage and gully damage associated with the systems are similarly revised.

In associating all forms of encountered flood damage with land use, the procedure employed estimates 24-hour runoff volumes directly from runoff percentages applicable to various cover conditions, conservation practices, and degrees of terracing. Runoff as between various cropping conditions and conservation practices other than terracing is determined from relative values observed for the 12 most erosive storms occurring at the Western Iowa Experimental Farm at Castana over the period 1948-56.[37] Runoff estimates relative to degree of field slope are based on 1933-38 studies at the Upper Mississippi Valley Conservation Experiment station at La Crosse, Wisconsin;[38] and estimates relative to slope length are based on 1933-42 data obtained at the Missouri Valley Loess Conserva-

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[37]W. E. Larson and F. W. Schaller. Spacing of level terraces in western Iowa. Agricultural Engineering. 39: 20-23. 1958.

[38]U. S. 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. Technical Bulletin 973. Wash., D. C., U. S. Govt. Print. Off. 1949.

tion Experiment Station at Clarinda, Iowa.[39] Coefficients thus derived from the Castana storm record and cited experiments are adjusted to a local basis by recourse to the record of 14 flood-producing storms occurring in the Nepper Watershed from April-September over the period 1950-54. Coefficients applicable to land use systems in effect on individual field units are then utilized in estimating average annual runoff volumes and related flood damages. Conversion of flood runoff to bottomland acreages flooded employs overflow-flood depth rating curves prepared by the Iowa State College Department of Agronomy. Also given are estimates of crop losses by flood depths and growth stages.

In correlating gully damage with land use, the study initially estimates rates of land destruction in conjunction with peak runoff rates expected with storms of 10-year average recurrence; the procedure being suggested by the Iowa State College Department of Agricultural Engineering. Rates of land destruction are then utilized in obtaining present values of maximum gully damage as the present values of maximum net income foregone over the 50-year project period if such rates should continue.

Detailed design and cost data required for benefit-cost analysis of feasible structures as installed in the 1948 Little Sioux Program are from files of the Little Sioux Flood Control Office in Sioux City, Iowa (Table 38).

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[39] U. S. 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. Technical Bulletin 959. Wash., D. C., U. S. Govt. Print. Off. 1948.

Observed damages

These include interview-type estimates of predevelopment damage to watershed transportation facilities and downstream damages to farmland and transportation-drainage facilities; associated runoff volumes are derived in the study, however.

Damage to on-site transportation facilities prior to 1948 is represented by an average annual $325 cost of frequently repairing a bridge on the Monona County road network, estimated in 1947 dollars.[40] This amount is made relatively comparable with projected commodity prices by inflation at the ratio of a long-term projected construction cost index (250) to a similar index available for 1949 (211); with both indexes in 1939 dollars.[41] As adjusted, average annual bridge damage expected with continuation of predevelopment land use without structural improvements amounts to $385 and represents maximum average annual benefits from reductions in the associated runoff.

Downstream damages prior to 1948 from the Nepper Watershed as a source-area are based on 1954 estimates for similar unimproved source watersheds located on the lower reaches of the Maple River, with combined floodwater-sedimentation damage to farmland and public facilities approximated at $187 per square mile of contributing watershed.[42] This

[40]Gertel, op. cit., p. 68.

[41]Selected as the U. S. Department of Commerce Composite Index of construction costs. U. S. Department of Agriculture. Agricultural Marketing Service. op. cit., p. 35.

[42]Cecil A. Saddoris. Des Moines, Iowa. Information on damages for the Nepper Watershed. Private communication. July 1955.

figure is the basis for $140 in annual damages estimated to originate within the 480-acre (0.75 sq. mi.) Nepper Watershed. Annual damages of $140 thus originating from the Nepper Watershed as estimated for 1954 if it were unimproved are taken as equivalent to projected damages because roughly 70 percent of the amount affects maintenance of transportation-drainage facilities; also, the projected construction cost index of 250 approximates the similar index of 251 for 1954. Maximum average annual downstream benefits of on-site runoff reductions are similarly the estimate of $140 in projected annual damage.

DEVELOPMENT POSSIBILITIES IN THE NEPPER WATERSHED

The Watershed as a Study and Planning Area

Physical description

Located 2 1/2 miles south of Mapleton in Monona County, Iowa, the 480-acre Nepper Watershed is tributary to the Maple River (740 sq. mi.), the Little Sioux River (4,502 sq. mi.) and the Missouri River (529,000 sq. mi.) drainages. The watershed has soils characteristic of the Monona-Ida-Hamburg soil association, with 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 but the Monona are calcareous to the surface.

A major portion (52 percent) of the 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 as next important (19 percent) have also been formed under grass and cover steeper slopes or sharp ridges. The McPaul series (15 percent) is an alluvial soil washed from Ida and Monona uplands, while the Napier (14 percent) are colluvial soils located along lower slopes and along principal drainageways. Slope phases within the various series mapped in the 1950 Monona County Soil Survey are shown in Figure 1 and tabulated by farms in Table 2.

Average annual rainfall in the watershed approximates 25 inches, with about 75 percent concentrated during the period April-September.

These months essentially represent the season during which intensive storms and flooding occur. In June 1951, a 5.62-inch storm (100-yr. average recurrence expectancy) produced an estimated 101 acre-feet of runoff (45 percent of the total rainfall volume) which, without installation of structural controls, would have flooded 41 acres of McPaul bottomland in addition to discharging 53 acre-feet of flood runoff into the Maple River. Flood-storm records available for 1950-54 (Table 37) indicate that a 1-inch storm is generally sufficient to produce some runoff, with 14 storms of this magnitude or greater occurring through the period. From the same record the average amount of flood-producing rainfall annually expected from April-September 30 approximates 6.26 inches, with about 20 percent occurring before June 1 and 80 percent through the remaining months. Under land use conditions prevailing in 1957, about 34 percent of the average of 6.26 inches of seasonal intense precipitation falling over the 480-acre watershed drainage area would have appeared as runoff, the percentage before June being slightly higher owing to a lesser interceptive effect of growing crops.

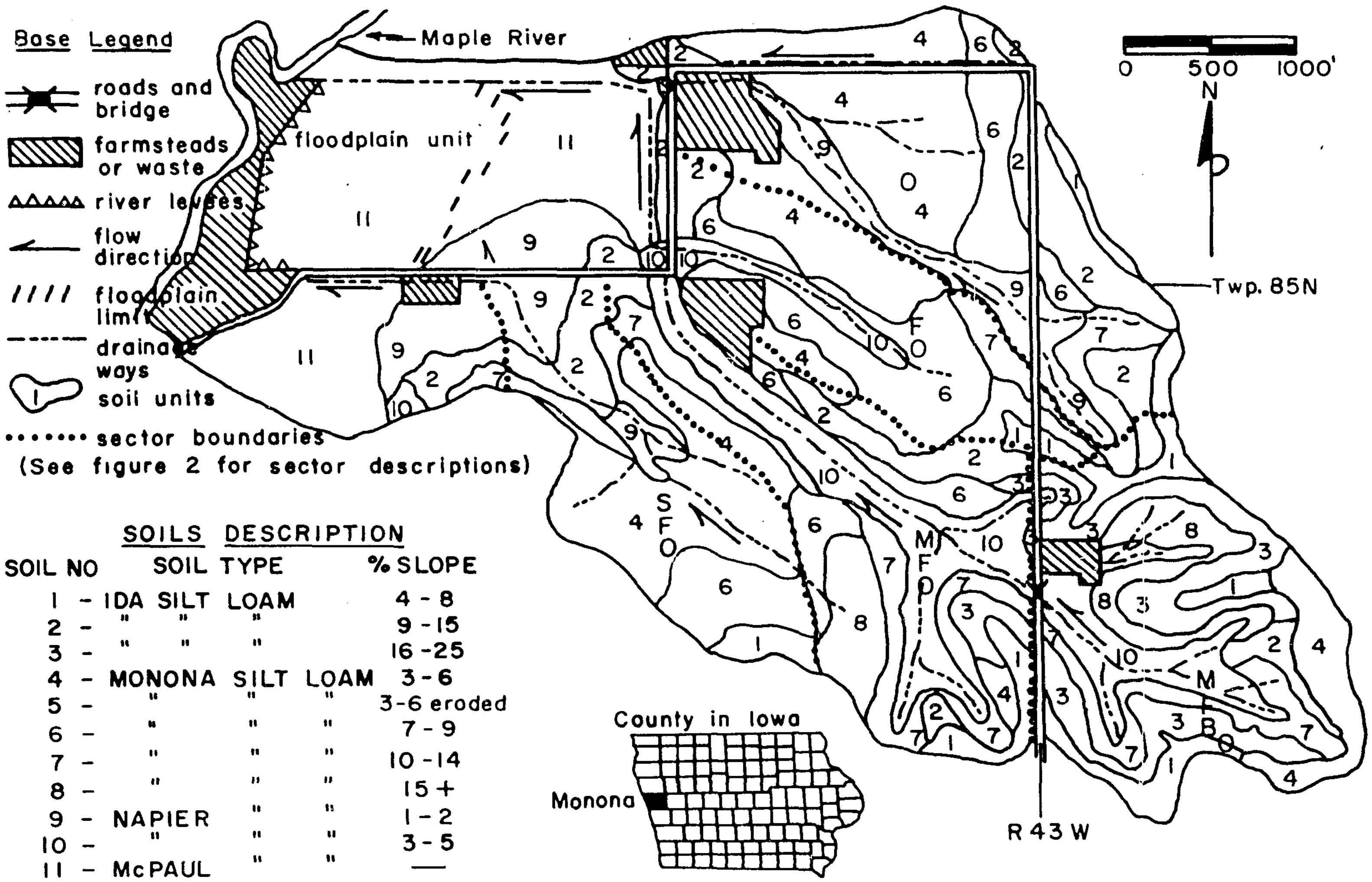
The general course of runoff from watershed uplands is indicated by the drainage pattern of Figure 1. Two outlets into the Maple River are shown, although minor discharges from the 20-acre low area in the extreme southwest corner are ignored. Additional hydrologic features are described with reference to the following potential problems posed by excess runoff originating on source areas, collecting in drainageways, and thence either overflowing McPaul bottomlands within the watershed or leaving the northwest outlet:

1. Losses in productivity from sheet erosion
2. Gully damage in the main drainage
3. Gully damage in the southwest drainage
4. Crop flood damage of on-site origin
5. County bridge damage of on-site origin
6. Off-site flood damage of on-site origin

The principal source-area damaging effects of runoff are the loss of water possibly utilized by growing crops or entering the soil moisture reservoir and loss of topsoil through sheet erosion. This hazard is particularly serious on Ida and Monona soils predominating on uplands generally increasing in slope southeastward from the township line road corner, shown in Figure 1 and other maps. Roughly 385 acres are subject to sheet erosion.

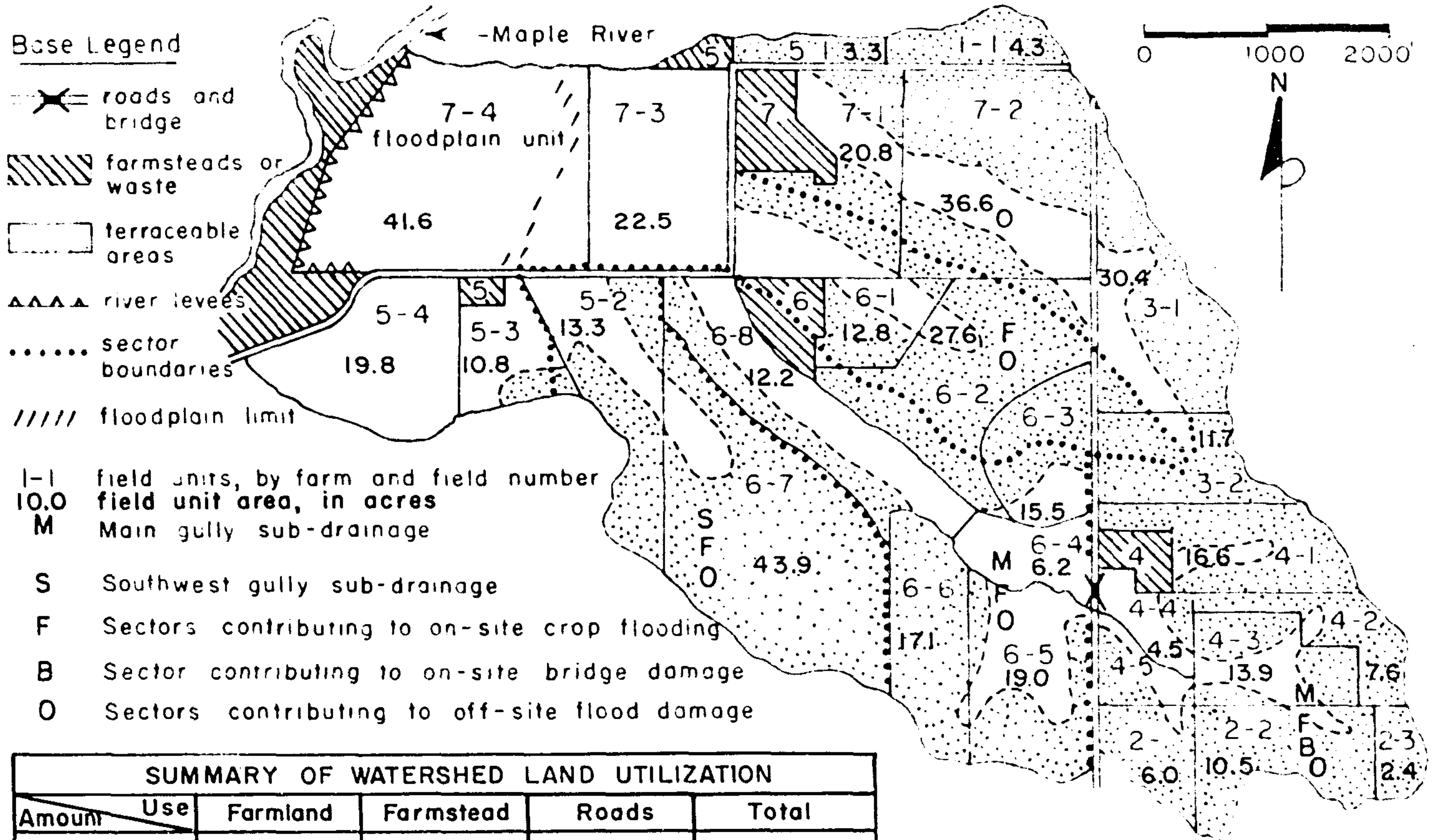
The 157-acre main drainage extends from the same road corner to the southeastern divide, including the two sectors designated as 'M' in Figure 1. Areas potentially destroyed include Napier soil units of 3-5 percent slope occupying drainageways. The 57-acre southwest drainage is designated as 'S' in Figure 2; here Napier soils of 1-2 percent slope are subject to destruction.

Crop flood damage of on-site origin potentially originates on all sectors designated as 'F'; 293 acres in total contribute. Bridge damage is concentrated at the single location given, being caused by excess runoff from the 89-acre sector designated as 'B'. All sectors (386 acres) designated by 'O' potentially contribute the bulk of runoff discharge into the river at the northwest outlet.



SOIL NO	SOIL TYPE	% SLOPE
1 -	IDA SILT LOAM	4 - 8
2 -	" " "	9 - 15
3 -	" " "	16 - 25
4 -	MONONA SILT LOAM	3 - 6
5 -	" " "	3-6 eroded
6 -	" " "	7 - 9
7 -	" " "	10 - 14
8 -	" " "	15 +
9 -	NAPIER " "	1 - 2
10 -	" " "	3 - 5
11 -	McPAUL " "	—

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



SUMMARY OF WATERSHED LAND UTILIZATION				
Amount \ Use	Farmland	Farmstead	Roads	Total
Acres	436.5	15.3	29.0	480.8
Per cent	91	3	6	100

Figure 2. Operating and planning units in the Nepper Watershed.

Table 2. Distribution of Nepper watershed soils, and damage sector relationships

Soil types by slope percent	On-site private participants (farms) 1	2	3	4	5	6	7	Watershed total
	Watershed soils distribution (acres)							
Ida silt loam, 4- 8%	-	3.4	5.7	1.6	-	8.0	-	18.7
Ida silt loam, 9-15%	-	0.2	14.1	3.7	9.80	10.6	6.8	45.2
Ida silt loam, 16-25%	-	6.4	1.7	12.9	-	4.5	-	25.5
Monona silt loam, 3- 6%	3.5	2.9	-	6.7	5.70	42.3	39.7	100.8
Monona silt loam, 3- 6% (e)[a]	-	-	-	-	-	8.5	-	37.5[b]
Monona silt loam, 7-10%	0.8	-	1.0	-	-	37.9	11.2	50.9
Monona silt loam, 10-14%	-	4.6	15.5	4.7	3.1	21.5	-	49.4
Monona silt loam, 15%	-	-	0.6	10.0	-	1.0	-	11.6
Napier silt loam, 1- 2%	-	-	3.3	-	10.70	4.6	13.5	32.1
Napier silt loam, 3- 6%	-	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 sector contributions (acres)							
Main gully	-	18.9	11.8	51.1	-	68.4	-	157.5[c]
Southwest gully	-	-	-	-	13.1	44.1	-	57.2[c]
On-site crop flooding	-	18.9	10.1	51.1	13.1	147.8	43.4	293.1[c]
On-site bridge damage	-	18.9	11.8	51.1	-	-	-	88.9[c]
Off-site 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% (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 the on-site crop flooding sector, 7.1 acres in the on-site bridge damage sector, and all 29 acres in the off-site flood damage sector (or watershed).

Table 3. Income and financial status of Nepper Watershed farmers; by tenure groups

Net worth[a] and income items[b]	Owners non-operators (dollars)	Owner-operators (dollars)	Owner-operators part tenant[c] (dollars)	Tenant operators (dollars)	All groups (dollars)	Average per farm unit (dollars)
Total local farm assets	109,500	108,503	101,356	27,617	346,976	49,548
Total farm liabilities	0	9,020	10,800	100	19,920	2,844
Personal net worth, farm basis	109,500	99,483	90,556	27,517	327,056	46,704
Net investment in farm inventories	109,500	74,313	67,794	16,887	268,494	38,340
Adjusted livestock sales	1,511	3,837	15,937	3,022	24,307	3,471
Adjusted crop sales	3,375	2,209	1,700	2,756	10,040	1,433
Other farm income	100	2,884	780	0	3,764	537
Total farm income	4,986	8,930	18,417	5,778	38,111	5,441
Fixed farm expenses	2,494	2,767	3,754	1,624	10,639	1,519
Variable farm expenses	1,527	3,336	6,144	1,441	12,448	1,777
Net farm income	965	2,827	8,519	2,713	15,024	2,145
Disposable farm income[d]	965	2,718	8,193	2,713	14,599	2,084
Population, including dependents	8	8	17	7	40	6
Per capita disposable income	120	339	482	387	365	347

[a]Assets and liabilities are estimated as of July 1, 1957, in current prices.

[b]Farm income and costs are estimated for 1956 in projected long-term prices. The 1956 season, because of abnormally dry weather, is not representative of average farm income.

[c]Includes a managing part owner.

[d]Net farm income less taxes on farm income.

Major economic activities[1]

Portions of seven farm operating units are included within watershed boundaries, with included acreages per farm ranging from 4.3 to 160. Total farm sizes range from 74 to 195 acres. In 1956, an abnormally dry year, livestock or livestock product sales per farm ranged from $1511 to $6836, accounting for approximately 70 percent of gross farm income. Crop sales similarly ranged from zero to $2633 per farm. In years of more average rainfall, livestock and livestock product sales still account for the slightly larger proportion (61 percent) of gross farm income.[2]

Tenure conditions have remained relatively stable over the period 1947-57; in 1957 two units were operated by tenants, two by owner-operators part tenant, two by owner-operators, and one by a one-eighth share-owner acting as manager. Intra-watershed boundaries of farm operating units and acreages of contained field units are shown in Figure 2, with Table 2 indicating the distribution of soil types, watershed area, and damage sectors as delineated above among the seven farms. Table 3 summarizes additional net worth and 1956 income data for watershed farmers classified by tenure groups.

[1]Unless otherwise indicated, economic data in this section are based on farm surveys conducted by the author in July 1957. Income and cost data are adjusted to projected long-term levels discussed on p. 30.

[2]Estimated from 1950 data for farms in Monona County. U. S. Census of Agriculture: 1954. Counties and state economic areas, 1, Part 9: 79. 1957.

About 29 acres of the watershed are taken up by the 2 miles of Monona County roads traversing the area as shown on all maps. Maintenance of these roads for public transportation is the principal on-site public service considered by the study in relation to land use on the contributing sector 'B' and consequent damage at the single bridge facility. Maintenance of transportation facilities and drainage improvements situated on Maple River bottomlands is the only off-site public service considered in relation to watershed land use; on watershed sectors indicated by 'O'.

Further investigations and subsequent planning attempt consideration of the economic interests of the seven watershed farm operating units (aggregated as on-site private participants), Monona County as a public entity, and the downstream area as an additional public entity. Farm operating units and Monona County represent aggregate on-site interests, while Monona County and the off-site area represent aggregated public interests. All participants or participant-groups represent an aggregated watershed community interest.

Hypothesized development possibilities

These relate to opportunities in 1947 for obtaining net benefits from development in terms of increased present values of on-site net farm incomes; or decreased present values of costs incurred in providing essential public services, if such net benefits accruing to any specified participant or participant group were not obtained at the expense of losses to other participants or groups.

Development possibilities for all participants were represented by land use changes and capital improvements yielding capitalized benefits in excess of capitalized assigned costs. On-farm benefits of these measures include any increases in gross farm income, and any reduction in associated operating expense, gully damage, or crop flood damage. Benefits to Monona County include reduced bridge maintenance expense associated with land use, while downstream benefits are the reduction in damages to drainage and transportation facilities associated with watershed land use. Assigned costs include possible decreases in gross farm income; also any increases in associated farm expenses, gully damage, crop flood damage, on-site bridge damage, downstream damage, and damage-control expenditures.

Quantitative specification of development possibilities requires detailed analysis of the range of land use systems and capital improvements feasible in the Nepper Watershed, including the land use systems current in 1947.

Inputs and Outputs of Feasible Land Use Systems

Elements of agronomically feasible systems

Land use systems considered on each field identified in Figure 2 are those combinations of rotations, conservation practices, and fertilizer treatments derived from the following conditions pertaining to agronomic feasibility on the particular soils mapped in Figure 1:

Rotations. Seven cropping methods or crop rotations feasible on all watershed field units range from continuous corn to continuous meadow, being designated as CCCC, CCCO, CO_c, CCOM, COMM, COM_4, and MMMM.[3]

Practices. All field slopes exceeding 2 percent can be contoured. For convenience terracing is included as an element of land use systems and is considered for all field slopes exceeding 3 percent, excepting Napier 3-5 percent slopes adjacent to drainageways where seepage might occur. Terraceable areas are stippled in Figure 2 and land use illustrations which follow. Only level terraces of 2-inch runoff retention capacity are considered.

Fertilizer treatment. All fields could either not be treated with commercial fertilizers, treated with moderate applications of nitrogen and phosphorus or treated with heavy applications, except that the latter would be unnecessary on successive meadow. Recommended moderate and heavy rates of application vary by soil-slope conditions, legume intensity as indicated by rotations, and to some degree by practices.

System inputs and outputs

Labor. Labor inputs for various systems feasible on each field are estimated by rotations and fertility treatments in Table 25 (Appendix A), with man-hour requirements not stratified by seasons and data uniform for all soil conditions. Additional requirements for terrace maintenance are discussed below under terracing inputs.

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

Operating capital. Requirements basic to rotations are presented in Table 26 and do not include harvesting expense variable with yields or outlays for recommended fertilizer applications. Harvesting expense is added at rates of $0.05 per bu. of corn or oats hauled and stored, and $2.72 per ton of hay baled, hauled, and stored. Fertilizer inputs are valued at $12.90 per cwt. of available nitrogen and $7.50 per cwt. of phosphorus (P_2O_5) applied. Additional requirements for terrace maintenance are discussed below.

Fertilizer. Fertilizer requirements on a field basis are aggregated from recommendations applicable to soils, rotations, and practices; recommendations are indicated in Table 27 for the predominating watershed soil type only.

Terracing inputs. On the basis of a $0.04 per linear foot local contract construction cost,[4] per-acre requirements of improvement capital for terrace installation are estimated by terraceable slope phases in Table 28, utilizing a Soil Conservation Service procedure for computing footage from field slopes, vertical intervals, and horizontal intervals. Recurring labor and capital requirements on a slope phase basis are then computed for each extra plowing operation intended to maintain initial design cross-sections (and retention capacity) by removing from channels the excess of annual silt deposits over those removed by normal field operations.

Annual rates of terrace channel siltation under various silt-pro-

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[4] See p. 31.

ducing rotations are given in Table 29, along with resultant adjustments for normal plowing, expected life without any maintenance, and straight-line depreciation estimates. To provide for complete maintenance, adjusted siltation rates are converted to numbers of repeated plowing operations in Table 30; final estimates of labor and capital for special maintenance are then derived as shown. Table 31 adds these capital requirements to those associated with acquisition of two-way plows for farming terraced areas in arriving at the total annual recurring expense of terraces in relation to soil conditions and cropping methods. Requirements for installation and maintenance are then extended to a field basis with reference to contained soils.

Crop yields. Outputs of corn, oats, and brome-alfalfa hay expected from various agronomically feasible systems in effect on fields are derived from estimates prepared for each of 11 watershed soil types, again given in Table 27 only for the predominant soil. The estimates are predicated on timely farming operations, adapted varieties, average weather conditions, and a maximum ten-year transitional period between yield levels of alternative systems. Supporting sources include 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.

Sheet erosion. Soil losses associated with production of farm commodities on fields are estimated by application of Browning's procedure for integrating the independent variables of soil type, degree of field slope, slope length, antecedent erosion, fertility practices, rotations, and conservation practices.[5] The procedure is applied to all systems for the purposes of (1) sorting those meeting minimum requirements for fertility maintenance through erosion control (reducing annual erosion rates to at least a 5-ton per acre permissible level); and (2) describing the seriousness of sheet erosion under the predevelopment land use pattern prevailing in 1947, the pattern recommended in the Little Sioux Program, and the pattern currently prevailing in 1957. A special application estimates requirements for terrace maintenance from rates of channel siltation, as discussed immediately above and presented in Table 29. In both cases a base rate of 8 tons per acre (applicable to a corn-oats-meadow rotation on Marshall silt loam with 9 percent slopes 72.6 feet in length) is utilized in computing absolute rates on each field.

Peak runoff and gully damage. Gully damage is evaluated as the present value annual equivalent of maximum net income foregone during the 50-year planning period on fields or field portions likely destroyed within the main and southwest drainages (designated by M and S in Figure 2), and then charged as a production cost on all fields within the two drainages. By 1947, the main gully had destroyed about 5.8 acres, it was advancing at an average rate of 0.13 acres per year; while the southwest gully occupied 0.89 acres, advancing at about 0.05 acres per year.

Projected rates of land destruction and consequent damages are estimated with reference to drainage runoff characteristics influencing peak runoff rates coinciding with storms of 10-yr. average recurrence

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[5]Louis M. Thompson. Soils and soil fertility. N. Y. McGraw-Hill Book Co., Inc. 1952. pp. 317-325.

expectancy.[6] Drainage characteristics include topography, vegetal cover, infiltration capacity, and provision for surface storage of runoff. The three latter vary by whatever land use systems may be established on different fields wholly or partially 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 are aggregated by fields in arriving at average indexes weighted both by proportionate areas of fields included and respective land uses.[7]

Figures 3 and 4 respectively indicate relations between average indexes of runoff characteristics (termed summation W) and peak discharge for the main and southwest drainages. Particular runoff-peak flow relations are dependent on local climatic conditions as expressed by rainfall factors; and on drainage area and the recurrence expectancy considered. Conversion of 10-yr. recurrence peak flow to estimated annual rates of land destruction in both the main and southwest drainages is illustrated in Figure 5. Higher rates in the main drainage for equivalent runoff indexes result chiefly from its larger area.

Average annual equivalents of discounted gully damage, D, expected from various land use patterns within the two sectors are plotted in

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[6] For the procedure of utilizing historical rates of land destruction in estimating projected rates with possible land use changes, see Iowa State College. Departments of Agronomy, Agricultural Engineering, and Economics and Sociology. op. cit., pp. 62-65.

[7] 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. N. Y., John Wiley and Sons, Inc., 1955. pp. 62, 436.

Figure 6 from rates of land destruction corresponding with various average indexes, assuming that affected areas could be farmed for maximum net income. Lacking knowledge of precise dates at which advancing gullies would reach potentially affected fields, both curves employ the formula

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

where a_i = total acreage of i^{th} field wholly or partially within the drainage; $i = 1, 2, \ldots m$

p_i = proportionate acreage of field susceptible to damage

N_i = maximum net income on i^{th} 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 Figure 5.

A_o = total acreage within the drainage susceptible to damage

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

n = 50 = planning period in years

[$312] = present value of $1.00 increasing by $1.00 for 50 years

Maximum average annual damage thus computed on affected fields is allocated among all drainage fields 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 i^{th} field

a_i = total acreage of i^{th} field wholly or partially within the drainage; $i = 1, 2, \ldots m$

p_i' = proportionate acreage of field within the drainage

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

A = total acreage within the drainage

(SW) = weighted average runoff index for the drainage

D = total annual damage, from Equation 1 and Figure 6.

For example, the land use pattern prevailing within the main drainage in 1947 (shown in Figure 11) corresponded to an average runoff index of 52; this is associated with a 215 cu. ft. sec. peak 10-yr. flow (point A, Figure 3), and a projected rate of land destruction of 0.133 acres per year (point A, Figure 5 on the upper curve). The annual equivalent of discounted damage derived from this rate by Equation 1 is given as $101 in Figure 6 (point A on the upper curve). 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 32 (Appendix B); while Table 33 prorates the damage back to contributing fields, or over the total drainage area.

Similarly, the average runoff index of 46 for 1947 land use in the southwest drainage is associated with 73 cu. ft. sec. of peak 10-yr. flow (point A, Figure 4) and a projected land destruction rate of 0.047 acres per year (point A, Figure 5 on the lower curve). From Figure 6 and Equation 1, resulting average annual damage is $35 (point A on the lower curve). Only fields 5-2 and 6-7 potentially contribute and are affected by this damage as shown in Figure 11; the procedure of evaluation and allocation is the same as illustrated in Tables 32 and 33 for the main drainage.

The relations of Figures 3 through 6 are later employed to estimate

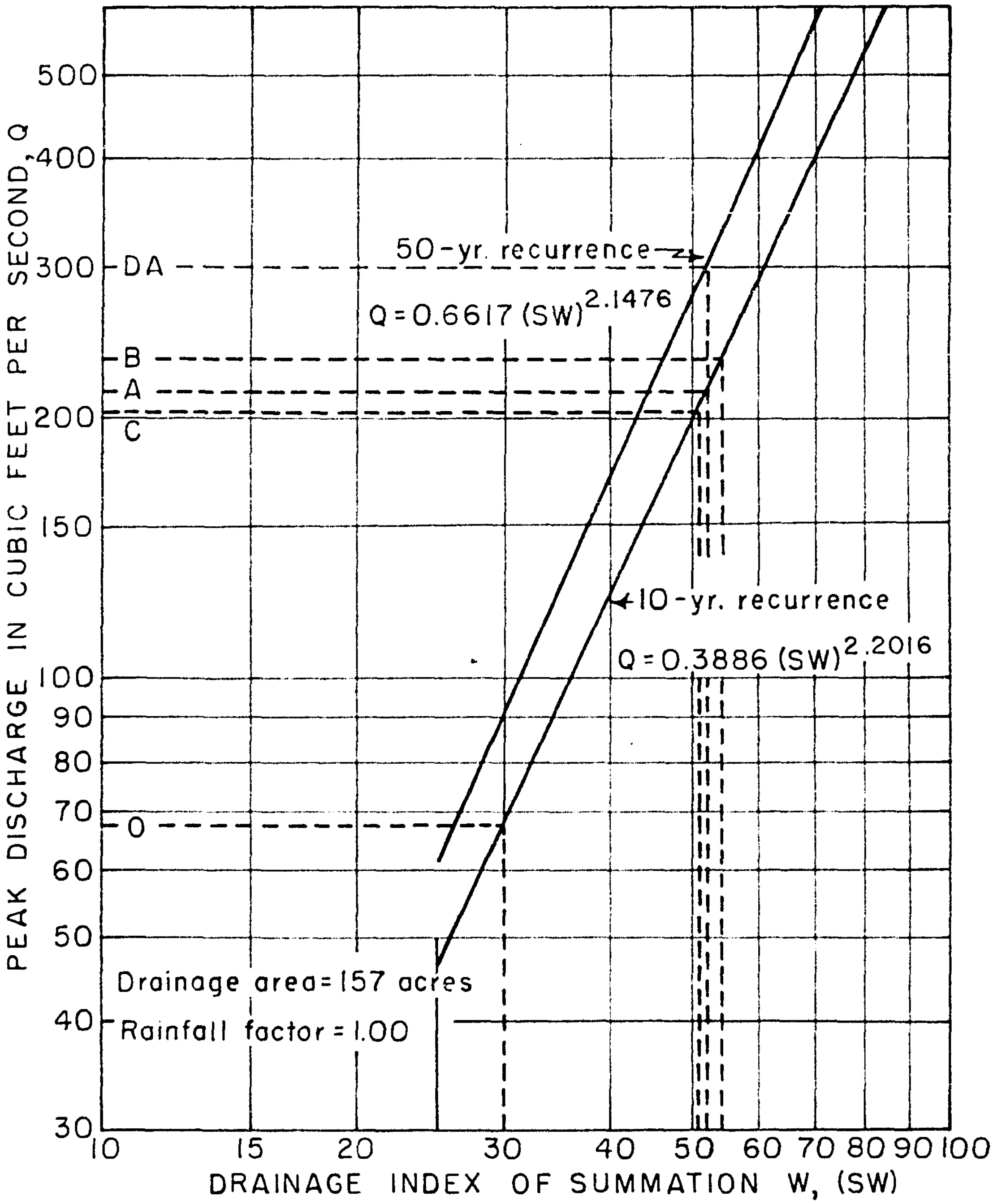

Figure 3. Main drainage peak discharge in relation to an index of runoff characteristics and storm recurrence.

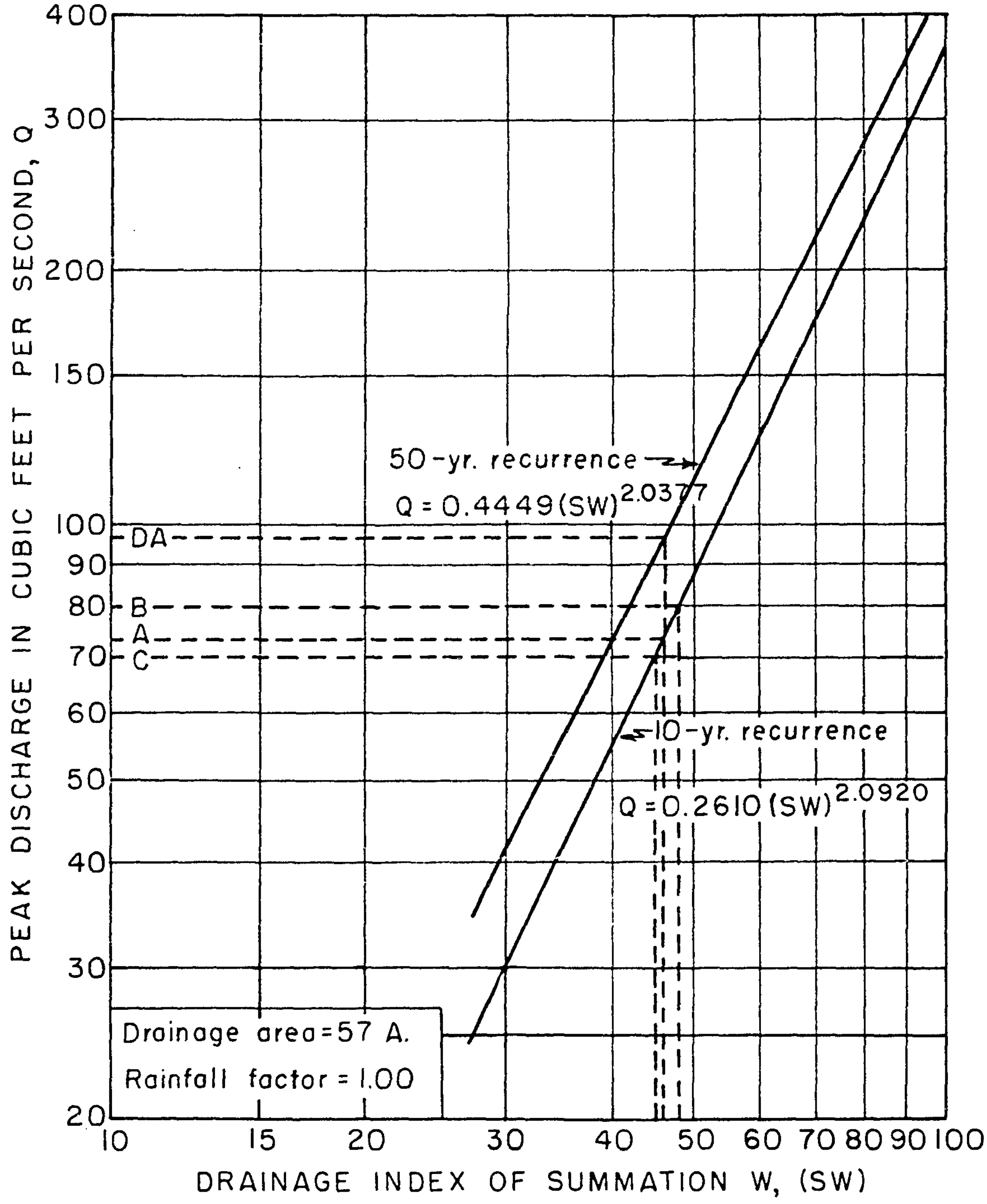

Figure 4. Southwest drainage peak discharge in relation to an index of runoff characteristics and storm recurrence.

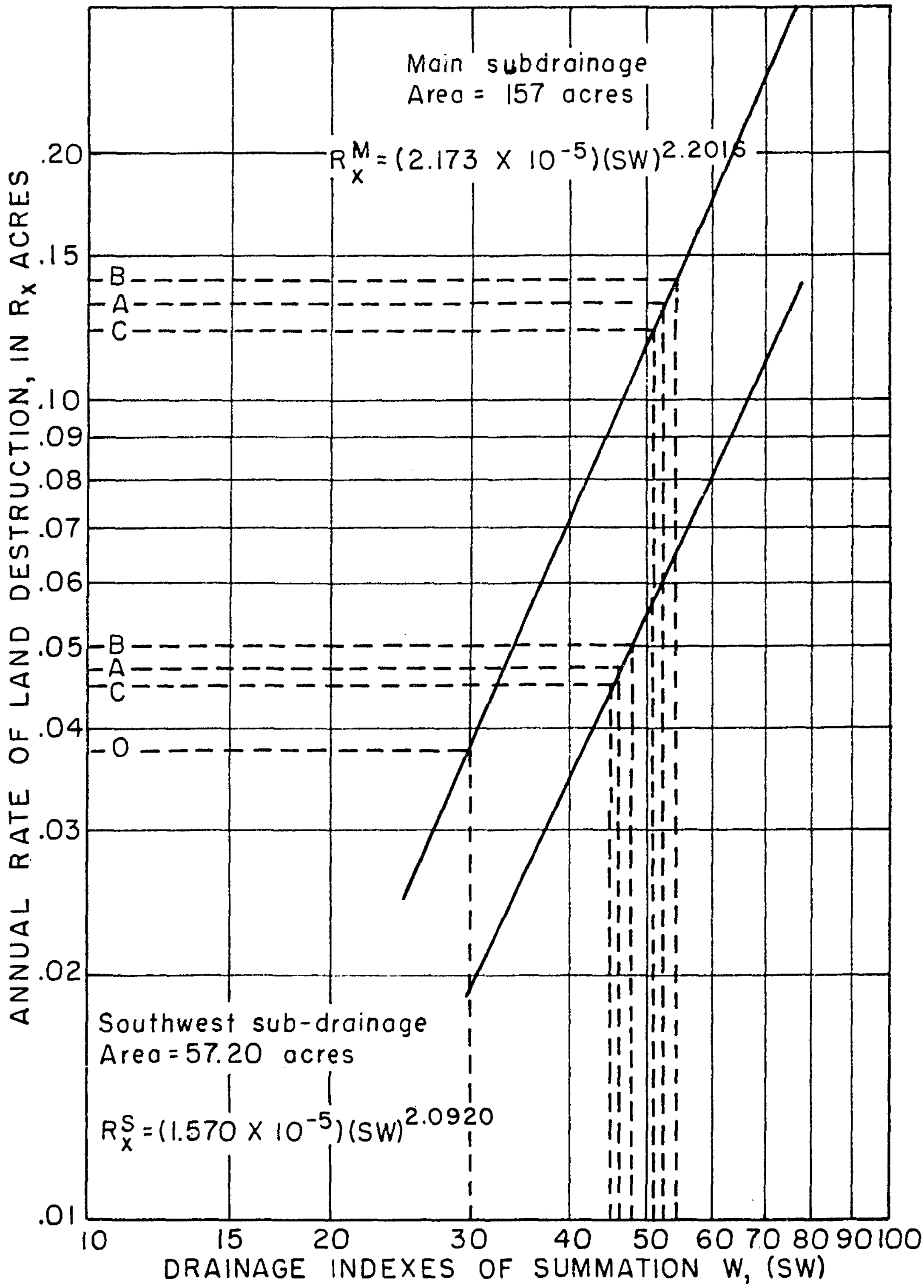

Figure 5. Rates of land destruction from gullies based on indexes of runoff characteristics and storm recurrence.

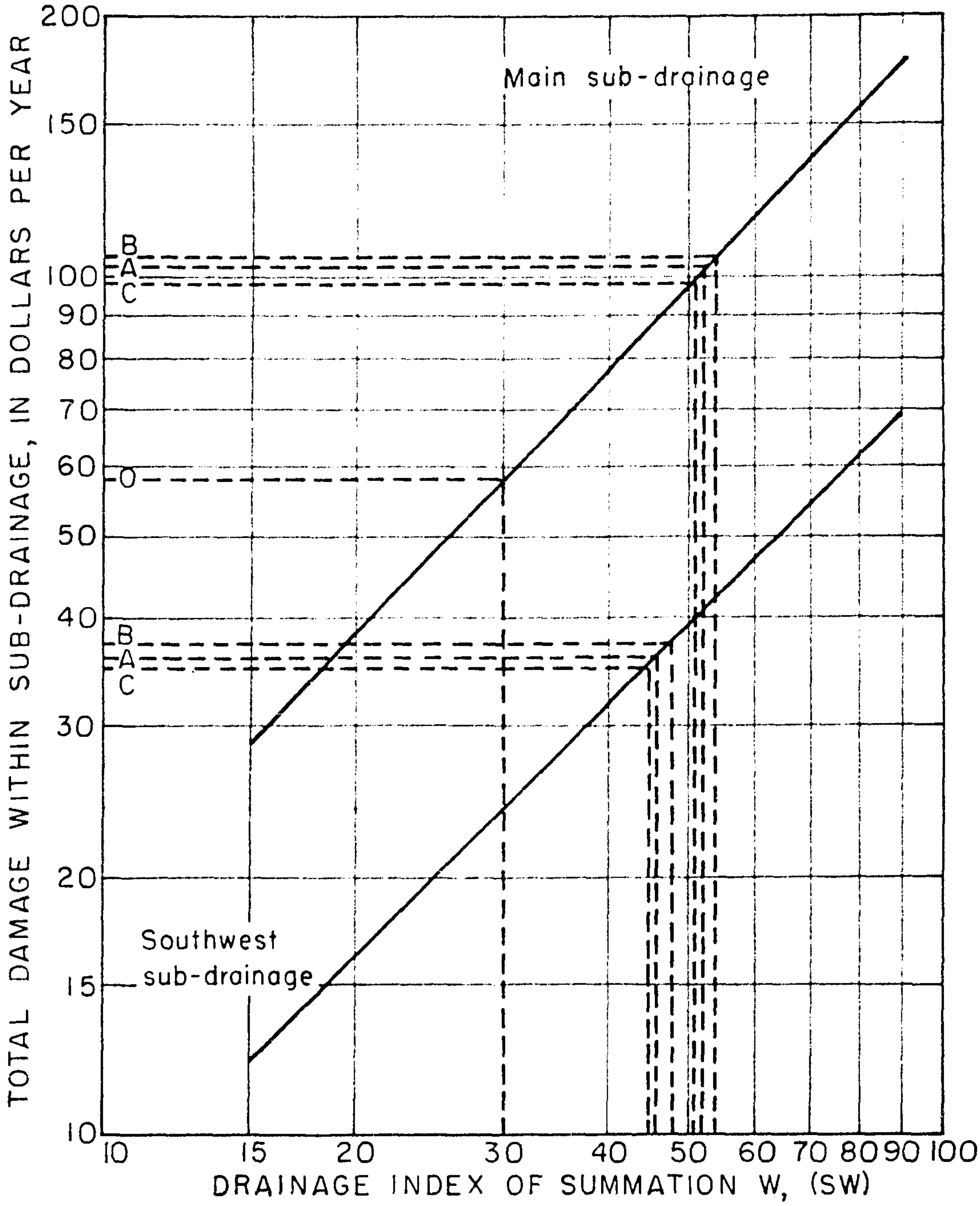

Figure 6. Damage from gullies based on indexes of runoff characteristics.

gully damage under land use patterns other than those prevailing in 1947, and damage-reduction benefits of shifting to alternative feasible land use systems on the particular fields representing sources of this damage.

Runoff and flood damage. Damaging effects of excess runoff as a detrimental output associated with land use systems are evaluated as the separate forms of potential flood damage; these include damage to crops on the watershed floodplain (field 7-4 in Figure 2 and maps following), damage at the Monona Country bridge site, and off-site 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 on-site crop flooding is, in this study, assumed to be overflow volume. Overflow volume is determined as the excess of storm-runoff from all fields within sectors denoted by F over the capacity of an unimproved drainageway to divert about 5.72 ac.ft. of storm runoff into the Maple River. Total runoff from all fields situated above the Monona County bridge is the variable directly related to bridge damage; while net watershed runoff (total watershed runoff less floodplain overflow) is directly related to off-site flood damage. In the absence of a more adequate long-term record, the 1950-54 flood storm record for the Nepper Watershed (Table 37) is selected as representative for computing average annual flood damage of all types. Initial runoff estimates required in all evaluations utilize the relation

$$R_i = (a_i\ k_i\ P)/12; \qquad (3)$$

where R_i = runoff in acre-feet from i^{th} field,

a_i = acreage of i^{th} watershed field, including farmsteads and roads; $i = 1, 2, \ldots 32$ watershed fields,

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

P = rainfall in inches.

Relative values of k_i as between cover conditions, practices, slope degree, and slope length are based on 1948-56 soil and water loss studies at the Western Iowa Experimental Farm at Castana summarized in Table 34. Relative values for land use systems feasible in the watershed are derived as shown in Tables 34 through 36. A runoff coefficient of 42.94 percent observed for continuous corn on 12 percent slope Ida silt loam plots (72.6 ft. in length) with no special tillage practices is the arbitrarily established base. Relative values as between early and later stages of the growing season and adjustment of the Castana plot relationships to a local basis are given in Table 37, where aggregate percentages derived by applying plot relationships to actual 1950-54 land use systems on each watershed field are compared with percentages derived from available hydrographs or stage records of individual storms. Average values of k_i for individual fields with any given feasible land use system assumed in effect are then determined from

$$k_i = (0.4295)(1.96)\ F_r\ F_c\ F_t\ F_s\ F_f\ F_p; \qquad (4)$$

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

0.4295 = proportionate runoff from continuous corn, discussed immediately above.

1.96 = uniform adjustment of observed experimental runoff at Castana to a Nepper Watershed basis; from Table 37.

F_r = runoff relative to rotations; from Table 36.

F_c = runoff relative to conservation practices; from Table 36.

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

F_s = runoff relative to degree of field slope; from Table 36.

F_f = runoff relative to field length; from Table 36.

F_p = runoff relative to period of growing season; from Table 36.

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 growth stages, floodplain land use (or crops actually grown), and projected prices of crops and related inputs, the procedure of evaluating such damage first estimates probable runoff for the period April 1-May 31 as follows:

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

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

a_i = acreage of i^{th} watershed field located wholly or partially within sectors designated by F on all maps.

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 37.

P_e = 1.31 inches = average annual flood-producing rainfall between April 1 and May 31; from Table 37.

Probable overflow before June 1 is then approximated from:

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

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 ac.ft.) x (relative annual frequency of flood-producing storms prior to June 1). The latter is noted from Table 37 as three storms during the 5-yr. 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 are obtained from the overflow-flood depth rating curves of Figure 7, constructed from hypothetical applications of estimated 1950-54 overflow quantities given in Table 37 to the Nepper Watershed floodplain. Table 4 below indicates the effects of inundations of the specified depths on crop yields or production costs during this period, including effects for the three crops likely grown on the floodplain. The effects per flooded acre are expressed as income losses in Table 5, 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 utilized for heavily fertilized continuous corn and the contributory area were utilized as in 1947.

A similar procedure applies to damage evaluation for the later stage of growth, presumed to run from June 1 through September 30. Probable

Table 4. Effect of flooding on Nepper Watershed crops; by seasonal periods and flood depths

Flood depth in inches	April 1-May 31			June 1-September 30		
	Corn[a]	Oats	Hay	Corn	Oats	Hay
		(percent)	(percent)	(percent)	(percent)	(percent)
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.)	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 annual yield per flood of given depths.

runoff for this period is estimated from:

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

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

k_i = proportionate runoff determined from Equation 4, with the period factor F_p selected as 0.96 from Table 37.

P_m = 4.95 inches = average annual flood-producing rainfall between June 1 and September 30, from Table 37; remaining terms are explained under Equation 5a.

Overflow after May 31 is then determined from:

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

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 ac.ft.) x (relative annual frequency of flood-producing storms after May 31). The latter is noted from Table 37 as 11 storms during the 5-yr. 1950-54 record, or as 2.20. Remaining items are explained under Equation 5a.

The overflow-flood depth curves of Figure 7 are 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 also given in Table 4. Damages per flooded acre with the floodplain in heavily fertilized continuous corn combined with areas flooded to various depths yield estimated annual damages of $2,252 after May 31, as shown in Table 5. Maximum average annual crop flood damage of $2,803 for the entire season is then given as the total of that probable between April 1 and September 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 is allocated among individual fields comprising the contributory area in proportion to overflow quantities initially estimated from Equations 6a and 6b. From Table 5, damage allocable per acre-foot of seasonal overflow under the specified land use conditions is given as $86.59; while average annual damage per acre of floodplain, assuming the entire 41.6-acre unit to be in fertilized continuous corn, is $67.40.

The calculation of average annual flood damage under predevelopment and alternative watershed land use systems is illustrated in Figures 8 and 9. With reference only to annual overflow from the 293-acre source

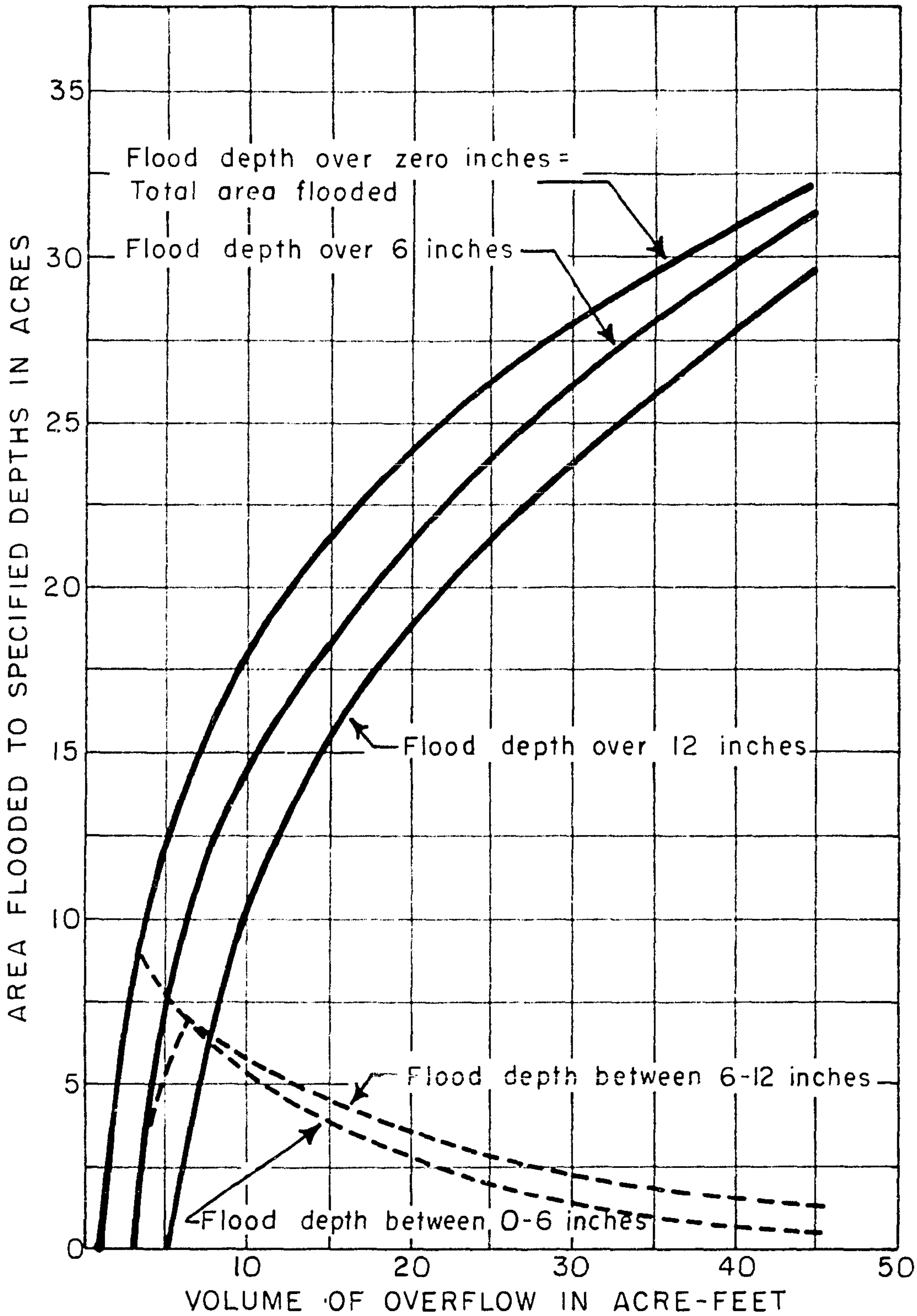

Figure 7. Overflow-flood depth rating curves for the Nepper Watershed floodplain.

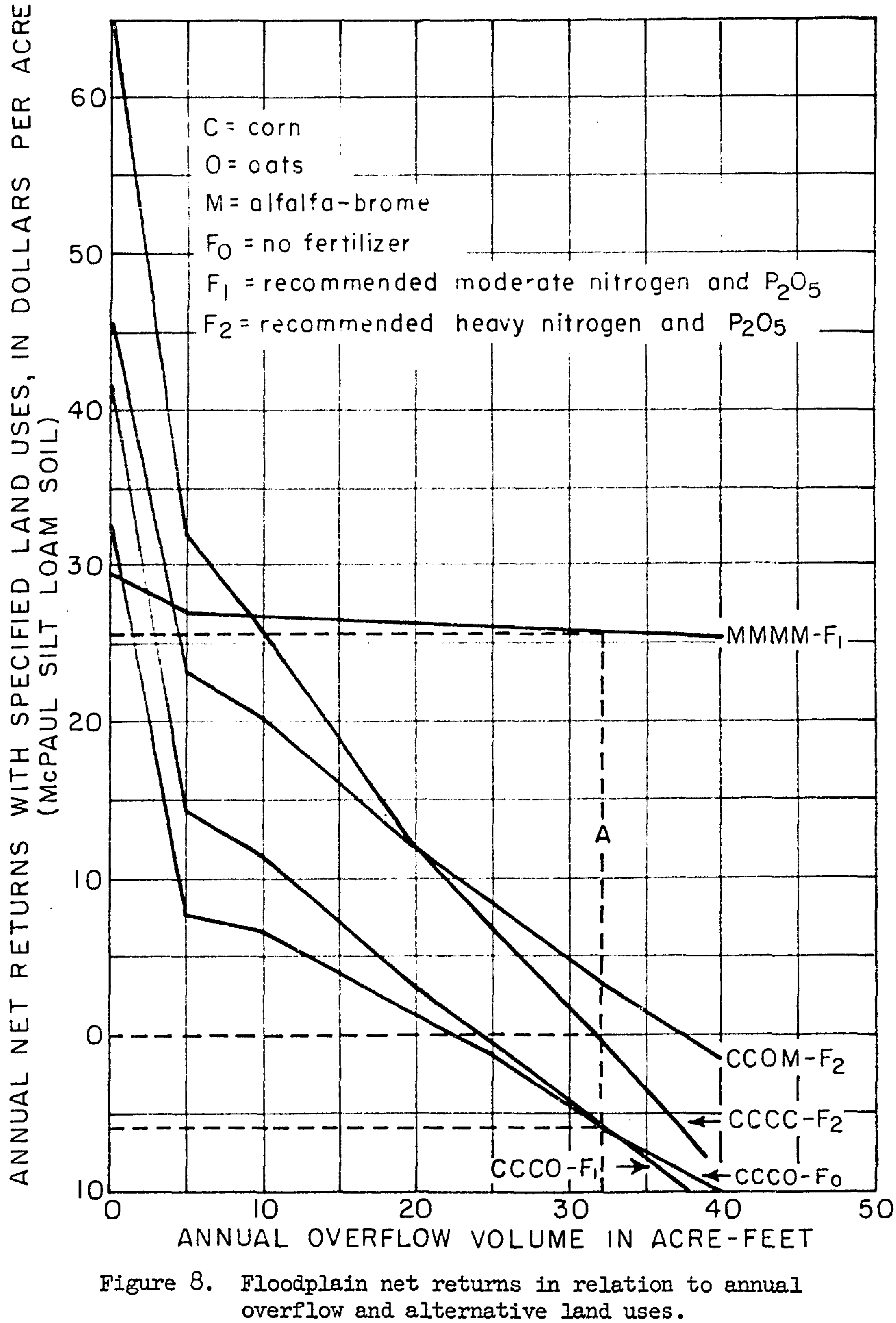

Figure 8. Floodplain net returns in relation to annual overflow and alternative land uses.

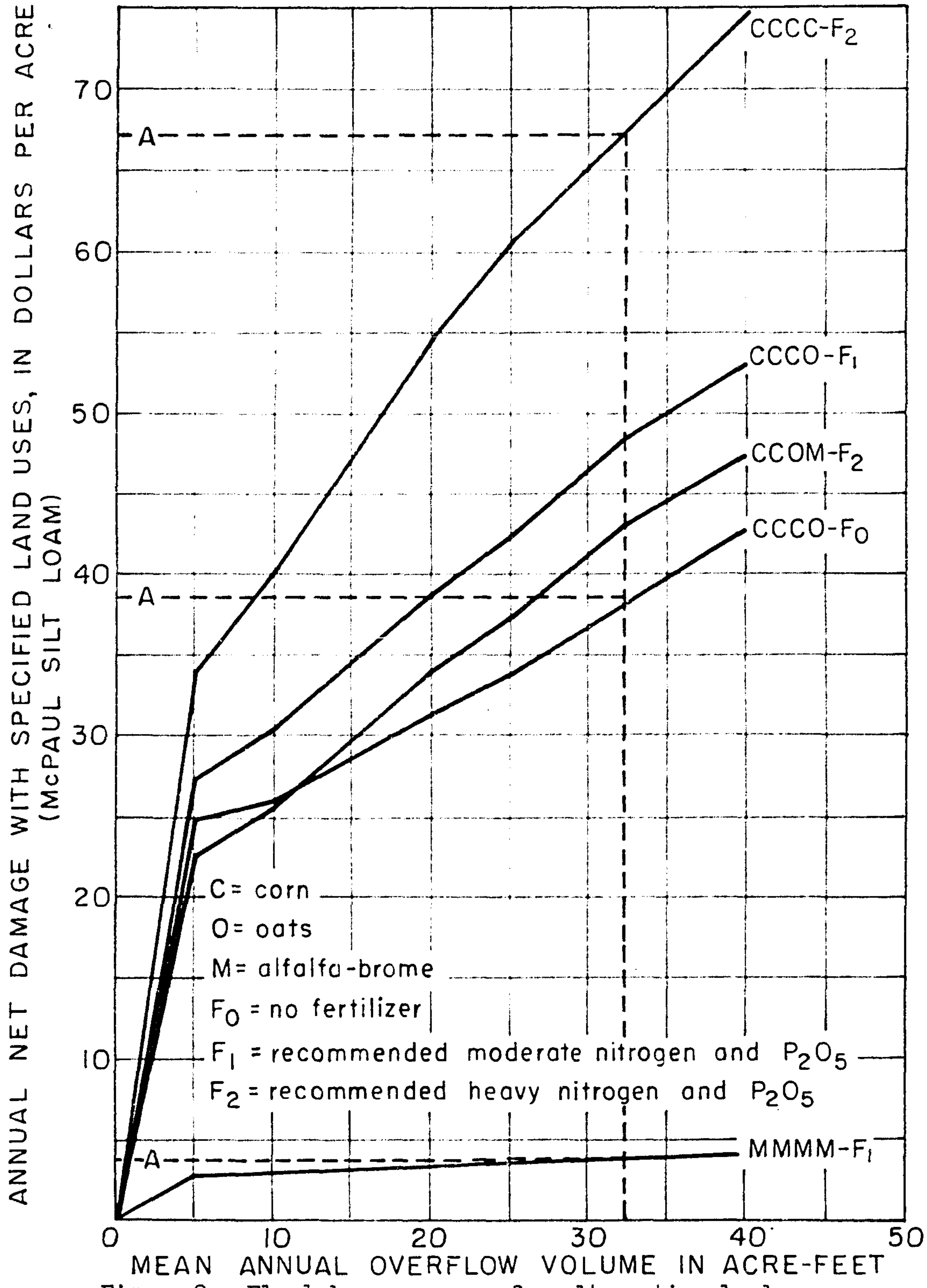

Figure 9. Flood damage curves for alternative land uses on the Nepper Watershed floodplain.

Table 5. Maximum average annual flood damage to crops under predevenlpment land use on contributing fields; by periods and depths

Items	Units or depths	Flood periods: April 1-May 31	June 1-September 30	Seasonal
Sector runoff[a]	ac.ft.	10.11	37.00	47.11
Ditch diversion[b]	ac.ft.	3.16	11.59	14.75
Sector overflow[c]	ac.ft.	6.95	25.41	32.36
Flood depths	inches	Floodplain area flooded by overflow (acres)[c]		
	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	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 flooded acre		$32.60	$82.80	$63.82[e] (67.40)
Damage per unit 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 Figure 2.

[b]Based on ditch diversion of 5.27 ac.ft. 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.

[c]Runoff less diversion; acreages flooded other than totals determined from rating curves in Figure 7.

[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.

[e]Total seasonal damage of $67.40 per flooded acre for 32 ac.ft. seasonal overflow is shown as point A on curve CCCC-F_2 in Figure 9. It is adjusted with reference to a maximum area flooded of 41.6 acres rather than the 43.91 acres computed from the rating curves of Figure 7.

area F (possibly resulting from many established land use patterns), Figure 8 indicates the decline in floodplain net returns for five selected floodplain land use systems. All rotations including corn are more profitable than continuous meadow if overflow can be diverted, eliminated by land use changes on contributing fields, or held by structures. Otherwise continuous meadow is most profitable at relatively small volumes of annual overflow expected, substituting for continuous corn at about 9 ac.ft. For any given volume of overflow, damage per floodplain acre is estimated as the loss in net income from the net income obtainable under non-flooding or fully protected conditions. Figure 9 is thus derived from Figure 8 and 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 5. Similar estimates corresponding with an equivalent volume of 32 ac.ft. in overflow are respectively given as \$38 and \$4 for an unfertilized CCCO rotation and successive meadow fertilized lightly.

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

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

where R_b = seasonal runoff, in acre-feet.

a_i = acreage of i^{th} watershed field located wholly or partially within the sector MFBO on all maps.

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

k_i = proportionate runoff, determined from Equation 4, with the period factor P_f selected as 1.00 from Table 37.

$P_s = P_e + P_m$ = 6.26 inches = average annual flood-producing rainfall between April 1 and September 30; from Table 37.

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

$$D_b = (R_b \; D_b')/R_b'; \tag{8}$$

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.

R_b' = 18.71 ac.ft. = runoff computed for predevelopment conditions from Equation 7.

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

The remaining problem of off-site or downstream flooding associated with watershed land use is evaluated in terms of net watershed runoff, represented by the excess of annual runoff from all sectors denoted by O (see Figure 2 and other maps) over the portion of such runoff appearing as overflow on the floodplain. Fields possibly contributing net runoff are separated by classes; class 1 includes those 23 located at least partially within the 293-acre on-site crop flooding drainage, while class 2 includes those 10 in the northeast section of the watershed wholly or partially outside the on-site crop flooding sector F. Contributions of the on-site crop flooding sector (class 1) to net watershed runoff are estimated as follows:

$R_{d_{11}} = R_e + R_m$; if runoff so computed from Equations 5a and 5b above is no greater than 14.75 ac.ft., the sum of average annual diversionary capacities of the unimproved drainage-way (see Equations 6a and 6b); or (9)

$R_{d_{12}}$ = 14.75 ac.ft.; if annual runoff exceeds this capacity, the excess appearing as floodplain overflow. (10)

Contributions of class 2 fields are obtained from

$$R_{d_{21}} = \sum_{i=1}^{10} (a_i \, p_i \, k_i \, P_s)/12; \qquad (11)$$

where $R_{d_{21}}$ = average annual flood runoff, in ac.ft.

a_i = acreage of i^{th} field wholly or partially in class 2, including farmsteads and portions of the County road network.

p_i = proportionate acreage of field in class 2.

k_i = proportionate runoff, determined from Equation 4 with the period factor P_f selected as 1.00 from Table 37.

P_s = 6.26 inches = average annual flood-producing rainfall between April 1 and September 30; from Table 37.

Net watershed runoff from both classes of contributing fields is then alternatively obtained as $(R_{d_{11}} + R_{d_{21}})$ or as $(R_{d_{12}} + R_{d_{21}})$, depending on the runoff computed for those fields also contributing to on-site flood damage to crops. With predevelopment damage of \$140 representing a single observed estimate related to net watershed runoff, annual downstream damage is assumed proportional to annual net runoff corresponding with predevelopment land use:

$$D_d = (R_{d_{12}} + R_{d_{21}})\ D_d'/(R_{d_{12}}' + R_{d_{21}}');\ \text{or} \qquad (12a)$$

$$D_d = (R_{d_{11}} + R_{d_{21}})\ D_d'/(R_{d_{12}}' + R_{d_{21}}'); \qquad (12b)$$

where D_d = average annual damage corresponding to net watershed runoff of $(R_{d_{11}} + R_{d_{21}})$ or $(R_{d_{12}} + R_{d_{21}})$ acre-feet.

D_d' = annual damage of $140 observed under predevelopment land use conditions.

$(R'_{d_{12}} + R'_{d_{21}})$ = 43.00 ac.ft. = net runoff computed for predevelopment land use conditions.

Downstream damage allocable to fields contributing net watershed runoff on the basis of Equation 12a is $140/43 = $3.24 per ac.ft. of net runoff. It is represented by the allocated diversionary capacity for class 1 fields if annual runoff exceeds proportionate allocations, and by actual runoff if computed runoff does not exceed proportionate allocations. Net watershed runoff from class 2 fields is represented in any case by runoff computed from Equation 11.

Results of applying the foregoing damage-evaluation procedures to predevelopment land use conditions prevailing in 1947 are summarized in Table 6 for each discussed damage problem. Also indicated is the distribution of damages among potential private and public participants, and among participants grouped by location. Unit damages given are taken to represent price or benefit equivalents of unit reductions in each relevant hydrologic variable modifiable by land use changes or

Table 6. Predevelopment maximum average annual damages in relation to hydrologic variables associated with watershed land use; distributed by private and public participants

	On-site gully damage		Flood damage			Total gully and flood damage
			On-site		Off-site flood damage	
Evaluation items or participants	Main drainage	Southwest drainage	Flood-plain crops	County bridge		
Damage evaluation (1947 land use)						
Hydrologic variable	Peak runoff	Peak runoff	Over-flow	Total runoff	Net runoff	-
Hydrologic units	Runoff index	Runoff index	Acre-feet	Acre-feet	Acre-feet	-
Evaluated units	52	46	32.36	18.71	43.00	-
Distribution by participants (dollars)						
Watershed farms	101[a]	36[a]	2,803[a]	0	0	2,940
Monona County	0	0	0	385[a]	0	385
Off-site public	0	0	0	0	140[a]	140
All participants	101	36	2,803	385	140	3,465
Damage per hydrologic unit[b]	1.92[c]	0.76[d]	86.59	20.51	3.24	-

[a]Approximate because of rounding.

[b]Ratios of damage for all participants to evaluated hydrologic units.

[c]As unaveraged, the weighted index approximates 8,218; unit damages on the latter basis are $0.01232.

[d]As unaveraged, the weighted index approximates 2,641; unit damages on the latter basis are $0.01361.

structural improvements.

Feasible Structural Improvements

Six major structural improvements in the Nepper Watershed are considered as alternatives to land use changes in controlling excess runoff rates or volumes associated with gully and flood damage as evaluated above. These include four structures controlling gully damage in the main drainage; a single structure having the same function in the southwest drainage; a single structure serving to replace the Monona County bridge frequently damaged; and three structures, including a levee system, designed to control floodplain crop damage.

Location and design features

Locations of individual structural improvements are shown in Figure 10, where each is identified by type. The system of river levees was installed prior to 1947 by the operators of farms 5 and 7 for protection against high stages of the Maple River; other improvements were installed in 1948 in a combined farmland treatment and gully control program for the Nepper Watershed as one phase of the Little Sioux Flood Control Program. According to one source,[8] these structures were installed at a total cost (in 1948 dollars) of $80,837. They were expected to yield annual benefits of $3,550 compared with amortized construction and recurring annual costs of $2,234. No separations of benefits and costs

[8]The President's Missouri Basin Survey Commission. Missouri: land and water. Wash., D. C., U. S. Govt. Print. Off., 1953. p. 95.

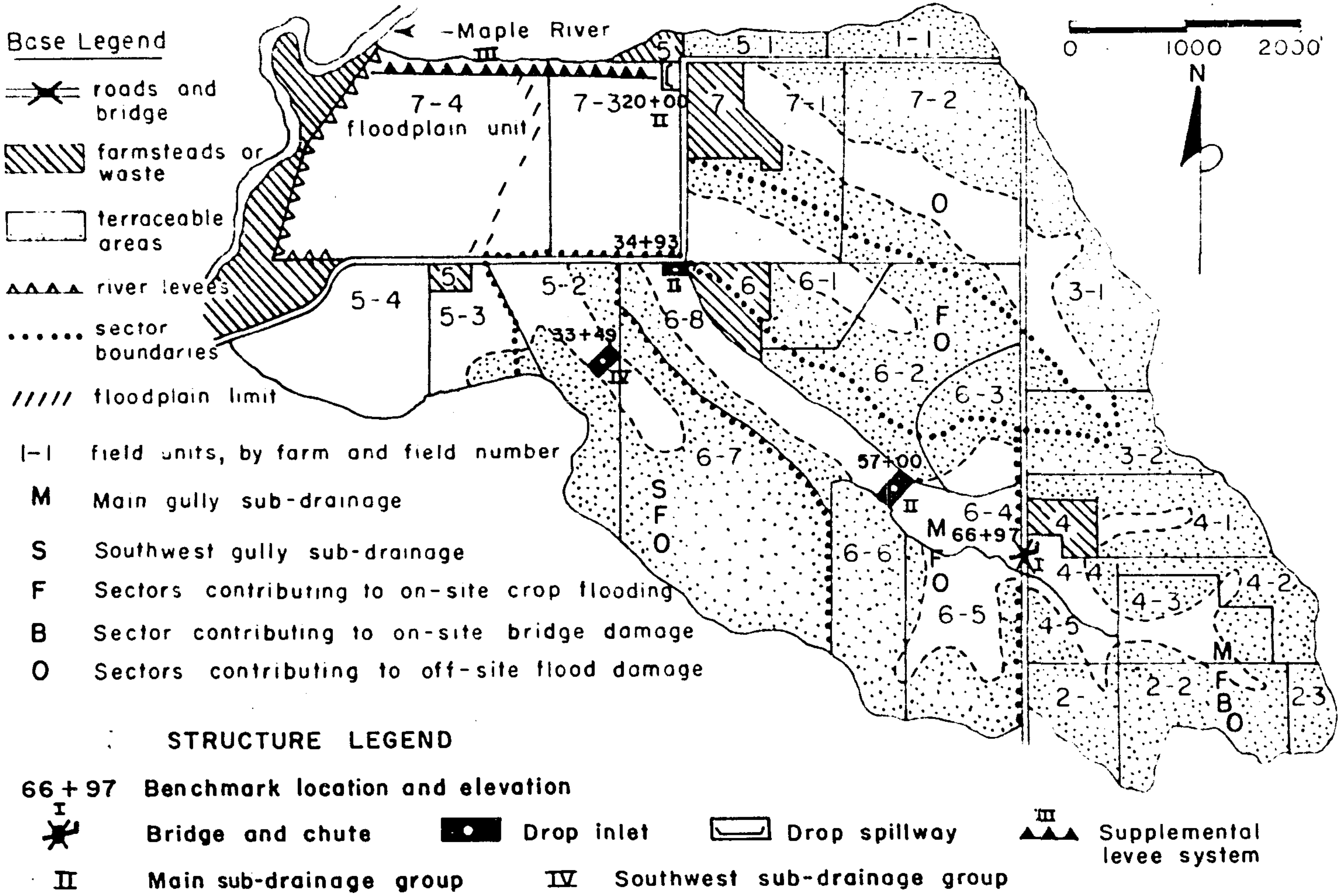

Figure 10. Feasible structural improvements for the Nepper Watershed.

individually associated with gully or flood control are available, however.

Detailed design specifications utilized in estimating inputs and outputs of each structure or structure-combination are given in Table 38 (Appendix C). Requirements for labor and materials in actual construction are grouped as contract construction costs, with land requirements given as site areas. Table 39 considers all resource requirements in terms of capitalized cost, with some facilities listed in Table 38 redefined as measures or measure-groups. The discrepancy of $2,053 in installation cost between the tabular amount of $82,890 and the $80,837 gross estimate given above by the Missouri Basin Commission probably lies in the manner of deriving site acquisition costs. The only basis for grouping certain of the facilities listed singly in Table 38 as combined structural measures is their apparent interdependence in either flood control or gully control, or both. The simplified discussion of functions below refers to the design data of Table 38 adjusted to a measure basis in Table 40, and to Figure 10 for locations by group designations.

<u>Functions of independent measures</u>

<u>Measure I; upper road chute</u>. The combined bridge-chute spillway at station 66+97 in Figure 10 operates independently of other measures in preventing headward extension of the main gully into the sector MFBO above the road, while replacing the Monona County bridge subject to damage from flood-runoff originating on the same sector.

Measure II; main drainage group. This measure is defined to jointly include the drop inlets at stations 57+00 and 34+93, the drop spillway at station 20+00, and related channel improvement necessary to facilitate installation of all these and, to some extent, prevent undercutting of the chute spillway of measure I. The measure is effective in gully control through peak flow reductions obtained by the drop inlet at station 57+00 and the drop spillway. Although gully control effectiveness is measured as reductions in 10-yr. peak flow, design is made to depend on storms of 50-yr. recurrence expenctancy. In Figure 3, for example, peak discharge resulting from storms expected to recur an average of one year in 10 with a main drainage runoff index of 52 is given at 215 cu. ft. sec. This rate was utilized in the foregoing section in estimating an annual rate of land destruction and consequent income losses from gullying. But for the two structures to provide continued elimination of 215 cu. ft. sec. in 10-yr. peak flow without accompanying reductions in the runoff index through land use changes, they must be adequate to withstand 300 cu. ft. sec. in peak flow, as indicated by point DA in Figure 3.

The floodwater detention capacity of the drop inlet at station 57+00, by temporarily confining overflow otherwise affecting floodplain crops, makes this grouped measure also effective in flood control for on-site crops.

Measure III; supplemental levees. Installed at the lower extremity of the main drainageway (from station 20+00 to the Maple River), this measure diverts overflow otherwise affecting floodplain crops directly into the Maple River, thus also being effective in on-site flood control. But since the previous analysis of runoff and flooding associated off-site flood damage with watershed net runoff, levee diversions add to net watershed runoff and consequent downstream flood damage. Although the levees in some instances could supplement those facing the river in protecting the Nepper floodplain from high river stages, this feature is considered secondary to the diversion of overflow of on-site origin.

Measure IV; southwest drainage group. This measure includes only the drop inlet at station 33+49 and related channel improvement. The drop inlet is effective in gully control through reductions in peak 10-yr. flow through the southwest drainageway. Design, however, is dependent on adequacy in withstanding a peak flow of 50-yr. recurrence expectancy, noted by point DA in Figure 4 as 96 cu. ft. sec. The single structure also provides floodwater detention capacity, by confining overflow originating within the southwest drainage. This overflow would otherwise merge with that originating from all other sectors indicated by F in affecting floodplain crops.

Benefits and costs of structural measures

Benefits are determined in relation to damage-control purposes and effects of the independent measures in modifying the hydrologic variables with which damages were previously associated. As indicated above, gully control benefits primarily result from any reductions in peak discharge rates related to rates of land destruction in the main or southwest drainageways. An exception is the full-flow road chute of measure I which, insofar as its gully control features are concerned, merely stabilizes the main gully head. Since only on-site flood control functions of structures are considered, corresponding benefits result either from seasonal control of runoff volumes affecting the Monona County bridge site or from seasonal control of overflow flooding bottomland crops.

In Table 40 design data for each facility of Table 38 are converted to a form applicable to the independent measures described above. In Table 41 these specifications are given on a constant average or incremental unit basis, since data required for analyzing other scales of installation are not available. Table 7 below illustrates derivation of annual benefits per installation increment for each measure with regard to its single or multi-purpose functions.

Measures are evaluated for economic feasibility in Table 8, The feasibility condition being that the present value of benefits from all purposes not be less than the present value of all costs distributed among beneficiaries proportionately with benefit present values. On the assumptions of a 50-yr. project period for capitalizing private benefits and costs at 5 percent, Monona County benefits and costs at 2 1/2 percent, and the above damage evaluation procedures for estimating benefits, all measures other than the road chute yield net benefits. They represent economically feasible alternatives to land use changes in reducing damages resulting from watershed land use.

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 prevented per unit control; 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]

[a]From Table 41.

[b]Equivalent to 34 percent of gully damage in the main drainage (101 in Table 6) divided by the 10.50 increments installed in 1948 (Table 38).

[c]Gully damage in the main drainage ($101 in Table 6 and point A_m, Figure 5) divided by 215 cu.ft.sec. (point A in Figure 3)

[d]Gully damage in the southwest drainage $36 in Table 6 and point A_s, Figure 5) divided by 72 cu.ft.sec. (point A, Figure 4).

[e]From Table 6.

[f]Equivalent to damage per unit overflow of $86.59 in Tables 5 and 6.

Table 7 (Continued)

Major purposes	Units	I Upper road chute	II Main drainage group	III Levee system	IV Southwest drainage group
		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

[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 foot height	1,000 cu.yds.
Benefits distributed by participants (dollars)				
On-site farmers	3.31	108.56	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]				
On-site 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]				
On-site 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)				
On-site 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; see Table 6 for damage distribution among participants.

[b]Totals from Table 41. Installation costs of the road chute are distributed in proportion to benefit present values, with a private discount rate of 5 percent and a Monona County rate of 2 1/2 percent.

[c]Includes amortized installation outlays above and required maintenance (Table 41).

[d]Also includes $31.48 in increased off-site flood damage associated with on-site levee construction.

Importance of preliminary input-output determinations

By indicating the resource requirements and outputs of land use systems and structural measures, the two foregoing sections permit (1) appraisal of any established or recommended resource use pattern for probable returns or costs to on-site farmers, Monona County, and downstream areas; and (2) formulation of development programs for the Nepper Watershed which maximize net benefits aggregated by all these participating economic units, without any participant suffering net losses.

Because conditions prevailing in 1947 are taken as benchmarks from which benefits and costs of development are to be determined, that pattern is first appraised in outlining the nature of development possibilities for the watershed. Following a brief review of the Little Sioux Flood Control Program as a one approach to planning, a procedure for isolating a number of alternative land and structural treatment activities is then illustrated. These discussions are all considered preparatory to formulation of alternative programs maximizing net benefits, a main objective of the study.

Predevelopment Land Use and Resultant Returns

A field-by-field summary of established 1947 land use associated with evaluated damages is shown in Figure 11. Roughly 53 percent of the total watershed area was annually in corn, 19 percent in oats and 28 percent in meadow. A negligible proportion of the cropland was

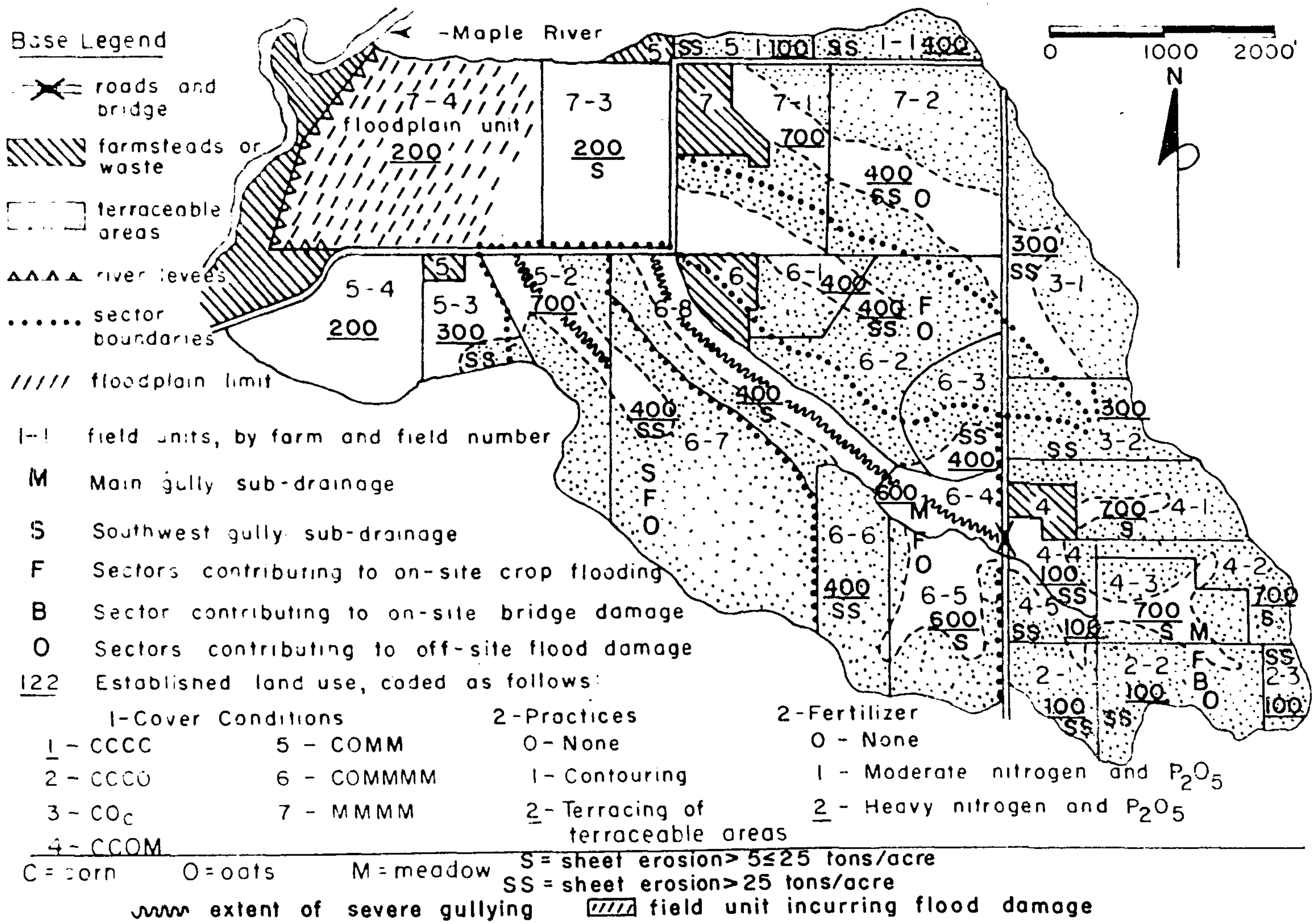

Figure 11. Pre-development land use and associated damage problems in the Nepper Watershed.

contoured or fertilized, and no terraces were installed. Rates of sheet erosion were very high, ranging on a computed basis from 15 to 200 tons per acre per farm and averaging 42 for all farms, farmsteads, and the Monona County roads.

Land use systems above the county bridge resulted in 19 ac.ft. of runoff annually damaging the bridge, equivalent to an average of 2.52 inches of runoff from the sector MFBO on Figure 11. This runoff also contributed to floodplain overflow, mingling with that from other fields in annually producing the 32 ac.ft. overflow volume damaging floodplain crops by $1,603, or by $38 per floodplain acre (point A, curve CCCO-F_o, Figure 9).[9] This volume is equivalent to about 1.93 inches of runoff and a 5.73-inch storm over the 293-acre contributory area.

Land use over all sectors denoted by O in Figure 11 in addition produced the 43 ac.ft. (1.33 inches) of runoff leaving the watershed and causing $140 in annual downstream flood damage. The gullies in the main and southwest drainageways occupied the area shown in Figure 11 and, as previously noted in Figure 5 (points A), were respectively advancing at rates of 0.133 and 0.047 acres per year. Over a 50-year period, the main gully could thus be expected to destroy an additional 6.65 acres of cropland or farmsteads. Units ultimately affected include

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[9]Evaluated per-acre damages of $67.40 given in Table 6, and by point A on curve CCCC-F_2 in Figure 9 are maximum annual damages from 32 ac.ft. of overflow. Because the latter represents maximum net income foregone on the floodplain by reason of the flood hazard then existing, it is related to predevelopment land use and later utilized in determining the comparative effectiveness of land treatment and structures.

farm 2 (2 fields), farm 3 (1 field), farm 4 (4 fields and the farmstead), and farm 6 (5 fields). The present value of net income lost from land destruction, on an annual basis, was previously given as $101 per year. Moving at a much slower rate, the southwest gully could be expected to destroy an additional 2.35 acres within field units 5-2 and 6-7, causing annual damages of $36.

Table 9 summarizes the land use information of Figure 11 on a farm-by-farm basis, indicating the contribution of each farm to various forms of gully and flood damage allocated in accordance with the foregoing gully and flood damage evaluations. Table 10 summarizes damages by various watershed interests, but on an incurred basis to indicate the incidence of consequences of the then-existing resource-use pattern. Data required to derive the aggregate private amounts are distributed among farms in Table 42 (Appendix D).

The relation of farm income, and costs of providing public services with watershed land use is shown in Table 10. Participant and watershed annual incomes or deficits are estimated as net values of crops produced, where the watershed net crop value of $7,568 represents net income on all farms (adjusted for privately incurred damages) further adjusted for undue costs of maintaining on-site transportation facilities and repairing off-site transportation and drainage facilities.

Table 9. Predevelopment annual damages allocated by farm units and the road system

Farm No. (Fig. 11)	Gully damage indexes: Main (index)	Gully damage indexes: Southwest (index)	Flood damage runoff volumes: On-site bridge (ac.ft.)	Flood damage runoff volumes: On-site crops (ac.ft.)	Flood damage runoff volumes: Off-site (ac.ft.)	Equivalent annual corn intensity (percent)	Equivalent annual corn intensity (rotation)	Sheet erosion (tons/acre)
1	0	0	0.00	0.00	0.67	50	CO_c	27
2	65	0	6.13	5.28	0.95	100	CCCC	206
3	58	0	2.83	1.98	8.37	63	CCCO	84
4	52	0	6.59	4.18	2.57	25	COMM	53
5	0	40	0.00	0.32	4.58	54	CO_c	22
6	47	48	0.00	15.60	9.07	46	CCOM	31
7	0	0	0.00	0.04	9.04	57	CO_c	15
Roads	50	0	3.16	4.96	7.92	100	CCCC	72
Watershed	52	47	18.71	32.36	43.17	52	CO_c	42
	Allocated annual damage (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 damages per hydrologic unit as estimated in Table 6.

Table 10. Predevelopment returns and costs distributed by potential private and public potential participants

Items by participants	On-site			Off-site public	Total public	Watershed total
	Private[a]	Public	Total			
	(dollars)	(dollars)	(dollars)	(dollars)	(dollars)	(dollars)
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; on-site crops	2,803	0	2,803	0	0	2,803
Flood damage; on-site bridge	0	385	385	0	385	385
Flood damage; off-site	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 42.

Elements of the Little Sioux Program

The general program[10]

Initiated in 1947 under authority of the 1936 and 1944 Federal Flood Control Acts, this program is concerned with the entire 4,502-sq.mi. Little Sioux drainage and damage problems heretofore discussed as evident in the Nepper Watershed. Problems noted in early surveys completed in 1943 included (1) the discharge of floodwater and sediment on the Missouri River floodplain; (2) flood overflow along upland streams, including the Maple River and its Nepper Watershed tributary; and (3) the rapid growth of gullies.

For planning and evaluation purposes, the Little Sioux drainage was partitioned as follows: (1) the 40-percent glaciated region lying above O'Brien and Buena Vista counties in Iowa was neither surveyed nor treated on the assumption of negligible flood control benefits; (2) a 33-percent Division A extending southward through the above counties to Woodbury and Ida counties was to receive farmland treatment only; while (3) the remaining 27-percent Division B was to jointly receive farmland and structural treatment. The 740-sq.mi. Maple River drainage about equally overlaps Divisions A and B; the 480-acre Nepper Watershed, however, lies entirely in Division B.

Farmland treatment proposed in Divisions A and B included a 35 percent area reduction in row crops, a 52 percent reduction in such small grain as oats, and a 182 percent increase in rotation or permanent

[10]Data quoted are from the various sources below Table 11.

pasture. Supplementary soil conservation practices proposed included 33,000 miles of terracing, 560,000 acres of contouring, and such numerous other measures as tree planting, fencing, and minor forms of gully stabilization. Land treatment was estimated to reduce sheet erosion losses by from 50 to 65 percent, and areas inundated by overflow from 10 to 38 percent. The maximum overflow reduction would be achieved in the Maple River drainage.

Structures proposed in Division B included 371 dams on major gullies, 73 dams on minor gullies, and 447 structures for conveying water into gullies. Structural measures were credited only with reductions in annual land damage amounting to about $185,000, and reduced ditch sedimentation of $7,016. Benefits and costs of the total Little Sioux Program planned in initial surveys are summarized in Table 11 below.

By 1953 the recommended land and structural treatment had been completed within 12 subwatersheds scattered through Divisions A and B, including the Nepper. The second section of Table 11 presents estimated benefits and costs of the program as partially installed in 1953.

The general character of the Little Sioux project was modified considerably after resurveys conducted in 1955 by the Soil Conservation Service. Estimates of benefits were revised in line with expected farmer adoption of conservation practices by 1975. Only 6 percent of the initially recommended terraces had been installed by 1955, although 50 percent of the recommended contouring was being practiced on farms. By 1975, however, it was expected that planned terraces would be 94

Table 11. Installation outlays, benefits, and costs of the Little Sioux Flood Control Program

Program components	Installation costs	Equivalent annual Costs	Equivalent annual Benefits	Equivalent annual Net benefits	Benefit-cost ratios
	(dollars)	(dollars)	(dollars)	(dollars)	
Initial Little Sioux Surveys (1943)[11]					
Land treatment	3,130,241	1,208,302	2,689,707	1,481,405	2.22
Structural measures	2,777,162	177,200	191,562	14,362	1.63
Program total	5,907,403	1,325,502	2,881,269	1,555,767	2.17
Watersheds (12) completed by 1953[12]					
Land treatment	143,789	42,412	137,384	94,972	3.24
Structural measures	2,361,629	64,650	57,553	-7,097	0.89
Program total	2,505,418	107,062	194,937	87,875	1.82
Little Sioux Resurvey (1955)					
Land treatment	--	--	--	--	--
Structural measures	17,123,163	604,229	--	--	--
Program total	--	--	999,365	--	--

[11] Source: U. S. Congress. House. Report of a survey of the Little Sioux Watershed in Iowa and Minnesota. 78th Cong., 1st sess., H. Doc. 268. Wash., D. C., U. S. Govt. Print. Off., 1943. pp. 18, 24.

[12] Source: The President's Missouri Basin Survey Commission. Missouri: land and water. Wash., D. C., U. S. Govt. Print. Off., 1953. p. 95.

percent installed while contouring would increase very little. Proposed investments in structures were increased from the $2.7 million initial amount to $17.1 million. Lacking indication of how revised annual benefits of about $1 million could be credited to land treatment or structures, limited data pertaining to the resurvey are also given in Table 11.

<u>The Little Sioux Program in the Nepper Watershed</u>

As initiated in 1948, the Nepper Watershed phase of the Little Sioux Program called for the watershed area in corn or its equivalent to be reduced to 46 percent from 53 percent, oats increased to 23 percent from 19 percent, and meadow increased to 31 from 29 percent. Contour tillage totaling 273 acres was recommended for practically all upland fields, fields comprising about 62 percent of the watershed cropland.[13] Land use systems recommended on specific fields are given in Figure 12. Comparison of this land use map with Figure 11 indicates recommended changes from predevelopment land use. Since structural improvements installed in 1948 have previously been evaluated as a single set of feasible structures for the watershed, improvements shown in Figure 12 are described in Figure 10 and Table 38.

Available benefit-cost appraisals of the Nepper project are somewhat contradictory. Working with data from the initial Little Sioux Survey and those provided by local Soil Conservation Service planners, Gertel[14] estimated the average annual total benefits of the project to be $2,598 compared with annual costs of $3,325, presuming that recommended land use changes would be fully adopted. However, net benefits of $1,326 and $176 would respectively accrue to on-site farmers and

[13]Although some terracing recommendations were also made, information relevant to individual farms and fields is inadequate for appraisal.

[14]Karl Kertel. Benefits and costs of land improvements. Unpublished M. S. Thesis. Ames, Iowa. Iowa State College Library. 1949.

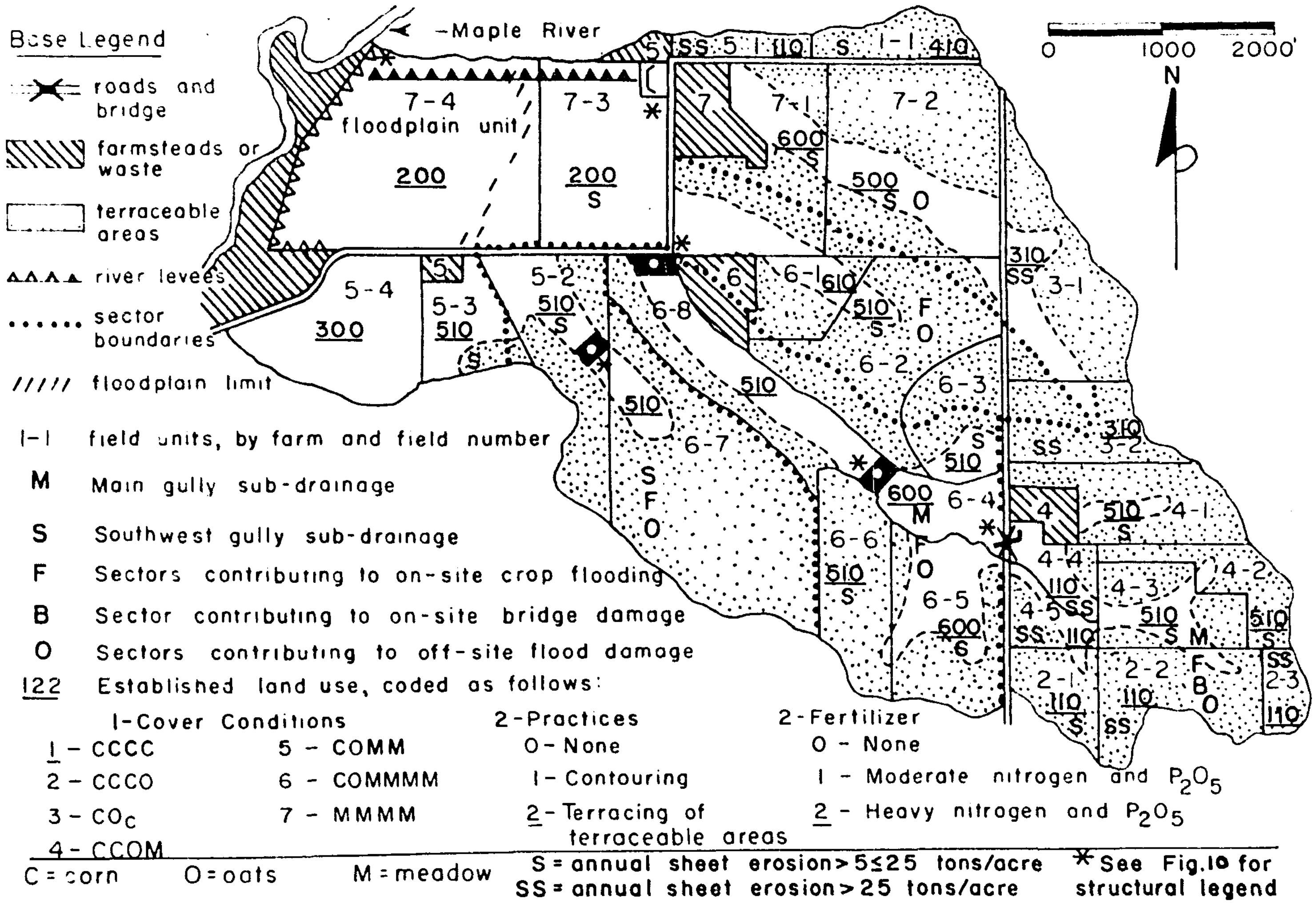

Figure 12. The Little Sioux Program in the Nepper Watershed.

Monona County on the approved cost-sharing basis.[15]

Reviewing the progress of the Little Sioux Program in the 12 minor watershed projects wholly or partially completed by 1953, the President's Missouri Basin Survey Commission estimated average annual total benefits of the Nepper project to be $8,526 compared with annual costs of $3,864. The findings of both Gertel and the Commission are presented in Table 12.

A third appraisal of the project is prepared here on the basis of the technical qualifications and input-output evaluations guiding this study, and can be instructive in indicating how any proposed watershed development plan or altered pattern of resource use can be compared in detail with existing patterns for resultant net returns accruing to various participants.

Applying these assumptions[16] and evaluations to the land use systems recommended and structures actually installed as shown in Figure 12, the major physical effect of the recommended rotational changes and contouring would be to decrease annual sheet erosion soil losses from a predevelopment average rate of 40 tons per acre to 19 tons per acre per farm, with losses on only farms 6 and 7 brought to rates below 10 tons. Estimates of reduced erosion on specific fields are also indi-

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[15] _Ibid._, p. 71.

[16] See page 29 for assumptions concerning viewpoints of analysis, economic horizons, discount rates, and projected prices. Cost sharing arrangements considered, however, are those recommended (in the case of land treatment) or actually noted (in the case of structures) when the project was planned, rather than arrangements based on proportionate benefits.

Table 12. Installation outlays, benefits, and costs of the Little Sioux Flood Control Program in the Nepper Watershed; appraisals compared with an optimum derived through linear programming

Program components	Installation outlays	Equivalent annual			Benefit-cost ratios
		Costs	Benefits	Net benefits	
		(dollars)	(dollars)	(dollars)	($/$)
I. Gertel's appraisal (1949)					
Land treatment	18,140	690	413	-277	0.59
Structural measures	78,146	2,634	2,185	-449	0.83
Program total	96,286	3,324	2,598	-726	0.78
II. Missouri Basin Survey Commission appraisal (1953)					
Land treatment	5,262	1,630	4,976	3,346	3.05
Structural measures	80,837	2,234	3,550	1,316	1.58
Program total	86,099	3,864	8,526	4,662	2.10
III. Preprogramming appraisal (1958)					
Land treatment	201	508[a]	-1,057[b]	-1,565	-2.08
Structural measures	82,890	3,198[c]	3,142[d]	-56	0.98
Program total	83,091	3,706	2,085	-1,621	0.56
IV. Annual outlay of $3,706 programmed (1958)					
Land treatment	5,586	3,281	10,796	7,515	3.27
Structural measures	5,200	425	1,141	716	2.70
Program total	10,786	3,706	11,937	8,231	3.23

[a]Includes an increase of $500 in direct production expense on farms and $8 as private and public investment in permanent pasture establishment respectively amortized at 5 and 2 1/2 percent over 50 years. See Table 14 for initial outlays.

[b]Includes a reduction of $183 in flood damage to on-site crops plus a $5 reduction in off-site flood damage, less a decrease of $1,211 in gross value of crops produced and less an increase of $34 in flood damage to the on-site County bridge.

[c]Includes private and public investment in structures respectively amortized at 5 and 2 1/2 percent over 50 years. See Table 14 for initial outlays.

[d]Includes elimination of $2,620 flood damage to on-site crops remaining after land treatment, elimination of $137 in gully damage, and elimination of $385 in flood damage to the on-site County bridge.

cated in Figure 12.

From Equations 4 and 7 above, the net effect[17] of adopting the recommended land use systems on the sector MFBO (Figure 12) would be to increase average annual runoff damaging the Monona County bridge from 18.71 to 20.41 ac.ft., thus increasing annual bridge damage from $385 to $419, the latter estimated from Equation 8.[18]

Although increased runoff from the sector MFBO would tend to also increase overflow volumes affecting the floodplain, the net effect of land use changes through the entire 293-acre contributing area (sectors indicated by F) would be to reduce average annual overflow from 32.36 to 28.12 ac.ft.,[19] thus reducing maximum annual flood damage from $2,803 ($67.40 per floodplain acre in Figure 9) to about $2,620 ($63 per floodplain acre).

From Equations 4, 10, and 11, average annual net watershed runoff attributable to land use on all fields within sectors indicated by O would be reduced slightly, from 43 to 42 ac.ft. Consequent downstream annual damage determined from Equation 12a would be reduced to $136 from $140.[20]

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[17]Runoff decreases would result from contouring of fields 2-1, 2-2, 2-3, 3-2, 4-4, and 4-5. Fields 4-1, 4-2, and 4-3 would also be contoured, but runoff increases result from changes from successive meadow to a COMM rotation. Runoff from the farm 4 farmstead remains unchanged.

[18]Or from unit damages of $20.51 in Table 6 and increased runoff of 20.41 ac.ft.

[19]From Equations 6a and 6b.

[20]Or from unit damages of $3.24 in Table 6 and decreased runoff of 42 ac.ft.

The net effect of land use changes in both the main and southwest drainages would be, by increasing indexes of peak runoff characteristics, to slightly increase rates of peak 10-yr. flow, annual rates of land destruction, and resulting damage or income foregone. An increase from 52 to 54 of the main drainage runoff index corresponds to an increased peak 10-yr discharge rate of 235 cu.ft.sec. (point B, Figure 3), a 0.14 ac. annual rate of land destruction (point B on the main curve of Figure 5), and increased annual damage of $105 (point B on the main curve of Figure 6). Reference to Figures 4, 5, and 6 likewise approximates increased gully damage of $38 from an increased runoff index of 48 in the southwest drainage.

If such long-term yield estimates as those given in Table 27 are utilized in approximating the production effects of the recommended land use pattern of Figure 12, average annual gross income from corn, oats, and hay would be increased on farms 1, 2, and 3; but decreased on all other farms.[21] Moreover, direct production costs would increase on all farms except farm 1, which has only 4.3 acres within watershed boundaries. Annual returns and costs expected if the 1948 program were totally in effect are summarized by farms in Table 43. Damage items included in Table 41 are omitted from Table 42 because structures installed in 1948 more than eliminate all damages reducing farm income. Contributions of farmers toward installation of land treatment[22] or

[21]Corn valued at $1.41 per bu., oats at $0.74 per bu., and alfalfa-brome hay at $15.70 per baled ton. See the price assumptions on page 30.

[22]Represented by present values of pasture establishment and re-establishment outlays, limited to farm 6.

structures and maintenance of the latter are included as annual costs.

With reference to the incremental benefits of Table 7 and installed units given in Table 39, the structural phase of the program eliminates all gully damage and flood damage to crops, eliminates $385 in damage at the Monona County bridge site,[23] and eliminates no off-site flood damage. Damages remaining with both land treatment and structural measures presumed installed are given in Table 13. Table 13 is comparable to Table 10 in showing the relation of farm income and costs of providing public services to watershed land use.

With program benefits defined as changes in gross farm income less all decreases in annual costs; and program costs defined as all increases in annual costs, benefits and costs of the proposed Little Sioux Program are given by Table 14, derived from Table 13 less Table 10. Corresponding data by farms are given in Table 44 (Table 43 less Table 42). Net crop values would be increased on 4 farms and decreased on 3 farms but increased $716 for all farms as a group, primarily because of the complete elimination of floodplain crop damage for farm 7. Table 14 indicates that, while the program would be profitable for on-site farmers as a group and Monona County in yielding net benefits of $955, annual net losses of $2,576 are sustained by the off-site or downstream interests. Total on-site gains of $955 are less than corresponding off-site losses of $2,576 by $1,621; consequently, the recommended

[23]Although the chute-spillway (measure I) is effective in eliminating $385 in undue bridge maintenance expense, adoption of recommended land use over the sector MFBO would, as already discussed, increase bridge maintenance expense to $419, leaving $34 in remaining damage after installation of the structure.

Table 13. Post-Little Sioux returns and costs distributed by private and public participants

Items by participants	On-site			Off-site public	Total public	Watershed total
	Private[a]	Public	Total			
	(dollars)	(dollars)	(dollars)	(dollars)	(dollars)	(dollars)
Annual returns						
Gross value of crops produced	18,539	0	18,539	0	0	18,539
Annual costs						
Direct production expense	9,217	0	9,217	0	0	9,217
Flood damage; on-site bridge	0	34[b]	34	0	34	34
Flood damage; off-site	0	0	0	135	135	135
Land treatment installation	4	0	4	4	4	8
Structure installation	466	112	578	2,577	2,689	3,155
Structure maintenance	43	0	43	0	0	43
Total annual costs	9,730	146	9,876	2,716	2,862	12,592
Net value of crops produced	8,809	-146	8,663	-2,716	-2,862	5,947
Initial installation; land treatment	80	0	80	121	121	201
Initial installation; structures	8,611	3,174	11,785	71,105	74,279	82,890

[a]Transferred from Table 43.

[b]Equivalent to damage of $419 associated with adjusted land use less damage of $385 eliminated by chute-spillway.

Table 14. Benefits and costs of the Little Sioux Program in the Nepper Watershed; distributed by private and public participants[a]

Items by participant groups	On-site			Off-site public	Total public	Watershed total
	Private[b] (dollars)	Public (dollars)	Total (dollars)	(dollars)	(dollars)	(dollars)
Changes in annual returns						
1. Gross value of crops produced	-1,211	0	-1,211	0	0	-1,211
Changes in annual costs						
2. Direct production expense	500	0	500	0	0	500
3. Gully damage; main drainage	-101	0	-101	0	0	-101
4. Gully damage; southwest drainage	-36	0	-36	0	0	-36
5. Flood damage; on-site crops	-2,803	0	-2,803	0	0	-2,803
6. Flood damage; on-site bridge	0	-351	-351	0	-351	-351
7. Flood damage; off-site	0	0	0	-5	-5	-5
8. Land treatment installation	4	0	4	4	4	8
9. Structure installation	466	112	578	2,577	2,689	3,155
10. Structure maintenance	43	0	43	0	0	43
11. Total cost decreases	-2,940	-351	-3,291	-5	-356	-3,296
12. Total program benefits (Item 1 less Item 11)	1,729	351	2,080	5	356	2,085
13. Total program cost (increases)	1,013	112	1,125	2,581	2,693	3,706
14. Net benefits (increased crop values) (Item 12 less Item 13)	716	239	955	-2,576	-2,337	-1,621
15. Ratio of total benefits to costs	1.70	3.16	1.87	0.00	0.13	0.56

[a]Data derived from Table 12 less Table 10.

[b]Distribution by farms given in Table 43.

program as reviewed here did not constitute an economic development plan for the Nepper Watershed. Major results of these benefit-cost determinations are compared with those of Gertel and the Missouri Basin Survey Commission in Table 12.

Elements of Treatment Analysis and Selection

Although the recommended Little Sioux project would largely eliminate all gully and flood damage, while reducing sheet erosion 45 percent under the average predevelopment rate of 42 tons per acre, that program was clearly uneconomic by failing to meet the criteria that (1) aggregate net benefits be positive; and that (2) net benefits accruing to any participant or group of participants not be negative. Annual net losses on farms 4, 5, and 6 (Table 44) would result largely from land use changes requiring additional capital outlays, reducing gross crop income, and primarily yielding gully and/or flood control benefits to other private and public participants. These uneconomic features are reflected in section III of Table 12, where $188 in identifiable land treatment flood control benefits for on-site crops and the downstream area are greatly exceeded by a required amortized investment of $8 in permanent pasture, and in addition to this, increased farm operating expense of $500 and increased flood damage of $34 at the County bridge site.

The failure also of structures to yield aggregate net benefits can be attributed to water-control capacities far exceeding capacities required for complete elimination of all on-site gully or flood damages associated with land use, despite facilities other than the chute-spillway (measure I) yielding incremental benefits in excess of costs at lesser capacities.

By enforcing the two above criteria for economic justification with respect to individual treatment measures as well as to programs in total or their major components, the inclusion of uneconomic measures and formulation of uneconomic programs could have been avoided. The remainder of this section consequently isolates a complex of land treatment and structural measures possibly included in an optimal development plan for the Nepper Watershed -- consistent with requirements for physical and economic feasibility and serving other possible objectives of participants. Basic hydrologic and economic data are drawn from the preliminary input-output studies of land use systems and structures. Crucial objectives and assumptions determining the specific measures included in the complex are briefly reviewed as follows:

1. Given a series of development measures evidencing aggregate discounted benefits greater than costs and participant benefits no less than assigned costs, measures are to be combined in programs to yield a maximum of discounted net benefits, or a maximum increase in watershed net crop values.[24] Provided watershed-wide benefits exceed costs, land treatment is limited to the rotations, conservation practices, and com-

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[24]With costs of multi-purpose and multi-beneficiary measures distributed proportionately with benefits, equivalent rates of return on contributed resources are realized by all beneficiaries and development interests of participants will not conflict. If compensated damages are included as costs, non-benefiting participants are indifferent to measures benefiting others.

mercial fertilizer applications which in combination will reduce sheet erosion rates to levels no greater than 5 tons per acre on cropland, while allowing corn to be grown relatively frequently. Additional restrictions on the range of land treatment measures given detailed benefit-cost appraisal are explained subsequently.

2. In computing present values or amortizing costs, a 50-year planning horizon or project period is considered relevant for all participants,[25] with corresponding discount rates of 5 percent applied to farmer-incurred values and 2 1/2 percent to public values. Maximum benefits of land treatment and structures are estimated with reference to maximum average annual yield increases and damage reductions, although yields could conceivably decrease for a short period after installation of terraces.[26]

Classes of benefits and costs

Benefits are classified as possible increases in gross crop values or possible decreases in any item of production cost noted in Table 10. Costs are represented by possible decreases in gross crop values, or by increases in any item of production cost; the latter including direct

[25] Program benefits and costs accruing to farm units are assumed to be capitalizable into farm values, thus allowing recovery of expenditures for unexhausted improvements under changing ownership. The assumption of proportionate cost sharing applied to landlord-tenant distributions of development benefits could similarly permit recovery of tenant expenditures for improvements.

[26] Operating against this possibility, however, is a tendency for subsequently analyzed land treatment to jointly involve terracing and fertilizing. Fertilization of newly-terraced fields, particularly terrace channels, is a common practice.

crop expense, associated gully or flood damages, and costs of installing and maintaining project improvements intended to reduce these damages. While increased crop values or decreased direct expense benefit only the farms on which land use changes are implemented, damage-reduction benefits are distributed among all participants initially affected. In these terms classes of benefits can be interpreted as program purposes identifying interests of various private and public participants, and imply that an optimal combination of program purposes is necessary for maximization of aggregate net benefits.

Alternative development activities

These include land treatment measures and structural improvements. With land treatment defined as transition to other feasible land use systems from those established in 1947, the effects of changed rotations, conservation practice adoption, and fertilizer application on watershed hydrology and net crop values are determined with reference to foregoing input-output evaluations. For example, land treatment measures throughout the watershed are first examined for the source-area effects of possible increases or decreases in gross crop values, aside from related damages. Measures within the sector MFBO (Figure 11) are then examined for further effects on gully damage in the main drainage, flood damage to on-site crops, flood damage to the Monona County bridge, and off-site flood damage. Consequent decreases in probable gully damage must be evaluated on farms 2, 3, 4, and 6, units containing the Napier 3-5 percent soils susceptible to destruction from continued gully advance in the main drainageway. Consequent decreases in flood damage to crops are realized only on farm 7 controlling the watershed floodplain, decreases in bridge damage solely by Monona County, and decreases in off-site flood damage by the downstream interest. The single- or multi-purpose character of land treatment on remaining cropland can be noted from sector designations applicable to individual field units within farms while individual participant interests in damage reduction benefits are shown by Tables 10 and 42.

In the event certain land treatment or structural measures should increase rather than decrease either gully or flood damage, participants otherwise damaged are assumed compensated, with compensation payments then representing added costs proportionately incurred by beneficiaries.

Land treatment delimitation

The method of selecting for each field the land treatment measures appraised in detail for benefits and costs and the appraisals as such are illustrated only for field unit 2-1, located within the 89-acre sector MFBO (Figure 11) and thus evidencing association with all damage problems other than gullying in the southwest drainage. Both apply to all fields, however, in following from similar assumptions and requirements;[27] final appraisals are summarized for all fields and farms.

Basic features and feasible land use. Totaling 6 acres in area, field 2-1 includes Ida soils of 4-8 percent slope, Ida soils of 16-25

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[27] Qualifications of the study with respect to land treatment delimitation are given on page 39.

percent slope, Monona soils of 10-14 percent slope, and Napier soils of 3-5 percent slope (see Figures 1 and 2). Possible land uses[28] indicate that, in addition to the entire range of cropping conditions being feasible, contouring and fertilizing are practicable on the entire area and about 84 percent is terraceable.[29] The mean slope degree is 11.9 percent and the slope length is 455 feet. As seen in Figure 2, the entire field potentially contributes to gully damage in the main drainage, and to all classes of flood damage.

Sheet erosion control. In conjunction with the general requirement that erosion be controlled if benefits exceed costs, application of Browning's procedure for estimating annual erosion rates suggests that a predevelopment rate of 27 tons per acre could be reduced to about 3 tons by terracing the field without abandoning continuous corn cropping (see Figure 11) or applying commercial fertilizer. Terracing would also be essential for erosion control if a CCCO rotation were considered. Erosion could be reduced to 5 tons with a CO_c rotation, however, if the change at the minimum involved contouring and fertilizing at moderate rates.[30] Contouring alone would be sufficient under a CCOM rotation, while a change to either COMM, COM_4, or continuous meadow without supplementary practices would also reduce erosion to the permissible 5-ton

[28] Refer to page 59.

[29] Non-terraceable Napier soils occupy 16 percent of the field, in this case equivalently the percent susceptible to future gully damage.

[30] Estimated from separate recommendations for each soil to be about 27 lbs. of available nitrogen and 25 lbs. of available phosphorus per acre.

rate. Requiring that sheet erosion be controlled eliminates for planning consideration 19 out of the range of 55 land use systems agronomically feasible for field unit 2-1; acceptable rates for the 36 remaining systems are shown in column 2 of Table 45 (Appendix D).

Corn frequency. A preference for corn as a cash crop, provided annual erosion rates would not exceed 5 tons per acre, is recognized by limiting the range of erosion-controlling land use systems given further analysis to (1) those involving only the three (or less) remaining rotations in which corn recurs most frequently;[31] and (2) the system recommended in the Little Sioux Program and/or observed as current at the time of this study in 1957. With terracing permitting continuous corn cropping on field unit 2-1, remaining rotations limited by corn frequency include continuous corn, CCCO, and CO_c. The Little Sioux recommendation of contoured continuous corn is eliminated on the basis of an estimated 14-ton erosion rate despite condition (2), but the current system of continuous meadow with negligible erosion is included by the same condition despite complete absence of corn. Imposing the additional requirement of (1) for frequent corn reduces the range of 36 systems effective in erosion control analyzed further to 12, including continuous meadow. Initial budgetary data for remaining systems are given in columns 3-6 of Table 45.

On-farm profit maximization. To apply a restriction of this nature, the 12 systems are then examined for source-area returns and costs. For

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[31] If both CO_c and CCOM control erosion, both are analyzed further.

all fields these amounts are computed independently of related damages[32] and are presumed to influence decisions of farm operators interested in holding erosion rates to permissible levels but not reducing associated gully and flood damage, although significant damage reductions are doubtless complementary with erosion control. Two general situations of capital availability on farms are considered by first eliminating systems failing to yield either maximum net returns per acre (representative of non-limiting capital), or maximum returns per unit of capital employed (reflecting profitable land use with capital limited). The system on field 2-1 yielding maximum net returns of $45 per acre is observed from column 5 in Table 45 as continuous corn terraced and heavily fertilized, while from column 6 the system yielding maximum net returns to capital of $1.83 is the permanent meadow noted as currently in effect.

Aggregate net benefit maximization. Although on-farm benefits are an important element in justification of watershed treatment measures, the possibility remains 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 to land or capital, through greater reduction of land-use-associated damages. This possibility is recognized by also including for benefit-cost analysis the system in column 2 of Table 45 which minimizes sheet erosion while satisfying the requirement for frequent corn; this is a CO_c rotation terraced and

[32]Amortized costs of installing terraces are also excluded from initial on-farm comparisons since such outlays were about 70 percent reimbursable under the Agricultural Conservation Program in 1948.

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 15. Gross crop values and direct production expense for the 6 acres are derived from the per-acre on-farm data of Table 45. Associated gully damage is based on damages of $0.01232 per unit[33] of the corresponding runoff index weighted for field area, as given in Table 6. The benchmark estimate of $4.81 in gully damage under predevelopment conditions is allocated to the field by the procedure illustrated in Table 33. Flood damage to on-site crops is estimated from the seasonal overflow volume probably originating from the field under each system shown, independent of conditions on other contributing fields. Unit damages of $86.59 per acre foot of seasonal overflow are given in Table 6. Flood damage to the on-site County bridge is derived from unit damages of $20.51 per acre-foot of seasonal runoff; and off-site flood damage from $3.24 per acre-foot of allocable net watershed runoff.

Damages of $86.59 per acre-foot of seasonal overflow presume a heavily fertilized continuous corn system on the watershed floodplain,

[33]Strictly, the relations of Figures 3-6 indicate a linear arithmetic relation between peak discharge and damage, rather than between runoff indexes and damage. The error resulting from employing the above estimate of unit damages for all land use systems in the main drainage is not great, however, and will subsequently be shown.

Table 15. Computation of land treatment benefits on field unit 2-1

Items by land use systems or land treatment measures[a]	A. Associated returns and costs				B. Associated benefits and costs[b]		
	122	322	700	100	122	322	700
	(dollars)	(dollars)	(dollars)	(dollars)	(dollars)	(dollars)	(dollars)
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; on-site crops	1.54	0.00	17.29	147.79	-146.25	-147.79	-130.49
Seasonal overflow (ac.ft.)	0.02	0.00	0.20	1.70	-1.68	-1.70	-1.50
5. Flood damage; on-site bridge	6.55	4.09	10.28	41.20	-34.64	-37.10	-30.91
Seasonal runoff (ac.ft.)	0.32	0.20	0.50	2.00	-1.68	-1.80	-1.50
6. Flood damage; off-site	0.97	0.67	0.97	0.97	0.00	-0.33	0.00
Net runoff (ac.ft.)	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 Figure 11 for explanation of land use codes.

[b]Computed as respective columns in the first section less the column headed 100, or as changes in items alternatively induced by shifting from predevelopment continuous corn (system 100) to other systems selected as in Table 45.

[c]For installation of 2890 linear feet of terraces at $0.04 per foot.

[d]Represents the present value of establishing and re-establishing permanent meadow at four-year intervals for 50 years.

32.36 ac.ft. of seasonal overflow, and corresponding damages of $67.40 per floodplain acre; the various estimates are noted either from Table 6 or Figure 9. The latter indicates decreasing average damages per acre with increasing runoff; or conversely, increasing average benefits with increasing overflow reductions, regardless of floodplain land use. Since total damage can be obtained as the product of the floodplain area of 41.6 acres and the per-acre amounts plotted, the same described relations apply if average damages refer to overflow rather than area. Despite Figure 9 indicating increasing average benefits of overflow reduction, this study (to illustrate planning procedures based on constant average benefits) values all overflow reductions resulting from upland treatment at a maximum of $86.59 per acre-foot, with such benefits limited by projected predevelopment damage totaling $2803.

With section A of Table 15 detailing returns and costs for alternative land use systems on field unit 2-1, benefits and costs of shifting from the predevelopment continuous corn system involving no conservation practices are computed in section B. Although mere adoption of terracing and fertilizing clearly provide greater benefits in total (largely credited to an increased corn output), the same practices combined with a shift to a CO_c rotation and a shift to continuous meadow alone are somewhat more effective in damage control. Terracing alone, however, would reduce average annual floodplain overflow volumes by 1.68 ac.ft. and floodplain damage by about $146 annually. The 1.68 ac.ft. of runoff retained by terraces[34] would also reduce damage to the

[34]Note from Equation 4 and Table 36 that fertilizing is not credited with reducing runoff, although slight reductions are likely.

County bridge by $34.64 annually.

Increased annual production costs associated with terracing and fertilizing alone are estimated at $123, and installation of the required 2890 feet of terraces at $115. Table 16 distributes these outlays among beneficiaries to establish whether the practices can be economically justified.

In presenting a complete appraisal of costs and benefits on both an annual equivalent and present value basis, Table 16 employs the cost-sharing criterion that, on either basis, total costs be shared proportionately with total benefits, or that contributed resources yield the same rate of net return for all beneficiaries. On an annual basis in section I for example, about 94 percent of the benefits of terracing and fertilizing field unit 2-1 accrue to four watershed farmers[35] and the remaining 6 percent to Monona County. Increased production expense on farm 2 is allocated to farmer-beneficiaries and Monona County in these proportions.[36] On a present value basis, however, about 90 percent of the benefits are received by farms and 10 percent by the

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[35]Increases in gross crop values are retained on farm 2; gully control benefits are distributed proportionately with predevelopment damages on farms 2, 3, 4, and 6; and flood control benefits to on-site crops are limited to farm 7. The cost allocation and net benefit determination procedures illustrated in Table 16 for farmers as a group and Monona County are also appropriate for inter-farm distributions. Although benefits, costs, and net benefits vary by individual farms, all realize the $3.61 rate of return computed below.

[36]In practice, increased farm production expenses are presumed borne by farmers controlling areas treated. Allocations are made here, however, in merely arriving at proportional total cost assignments; variations of individual cost items consistent with the total allocations are not ruled out.

Table 16. Benefits and costs of terracing and fertilization of field unit 2-1; distributed by private and public participants

Annual or present value items	I. Annual equivalents			II. Present values		
	On-site private (dollars)	On-site public (dollars)	Watershed total (dollars)	On-site private (dollars)	On-site public (dollars)	Watershed total (dollars)
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 (Table 15)[a]	355.68	0.00	355.68	6,492.87	0.00	6,492.87
Changes in costs						
5. Direct production expense (Table 15)	123.54	0.00	123.54	2,255.20	0.00	2,255.20
6. Gully damage; main drainage (Table 15)	-2.59	0.00	-2.59	-47.28	0.00	-47.28
7. Flood damage; on-site crops (Table 15)	-146.25	0.00	-146.25	-2,669.76	0.00	-2,669.76
8. Flood damage; on-site bridge (Table 15)	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

[a]Table 15 references apply only to section I; section II is derived from section I, except as noted below.

Table 16 (Continued)

Annual or present value items	I. Annual equivalents: On-site private (dollars)	I. Annual equivalents: On-site public (dollars)	I. Annual equivalents: Watershed total (dollars)	II. Present values: On-site private (dollars)	II. Present values: On-site public (dollars)	II. Present values: Watershed total (dollars)
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 cost (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

[b] Items 12 and 14 in section II are computed independently of section I; remaining items in section II computed as products of annual values and the present value factors of item 2 above.

County. The required investment of $115 in terrace construction is assigned by these percentages, but then spread over the project period by the respective amortization factors of item 3. Total annual net benefits of $409 resulting from identified benefits less costs thus assigned represent an annual net return for all beneficiaries of $3.16 per unit value of all contributed resources, including initial capital outlays.

In section II all annual amounts are converted to present values by the present value factors of item 2 corresponding with the discount rates of 5 and 2 1/2 percent. If adopted in 1948 on field unit 2-1, the practices of terracing and fertilizing would return $10,192 as the present value of $539 in annual benefits received over the 50-year project period, with all immediate and future outlays comparably valued at $2,450. Net benefits of $7,741 again represent for all beneficiaries a return of $3.16 per unit value of contributed resources.

Appraisals of the three land treatment alternatives for field unit 2-1 by the method of Table 16 are summarized in annual equivalent form in Table 17 below. All measures are economically justified in yielding net benefits, both in the aggregate and, by reason of proportionate cost sharing, for all beneficiaries. While all benefit farms 2, 3, 4, 6, and 7 as well as Monona County, only the second provides any measure of off-site flood control as an added public benefit. Farms 1 and 5 are neither benefited nor damaged, since both lie outside the main gully drainage and also are unaffected by flood runoff. Higher rates of return with adoption of a CO_c rotation or permanent meadow relate to

Table 17. Benefits and costs of alternative land treatments on field unit 2-1[a]

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

[a]From Figure 11, the base system is CCCC with no practices.

[b]From item 8, Table 15.

[c]See Table 16 for detailed costs and benefits.

requirements for operating capital; in Table 15 the latter requires $90 in operating capital, or $26 less than the predevelopment system of continuous corn. High rates imply also that field unit 2-1 is a critical treatment area; that is, initial inputs of scarce resources allocated to establishment and continuation of permanent meadow on the field should be an effective means for maximizing net benefits in a watershed development program.

<u>Comprehensive land treatment</u>

To specify the complex of land treatment measures economically undertaken on all Nepper Watershed cropland, the foregoing procedure outlining possibilities on field 2-1 is extended to the 26 remaining fields scattered among the seven watershed farms. Results of successively imposing conditions for erosion control, corn frequency, on farm profitability, etc., with regard to the entire cropland area are given in Table 18; both for field 2-1 as reviewed and for all fields. Two added conditions are arbitrarily imposed, however, in ultimate selection of the 47 land treatment measures considered in formulating an optimal development program. These are that measures for each field yielding net benefits must either (1) yield maximum net benefits; or (2) yield a maximum ratio of benefits per unit outlay.[37] Column 4 in Table 18 below indicates necessary computation of erosion rates for 1,359 systems (50 per field); on-farm budgetary comparison of 185 systems (7 per field); detailed benefit-cost appraisals of 75 systems (about 3 per field); and eventual planning consideration of 47 new systems (from 1 to 5 per field), plus the 27 predevelopment systems (1 per field) from which benefits and costs of the new systems are determined.

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[37] In Table 18, the final conditions are applied to 69 systems providing net benefits; the objective is simply isolation of measures most expedient in illustrating planning under contrasting situations of limited and unlimited development capital. Field units 2-1 and 7-4 (the floodplain) are excepted; the former to permit further comparison of the three measures appraised in Tables 15 and 17, and the latter to compare five alternative floodplain land use adjustments to possible continued flooding.

Table 18. Selection of land treatment activities for watershed planning

Conditions for selection as watershed treatment activities	Field unit 2-1 Systems excluded	Field unit 2-1 Systems remaining	All fields (27) Systems excluded	All fields (27) Systems remaining
	(N)	(N)	(N)	(N)
Entire range of feasible systems	0	55	0	1,359
Annual erosion no greater than 5 tons per acre	19	36	928	431
Corn relatively frequent	24	12	246	185
Maximum on-farm returns per acre	10	2	152	33
Maximum on-farm returns to capital	0	2	-19[a]	52
Minimized sheet erosion	-1[a]	3	-23[a]	75
Net benefits (over pre-development)	0	3	6	69
Maximum net benefits	1	2	38	31
Maximum benefit per unit outlay	-1[a]	3	-16[a]	47

[a]Additions.

Aggregate benefits, costs, rates of return, and fields relevant to each of the 47 land treatment measures are listed in Table 19. The 27 fields are defined as subclasses of the total cropland area of 442 acres susceptible of treatment, and thus represent area restrictions on land resources available for obtaining development benefits. The nature of treatments is indicated by the two columns headed "Analysis codes." In Table 19 and Figure 11, for example, a CCOM rotation with no practices is the system noted established in 1947 on field 1-1. The conditions listed in Table 18 reduce the range of feasible systems given planning consideration to a single alternative -- a shift to a continuous corn cropping system involving terracing (of the entire field) and heavy applications of nitrogen and phosphorus. Gross benefits of $191 accrue jointly to farm 1 and the off-site area, since the field is located only within sector 0.[38] Proportionate sharing of $131 in increased annual costs yields net return rates of $2.18 for farm 1 and the downstream public interest. Data following in Table 19 for field unit 2-1, contributing to four classes of watershed damages, are from Tables 15-17 as previously explained.

Structural treatment

The final section of Table 19 presents comparable planning data for the three structural measures yielding net benefits as computed in Tables 7 and 8, with locations of facilities given in Figure 10. Whereas field areas denote a limited land supply, similar restrictions on structure size effectively limit capacities of structural measures for water-control and consequent flood or gully damage reduction benefits. Limits on structure size are 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 40. Design and cost data presented in Table 41 include estimated land or site area requirements of the various measures on an

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[38]Annual on-farm benefits of increased crop values are $189 and off-site flood control benefits are about $2.00.

incremental basis, or per unit of earth fill or bank height. The requirements are transferred to Table 19 as land inputs of the 48th, 49th, and 50th alternative watershed treatment activities. Land inputs indicate that, within limits imposed by field areas and maximum earth-fill volumes, a predevelopment CCCO rotation could be retained on field unit 7-3; the field could be shifted to a CCOM rotation and fertilized; and the field could provide land for the group of structures installed in the main drainage (measure II) or for the levees of measure III. Similar considerations determine alternative uses of field units 6-7 and 7-4.

Table 19. Benefits and costs of alternative land treatment and structural activities for the Nepper Watershed

Field units (Figure 11)	Program disposal code (Pj)	Land supply P_o (acres)	Initial system (See Figure 11)	Analysis codes	Watershed land treatment activities: Program code (Pj)	Unit costs \$(aj)	Unit net benefit \$(cj)	Net benefit / costs \$(dj)
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

Table 19 (Continued)

Field units (Figure 11)	Program disposal code (Pj)	Land supply P_o (acres)	Initial system	Analysis codes (See Figure 11)	Watershed land treatment activities: Program code (Pj)	Unit costs $(aj)	Unit net benefit $(cj)	Net benefit / costs $(dj)
5-1	j=62	3.3	100	321	j=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

Table 19 (Continued)

Field units (Figure 11)	Program disposal code (Pj)	Land supply P_o (acres)	Initial system Analysis codes (See Figure 11)		Watershed land treatment activities Program code (Pj)	Unit costs $(aj)	Unit net benefit $(cj)	Net benefit costs $(dj)
7-1	j=74	20.8	700	122	j=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 (Figure 10 and Tables 7, 8)	Program disposal code (Pj)	Earth-fill supply P_o (1000 cu.yds.)	Watershed structural treatment activities Program code (Pj)	Land inputs, by field units 6-7 (acres)	7-3 (acres)	7-4 (acres)	Unit costs $(aj)	Net benefit $(cj)	Net costs $(dj)
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

PROGRAM FORMULATION THROUGH LINEAR PROGRAMMING

With the central objective of watershed planning specified as achieving combinations of treatment measures maximizing aggregate discounted net benefits, the problem of project formulation in the Nepper Watershed reduces to indicating how the various land treatment and structural activities delimited in the foregoing section (and Table 19) might have been so combined in 1947 (the assumed planning date) and continued over the 50-year (1947-97) planning period. In principle, any pair of activities x and y would be combined in proportions to equate the marginal rate[1] at which x substituted for y as specified by resource requirements with the marginal value of x relative to y; the latter relation given by ratios of discounted benefits. The mathematical device employed to optimally combine the activities of Table 19 in a development program for the Nepper Watershed is "linear programming," a technique appropriate for planning economic activities subject to restrictions of a resource-supply or technological nature.

Programming in Relation to Watershed Planning

Activity unit levels defined

Because the "activity at unit level" concept is basic in linear programming, unit levels of the land treatment and structural activities

[1]Defined as the number of units of y sacrificed if resources were used to provide an added unit of x. If the value of x were twice that of y, x could be profitably increased at the expense of y until an added unit of x displaced more than two units of y.

considered in its application to the Nepper Watershed are defined as follows:

1. The unit level of any of the land treatment measures listed in Table 19 as P_j (j = 1, 2, ... 47) is taken as the given treatment applied over 100 percent of the corresponding field area tabulated in the P_o or land supply column. The cost-benefit data of the columns labeled a_j, c_j, and d_j thus apply to entire field areas.[2]

2. The unit levels of the structural measures listed as P_j (j = 48, 49, 50) are taken as single installation increments indicated under P_o. The unit levels of measures II and IV, for instance, are 1,000 cu.yds. of earth fill, and the unit level of measure III is 1 foot of levee bank height. Incremental benefit-cost data are given in Table 8; a unit level net loss of $23.49 for measure I in Table 8 explains its absence from Table 19. Additional design and cost data on structures, including land inputs from fields 6-7, 7-3, and 7-4, are given in Table 41 (Appendix C).

Specified restrictions on activities

These refer to limits on the intensity of land treatment and structural activities possibly imposed by fixed quantities of land, labor, and capital resources; plus maximum benefits derived from eliminating particular watershed damage problems and maximum structure capacities imposed by engineering considerations.

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[2] By dividing the columns a_j and c_j by the respective acreages under P_o, unit levels of land treatment can alternatively be defined in per-acre terms. The above interpretation has been adopted, however, to avoid manipulation of extremely small per-acre amounts of associated costs and benefits.

Land. The above unit level definition of land treatment indicates an obvious class of land limitations to be the respective areas of each field possibly treated; that is, no land treatment activity can be undertaken at more than its unit level, or on more than an entire field. Also, intensities of combined land treatment or non-treatment on the same field (measured in percent of the total field area) can add to no more than 100 percent; nor can respective area percentages involved in treating or not treating portions of fields and utilizing other portions as structure sites add to more than 100 percent. Twenty-seven land supply limitations (27 fields) are consequently denoted by P_j (j = 51, 52, ... 77) in column 2 of Table 19, with watershed and farm locations noted in column 1 and total areas in column 3.

Labor. Although some land treatment activities appropriate in the Nepper Watershed in 1947 would require added inputs of farm labor (and some less), labor is presumed to be non-limiting; that is, assumed adoption of labor-intensive treatments throughout the watershed would likely require no more labor inputs than were currently being unutilized. The basis for thus eliminating labor as a programming restriction is comparison of 1947 labor use estimates computed from the per-acre requirements of Table 25 (and the corresponding land use pattern of Figure 11) with labor availability as determined by farm surveys conducted in 1957. The comparison indicated that from 30 to about 2,400 man-hours of farm labor (family and hired) available for field work were not being used on all watershed farms in 1947, and that actual labor use could be increased a minimum of 17 percent per farm and a maximum of 90 percent without exceeding available supplies.[3]

Maximum structure size. These restrictions are designated in Table 19, column 2 by P_j (j = 78, 79, 80), and specify that the total earth-fill volume of structures combined as the main drainage group cannot exceed 40,850 cu. yds.; the levees protecting the watershed floodplain from upland runoff cannot exceed a height of 6 feet, and that the total earth-fill volume of the single structure termed the southwest drainage group (grouped to account for related channel improvement) cannot exceed 14,400 cu. yds. The limits are equivalent to actual volumes or heights of the structures installed in the 1948 Little Sioux Program, and are assumed to approximate water-control capacities required for complete elimination of gully damage as well as flood damage on the watershed floodplain, independent of any reductions credited to land treatment on upland fields.

Maximum damage averted. Though not specifically designated in Table 19, restrictions of this nature are allowed to limit the intensity of land treatment measures and structures, particularly with regard to benefits obtained through reduction of flood damage to on-site crops. These restrictions are based on the reasoning that land treatment or structures independently providing damage-reduction benefits cannot be credited with such benefits if other activities already included as program components entirely eliminate such entirely while being in the

[3]Although several tenure changes took place between 1947 and 1957, the number of operators and hired workers remained unchanged and a family worker was added on one farm.

aggregate more profitable than the non-credited activities. Explanation of the method for enforcing these restrictions is deferred until results of program formulation are reviewed.

Required resource outlays. A final restriction on watershed treatment activities is represented by the present value of all immediate and recurring outlays necessary to initiate and continue land use changes, or to install and maintain structures over the project period. In Table 19 these amounts are given for each activity at its unit level under the column headed a_j; and are computed as the annual equivalent of capitalized cost.[4] Total benefits are obtained from (a_j+c_j), and ratios of net benefit per unit outlay (d_j) from (c_j/a_j). The latter are intended to reflect the marginal productivity of committed resources in providing development benefits by any of the 50 listed watershed treatment activities.

In the P_o column of Table 19, no discrete total program expenditure is given for P_{81}, but this does not assume that capital[5] as well as labor is in excess supply. The procedure will be to devise a series of optimal development programs (activity combinations) for the Nepper Watershed with reference to successively greater required program outlays. This approach will (1) illustrate how various expenditures involved in acquiring non-limiting resources (labor, fertilizer, seed, construction materials) for watershed treatment effectively determine how limiting resources (land, structure size maxima) are best allocated among com-

[4] Computation of a_3 = \$129.65 (item 15) is illustrated in Table 16.

[5] In the sense of capitalized cost.

peting activities; and (2) indicate the applicability of linear programming to conventional principles of program formulation by activity benefit-cost comparisons. The maximum program outlay of interest, however, is that at which net program benefits cannot be increased, or where an added increment of expenditure would return no discounted net benefits.

Relevance of major assumptions[6]

Linearity. The definitional assumption of linear programming states that inputs required and outputs forthcoming from alternative activities are directly proportional to activity levels, such as defined above. With respect to land treatment activities, the assumption merely says that if treatment of 100 percent of a field containing 20 acres provided an annual benefit of $50 at a cost of $20, treatment of 50 percent or 10 acres would provide an annual benefit of $25 at a cost of $10; and that the average and marginal benefit in both cases would equal $2.50 per unit outlay or $2.50 per acre treated. Consequently, effective limits on land treatment of a single field are determined by resource supplies rather than decreasing marginal benefits and/or increasing marginal costs.

Applied to a structural measure such as P_{48} in Table 19, linearity implies that for each added 1,000 cu. yds. of earth fill (the unit

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

level), measure II occupies an added area of 0.051 acres in field 7-3 otherwise utilizable for crop production, program costs are increased by $55.10, gross benefits by $108.56, and net benefits by $53.46. These amounts would be decreased by 50 percent to obtain the incremental effects of a 500 cu. yd. increase or decrease in earth fill volume.

An added aspect of linearity is its application to cost sharing arrangements. In Tables 19 and 16 the unit level annual costs of activity P_3 are given as $129.65, net benefits as $409.51, and total benefits are derivable as $539.16. Table 16 indicates the distribution of unit level benefits and costs between farmer-beneficiaries and Monona County. If the activity were undertaken over only 3 acres of field 2-1 rather than the total area of 6 acres, all absolute annual and present value amounts in Table 16 would correspondingly be reduced by 50 percent. The immediate terrace installation outlay (item 14) charged to benefiting farmers would be reduced to $52.235 from $104.47 and that charged to Monona County to $5.575 from $11.15. The percentage benefit distributions of item 12 and the net benefit ratios of item 17 would remain unchanged.

<u>Divisibility</u>. This assumption refers to the possibility of continuously increasing or decreasing the level of treatment activities; that is, a land treatment activity level could range continuously from zero to 100 percent, rather than only by the discrete levels of say zero, 25, 50, and 100 percent. The assumption thereby implies that a given treatment could be applied over one portion of a field and another over the remaining portion, and raises difficulties if land

treatment is defined to include complementary changes in cropping methods, tillage practices, fertilizer treatment, or terrace installation. Whereas terracing can be limited to steeper slopes or installed as construction funds become available, the remaining elements of treatment generally apply to entire fields. An illustration to follow indicates how capital or other limitations can theoretically specify the adoption of two rotations on different portions of a predefined field unit, but the solution of the programming problem for the Nepper Watershed specifies no more than one land treatment activity for each field.

Similarly for structures an optimal combination of all activities might suggest that levees (activity P_{49}, in Table 19) be built to a height of 4.75 feet, a height estimated from Table 7 to annually divert (4.75)(5.57) = 26.45 ac. ft. of floodwater from watershed uplands into the Maple River. From Tables 8 or 19, corresponding total annual benefits would be (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 total (4.75)($1,314.75) = $6,245.06 (from Table 8). Aside from probable inaccuracies in these precisely stated estimates of floodwater control and associated benefits and costs, the levee design height would likely be increased to 5 feet, although the added 3 inches would involve an opportunity cost represented by the net program benefit foregone by resulting adjustments in the optimal activity combination.

Additivity. This could be termed an assumption of activity independence in that the total effects of combining certain activities, with respect to both inputs and outputs, are obtained by adding effects attributable to each activity if conducted alone at the specified combination level. Thus fertilization of upper portions of a sloping field is assumed not to enhance yields on untreated portions; also, though terracing steeper slopes will decrease per-acre erosion rates over lower unterraced slopes as well as terraced areas (through an effective reduction in slope length), the effect is ignored.

Finiteness. This requires use of the unique activity concept to specify a limited number of treatment possibilities within a treatment continuum for each watershed field and the total watershed area. With the land treatment continuum for each field represented by alternative shifts to many agronomically feasible land use systems from the system followed in 1947, the foregoing chapter attempted isolation of reasonable alternatives with reference to erosion control, corn frequency, and benefit-cost appraisals. The finite alternative land treatments have thus been presented as the activities P_j ($j = 1, 2, \ldots 47$) in Table 19.

Applied to required inputs, finiteness specifies that the quantities of at least some resources required to carry out the 50 land and structural treatment measures are limited; otherwise the scope of development programs would be unlimited[7] and the programming method superfluous. Table 19 denotes 27 classes of limited land resources

[7] This follows from the linearity feature of programming indicating that if an activity yields net benefits at its unit level, net benefits can be increased indefinitely by increasing the activity level.

representing field areas, and three capacity restrictions on structures as P_j ($j = 51, 52, \ldots 80$); capitalized cost taken at various restrictive levels is designated as P_{81}.

Elements of the programming method

Simple applications to the problems of determining optimal combinations of competitive land treatment activities, and similar combinations of land treatment and structural activities illustrate how linear programming can arrive at comprehensive projects maximizing net benefits subject to planning restrictions.

Combining land treatment. In Table 19 two alternative treatments (P_{19}, P_{20}) given for field unit 5-1 located on the northern boundary of the Nepper Watershed (see Figure 11) include a shift from continuous corn with no conservation practices to either a CCOM or CO_c rotation, with terraces installed over the entire field and commercial fertilizer applied at moderate rates. Corresponding benefit-cost data and resource-inter-relationships of the two possibilities are shown in Figure 13.[8] If the CO_c rotation rather than the CCOM rotation is adopted over the entire 3.3 acres (at its unit level), the available treatment area L_b is entirely utilized at B, the required outlay is C_b or $21.45, and resulting net benefits are $23.04. If the CCOM rotation is selected at its unit level, the land resource L_d (= L_b) is again fully utilized at D, the required outlay is C_d or $29.30, and net benefits are $25.26.

[8] The construction is adapted from Robert Dorfman. Mathematical, or "linear" programming: a non-mathematical exposition. American Economic Review. 43: 805. 1953.

Consequently, \$29.30 in capital available to finance a shift to either of the two rotations and their similar added practices suggests 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 is indicated. And if a capital outlay less than C_b were being allocated, say C_a, a maximum of \$15 in net benefits obtainable at A would result from adopting the CO_c rotation and related practices on 65 percent of the field and leaving the remaining area in continuous corn. This suggests that three land use alternatives are actually posed to the farmer; the two involving changed cropping methods with related practices and that involving no change.[9]

The relations of Figure 13 also facilitate decisions as to how available capital outlays ranging between C_b and C_d are best allocated among competing treatments. The equilibrium condition for such allocations specifies that each of the CO_c and CCOM rotations be adopted on the field in proportions equating the marginal rate at which CO_c substitutes for CCOM with the ratio of discounted net benefits from CO_c to those for CCOM. With respect to capital, the percent of the field not shiftable to a CCOM rotation for each percent shifted to CO_c is given as constant at \$21.45/\$29.30 = 0.73, or from C_b/C_d in Figure 13; and with respect to land is constant at 100/100 = 1.00 or L_b/L_d. Since only capital and land are limiting, the marginal rate of activity substitution ranges between 0.73 and 1.00. The CO_c/CCOM net benefit ratio

[9]Since the two treatment alternatives are evaluated in terms of a change from predevelopment land use, leaving a field portion untreated is the logical equivalent of allowing land resources to go unused.

is computed as \$23.04/\$25.26 = 0.90 and indicates that a CCOM rotation adopted on only 90 percent of the field would provide net benefits of \$23.04 equivalent to a 100 percent adoption of CO_c. This is shown along the \$23 iso-net benefit contour of Figure 13, but the same net benefit substitution ratio applies on all such curves.

A typical programming problem can then be 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 were non-limiting has already been given 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 gained from an outlay of C_e, however, is about \$24 (\$23.87), shown as the iso-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 benefit for a reduced outlay imply treatment of more than 100 percent of the field area and are thus precluded by the land limitation. Also, points above E maintaining or increasing net benefits of \$24 with treatment of a smaller land area, or increasing benefits above \$24 while treating the total field are disallowed by the C_e capital limitation. Point E is therefore optimal, in that any other percentage combination of the two rotational-practice treatments fails to maximize net benefits subject to the stated resource restrictions, either by failing to efficiently use or by requiring more than C_e in available capital.

With point E in Figure 13 specifying total treatment by some combination of CO_c and CCOM, the particular combination is graphically determined[10] 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. The latter percentage is alternatively determined by moving from O along OB to E_2, where $OE_2 = EE_1$ and $OE_2/OB = 0.63$. Thus the total area treated is 100 percent of the area feasibly treated, the total capital allocation of \$24.25 is utilized $[= 0.37\ (29.30) + 0.63\ (21.45)]$ and net benefits are a maximum of \$23.87 $[= 0.37\ (25.26) + 0.63\ (23.04)]$.

Combining land treatment and structures. In its simplest form this is also a problem of optimally allocating a given capital expenditure and land area, but where the land area can alternatively be used for non-structural purposes or serve as structure sites. In Table 19 a single land treatment activity, P_{42}, considered for field unit 7-3 involves a change from an unfertilized CCCO rotation (noted in Figure 11) to a CCOM rotation heavily fertilized with nitrogen and phosphorus; but since 50 percent of the site area required by the levee system (activity P_{49}) must necessarily come out of the croppable field area, the field is nevertheless concerned in two treatment activities. Table 19 and OB in Figure 14 indicate that, if the entire 22.5-acre area L_b is shifted to a CCOM rotation and heavily fertilized, an annual capital outlay of C_b or \$215 is involved and net benefits will approximate \$300, the data referring to the treatment at its unit level. Unit level data for the

[10] Ibid., pp. 805-806.

levee (P_{49}) refer to height increments of 1 foot and are given in Table 19 as a \$106 capital expenditure and \$374 in net benefit. Ignoring the land area occupied in field 7-4, the curve OD in Figure 14 applies to levees, and is scaled by various bank heights up to the 6-foot maximum permitted by the P_{79} size limitation. If the levees are built to a maximum height of 6 feet, an annual capital expenditure of C_d or \$640 is involved, net benefits are \$2,250, and 1.05 acres or 4.67 percent (L_d) of field unit 7-3 are diverted from crop production.

With OD and OB representing alternative means of attaining given iso-benefit contours, Figure 14 shows that land and capital resources are most profitably allocated exclusively to levee construction, subject only to the 6-foot height restriction. A capital outlay of C_a (\$284) available, for example, permits a maximum of \$1,000 in net benefit at point A while requiring a very small proportion (2 percent) of the available field area; the appropriate levee height is directly read as 2.67 feet. Similar conclusions hold for any capital outlay not exceeding C_d (\$640).

The over-riding profitability of the levees relative to land treatment can also be verified by comparison of the capital outlays required to yield specified benefit amounts. With the OD and OB intercepts of the iso-net benefit contours of Figure 14 correspondingly indicating least-cost activity levels, the only least-cost means of obtaining \$1,000 in annual net benefits is given by point A denoting an annual expenditure of C_a or \$284 on levees built to a height of 2.67 feet. The same interpretation governs benefit specifications not exceeding \$2,250;

the relevant minimum cost of C_d (\$640) for levees 6 feet in height is given at point D.

Concerning capital outlays exceeding C_d, net benefits are 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) is specified, the maximum net benefit permitted without the land or levee height restrictions being exceeded is \$2,534 at point E in Figure 14. With the levee capital allocation known as \$640, an amount \$204 (\$844-\$640) remains for financing land treatment on the 95 percent field area (21.45 acres) remaining; permitting point E_2 being reached along OB. Point E_2 is alternatively specified by extending point E parallel to OD through OB, where the distance OE_1 is equivalent to EE_2. Thus the entire field is utilized either for levee installation (5 percent) or treated by the CCOM-F_2 system (95 percent); the available expenditure of \$844 is utilized $\left[= 6(106.79) + 0.95(214.87)\right]$; and net benefits are a maximum of \$2,534 $\left[= 6(374.57) + 0.95(298.57)\right]$.[11]

Utility in comprehensive planning. Although Figures 13 and 14 discuss allocations of resources between competing activities within fields, the principles outlined can be generalized to the comprehensive planning problem of allocating available resources among competing activities among fields, and hence among farms or throughout the watershed. For any resource-use situation, this involves specifying the intensity

[11]Refer to Table 19 for detailed benefit-cost data.

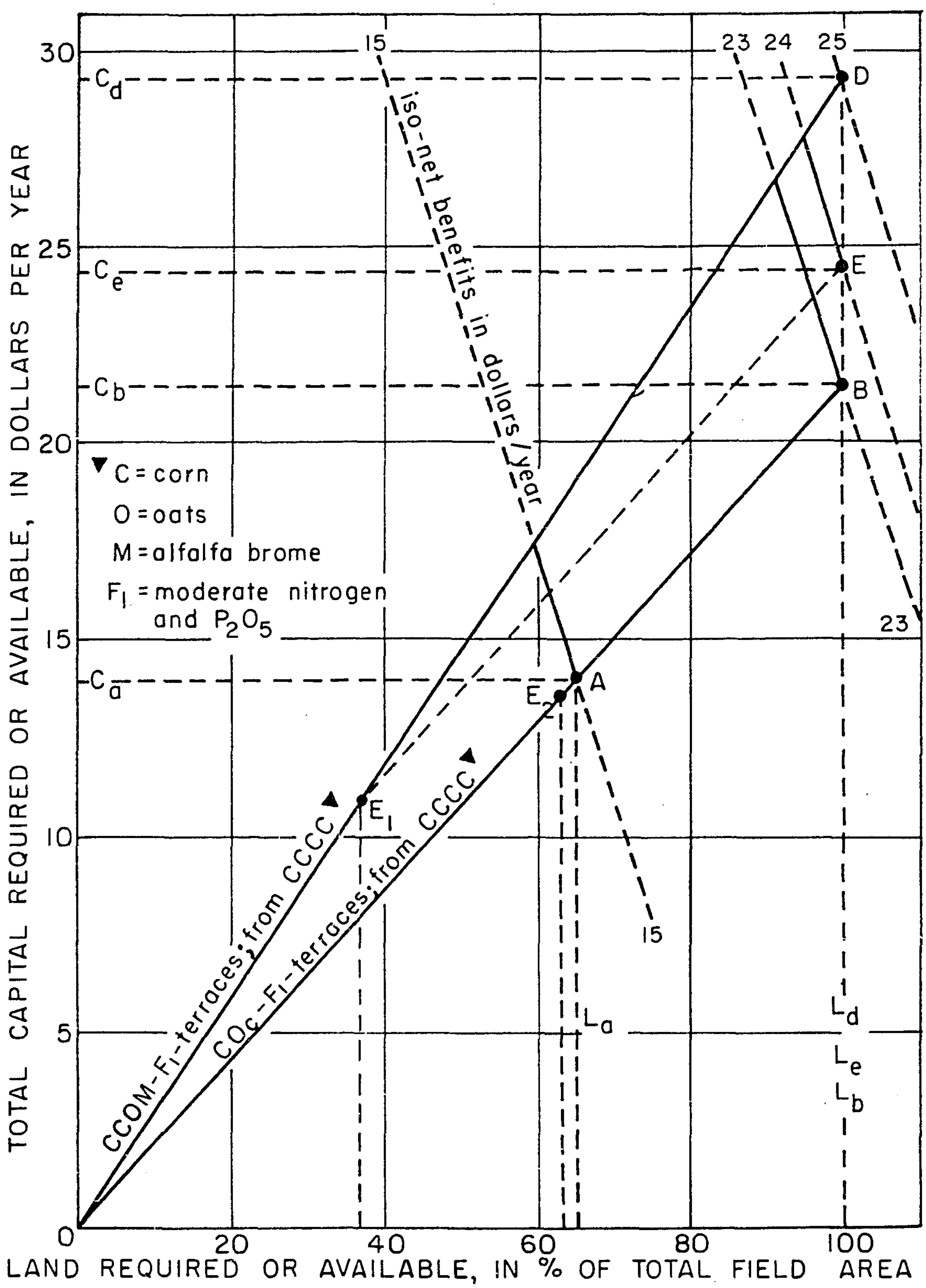

Figure 13. Optimal land use changes for various capital outlays.

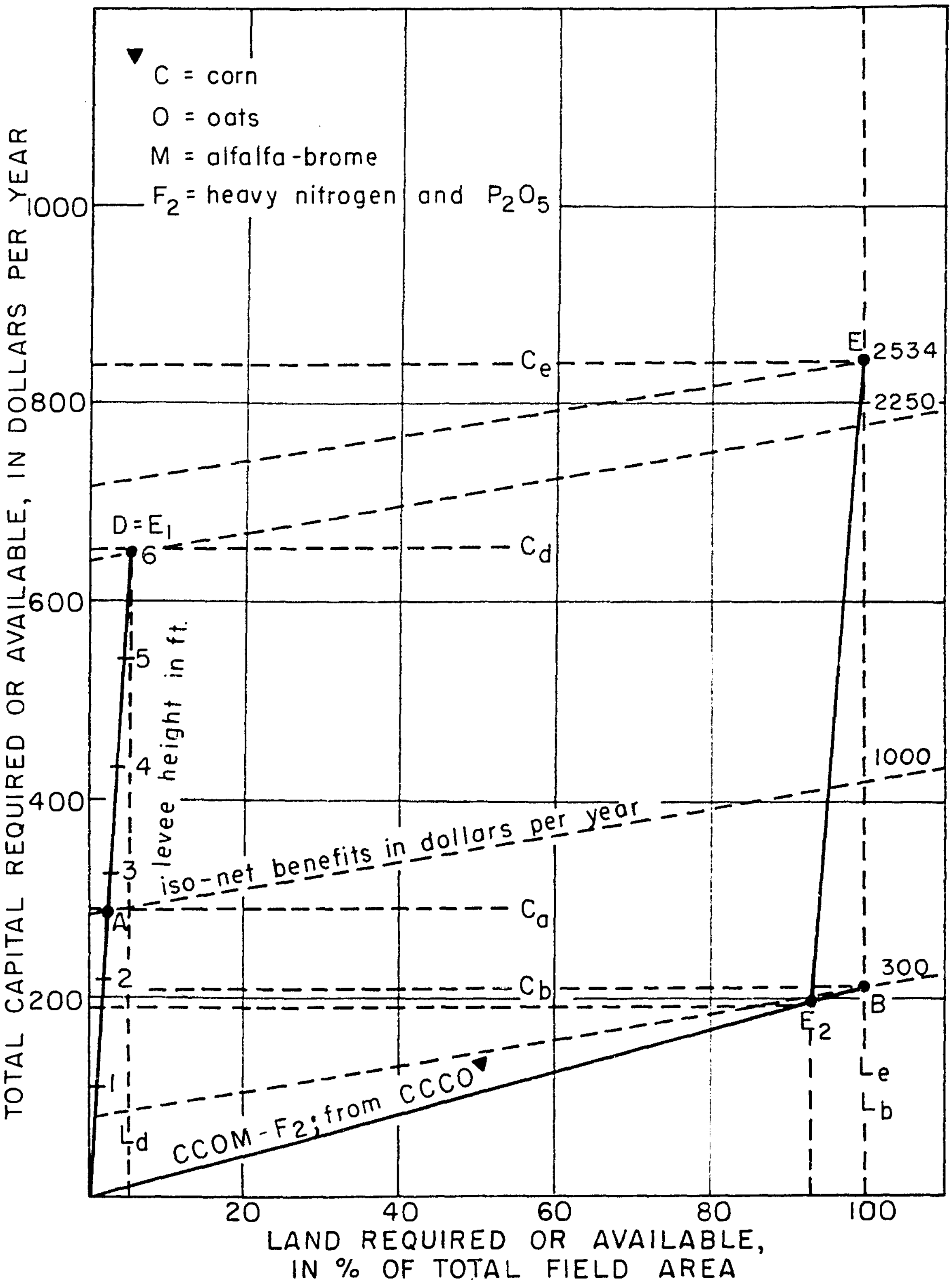

Figure 14. Optimal land use changes for various capital outlays and land requirements of structures.

of land treatment within various sectors of the watershed and structure capacities maximizing aggregate discounted net benefits. In terms of Table 19 and the illustrated programming concepts, an optimal intensity of land treatment would be indicated by optimal levels of the activities designated P_j (j = 1, 2, . . . 47), and optimal structure capacities by optimal levels of P_j (j = 48, 49, 50). And since the unit level benefit-cost data of the columns a_j, c_j, and d_j of Table 19 are 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 simultaneously specifies patterns of watershed land use, combinations of program purposes, and participant-distributions of benefits and costs consistent with optimal development programs. Thus the major problems of project formulation involving project feasibility, scale, selection of alternative improvement measures; and the distributive problem of assigning costs can be resolved within a linear programming framework.

A Planning Application to the Nepper Watershed

Devising alternative optimal programs

If program costs measured as the present value of all immediate and deferred outlays were only of interest in computing discounted net benefits and assigning costs among beneficiaries, rather than also influencing planning decisions, the treatment activities P_j (j = 1, 2, . . . 50) of Table 19 could be combined subject only to the land area and structure capacity restrictions P_j (j = 51, 52, . . . 80). Except in cases where field areas also served 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 could unequivocably be selected as that yielding maximum net benefits per acre treated. The programming problem would then be confined to structure sites and the relevant non-capital limitations. Despite this approach being instructive in specifying maximum justified expenditures, and appropriate where development funds could be presumed unlimited, it ignores the more general and interesting problem of allocating limited outlays.

To illustrate project formulation under conditions of both limited and unlimited capital, the Nepper application of programming combines activities with reference to ratios of net benefits per unit of capitalized cost; designated as the d_j values in Table 19 for each activity if considered independently. The d_j ratio for P_4, for example, indicates that an optimal program for a capitalized expenditure limited to \$9.60[12] would involve adoption of continuous meadow on field 2-1 and provide net benefits of \$280.95.[13] No other listed activity would provide net benefits equal to this amount if funds were limited to \$9.60, because no d_j values exceed the \$29.26 ratio for activity P_4.

If \$10.60 rather than \$9.60 were taken as the permissible capitalized expenditure, the added dollar would most economically be

[12] The expenditure of \$9.60 is given as the annual equivalent of \$185.56 in present value terms.

[13] See Table 17 for the distribution of benefits and costs among private farmer beneficiaries, and Monona County as the benefiting public interest.

allocated to P_{17} having a marginal rate of return of \$22.35. An optimal program would then involve continuous meadow on field 2-1 (the prior activity P_4 at its unit level) and a shift from continuous corn cropping to a COMM rotation joint with terracing-contouring[14] and moderate fertilizing on about 12 percent (1/2 acre) of field 4-4 (activity P_{17} at a level of 0.12121). Net program benefits would be a maximum of about \$303 [= 1(\$280.95) + 0.121(\$184.44)] for the total outlay of \$10.60; marginal net benefits a maximum of \$22.35; and the average net benefit-cost ratio a maximum of \$28.55 [= 1(\$29.26) + 0.121(\$22.35)] or \$303/\$10.60 .

The same principles of optimal program formulation apply to expenditures successively greater than \$9.60 and \$10.60, except that at higher capital levels marginal benefit ratios applicable to substitutions among activities as well as the independent d_j ratios of Table 19 possibly control programming decisions. A maximum justified program expenditure is then given by the outlay involved when an added increment of expenditure in terms of capitalized cost will return less than an equal increment of discounted benefit, or when marginal discounted net benefits are zero. Although a maximum justified expenditure determined in this manner is equivalent to that corresponding with an initial assumption of unlimited capital, the intermediate optimal programs for any capitalized outlay permit evaluation of any recommended or installed

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[14]Note in Figure 11 that only 38 percent of field 4-4 is terraceable. Where activities of Table 19 denote terracing, the corresponding benefit-cost data assume proportional terracing on terraceable portions and contouring on non-terraceable portions. Thus 0.12(38) = 4.5 percent would be terraced and 0.12(62) = 7.5 percent contoured.

program with regard to the criterion that discounted net benefits be maximized. Following application of the procedure, two alternative patterns of resource use evaluated on this basis are (1) that represented by the land treatment recommended and structures actually installed in the 1948 Little Sioux Program for the Nepper Watershed; and (2) that represented by current (1957) land use in the watershed and the existing Little Sioux structures. The first evaluation, for example, essentially involves specification of an optimal development program requiring the total annual equivalent outlay of $3,706 noted in Table 12 as expended in the Little Sioux Program; followed by estimates of discounted net benefits foregone by the non-optimal combination of land treatment and structural activities.

The simplex method of solution[15]

The mathematical method employed to combine the 50 land and structural treatment activities (P_j; j = 1, 2, . . . 50) of Table 19 subject to the 31 planning restrictions (P_j; j = 51, 52, . . . 81) is basically the "simplex" solution, whereby an optimal combination is derived through a series of successive approximations, or "iterations." The method accounts for the possibility that benefits could be maximized without all planning restrictions being precisely met by defining non-treatment of susceptibly treated fields, non-installation of permitted structure

[15]For details of the method in agricultural applications see James N. Boles. Linear programming and farm management analysis. Journal of Farm Economics. 37:1-24. 1955; or Earl O. Heady. Simplified presentation and logical aspects of linear programming technique. Journal of Farm Economics. 36:1035-1042. 1954.

capacities, and capital non-use as artificial or "disposal" activities. The programming problem consists then of determining optimal percentages of each field treated by respective land treatment activities, the percentage possibly not treated (or farmed by the predevelopment land use system), installed and non-installed structure capacities, and unused amounts of available development capital; where optimal refers to levels of both "real" and "disposal" activities resulting in a net benefit maximum.

By implication the unit level of non-treatment for each of the 27 watershed fields designated as P_j (j = 51, 52, . . . 77) in Table 19 is retention of predevelopment cropping and tillage methods on 100 percent of the respective field area. The unit levels of the structure capacity disposals designated as P_j (j = 78, 79, 80) are 1,000 cu. yds. of earth fill not installed in structural measures II and IV, and 1 foot of levee bank height not installed for measure III; while the unit level of the capital disposal activity P_{81} is $1.00 of capital unused. Since leaving field areas untreated, not utilizing permitted structure capacities, and not utilizing available capital do not directly increase net benefits, values of c_j for all disposal activities P_j (j = 51, 52, . . . 81) remain at zero and their values of d_j are initially zero.

The addition or substitution of activities in descending order of opportunity net benefits to capital $(-\alpha_j)$[16] rather than marginal net

[16]Opportunity net benefits to capital $(-d_j)$ are defined as the net benefit foregone per unit of capital not diverted to activity P_j, meaning that for each dollar not initially allocated to activity P_4 in Table 19, $29.26 in discounted net benefits are foregone.

benefits foregone per activity unit[17] not added ($OC_j - c_j$) employ a variation of the simplex procedure proposed by Candler.[18] In this procedure capital expenditures involved in successive programs are determined by the respective levels of capital-using activities permitted only by other limiting resources, rather than levels permitted by specified amounts of capital and other resources. Each successive program is optimal in that total (and average) discounted benefits for the determined expenditures are maximized. A maximum justified expenditure and maximum net benefits are given when the land area and structure capacity supplies are exhausted; indicating that because of these restrictions, an added increment of expenditure cannot increase net benefits.

Results for the Nepper Watershed

These are discussed in order of variable-capital programming being useful in planning watershed projects of (1) a limited scope because of severe capital or other restrictions; (2) an expanded scope as increased but still limited outlays are considered; and (3) a scope limited only by the availability of resources other than capital or by

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[17] Marginal net benefits (or marginal return) foregone per unit of P_j not added are computed from ($OC_j - c_j$), where OC_j is the addition to net benefits if activities other than P_j were added in place of one unit of P_j; and c_j is the net benefit per added unit of P_j as listed in Table 19. Values of ($OC_j - c_j$) in the initial programming matrix are all ($-c_j$) because all resources are in disposal or non-use.

[18] Wilfred Candler. A modified simplex solution for linear programming with variable capital restrictions. Journal of Farm Economics 38: 940-955. 1956.

technological restrictions. Limited projects for the Nepper Watershed (with 1947 as the planning date or benchmark year) are given as including activities termed "critical" in providing aggregate development benefits, whether promoted on upland or bottomland areas. Descriptive advantages of programming in indicating optimal land use conditions, damage reductions, and degrees of hydrologic control corresponding with net benefit maximization are illustrated both for projects of limited and expanded scope. A project of the latter type is described in terms of watershed land use conditions and damage reduction benefits corresponding with optimal reallocation of the $3,706 annually expended in the Nepper Watershed (Table 12) if the land treatment measures as well as structural activities proposed in the 1948 Little Sioux Program were fully installed.[19] Finally discussed is a project for the Nepper Watershed in which aggregate net benefits are maximized with expenditure restricted only by the condition that marginal discounted benefits not be exceeded by marginal discounted costs. Elements of this program in terms of optimal land treatment activities, structural activities, and gully or flood damage reduction are given in some detail. Its described physical character is followed by a distribution of benefits and costs (as proportionally assigned) among the seven on-site farm units, Monona County as an on-site public unit, and the immediate downstream area as an additional public interest.

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[19]The estimate of $3,706 is selected in preference to those of Gertel and the Missouri Basin Survey Commission only because it is derived from the same input-output evaluations (of this study) upon which the programming analysis is based.

Critical treatment activities

In the ordinary terms of watershed protection, these are frequently recommended as land use changes or structural improvements probably most effective in reducing specified types of damage. In this study, however, the critical nature of treatment activities is supposed given by relatively extreme marginal rates of return in providing aggregate benefits, the latter including increased crop values and decreased farm production expense as well as reduction of all damages associated with watershed land use. Two types of critical activities 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 income under conditions where overflow volumes were less than completely eliminated.

Upland treatment. Activity P_4 on field 2-1 in Table 19, previously noted to yield marginal discounted benefits of $29.26 per unit of capitalized expenditure, would appear to have first priority in a comprehensive development program for the Nepper Watershed, providing $290.55 ($280.95 + $9.60) in total annual benefits for the annual equivalent outlay of $9.60. The multiple annual benefits derived from shifting the 6-acre field from continuous corn to continuous meadow are shown in the last column of Table 15, indicating the major benefit to be an increased crop income of $130 on the watershed floodplain resulting from the 1.50 ac. ft. reduction in average annual overflow. Also significant, however, are $101 in increased crop income and $26 in decreased operating expense on the field itself, the former constituting the difference between an annual gross income from hay of $255 and a gross income from corn of $154. Monona County would benefit from the 1.50 ac. ft. reduction in average annual runoff to the extent of $30.91 saved in costs of bridge maintenance or periodic replacement; while gully control benefits of $1.47 accruing to farms 2, 3, 4, and 6 are minor.

For an additional annual outlay of $8.25, activity P_{17} on field 4-4 returns $184.44 in annual net benefits, or $22.35 per unit outlay, and can also be termed a critical activity. Adoption of a COMM-terrace-fertilizer system on this 4.5-acre field is associated with $90 in increased crop income from the field, an $81 reduction in floodplain crop damage (from a 0.93 ac. ft. reduction in annual floodplain overflow), and an annual saving of $19.40 in maintenance of the Monona County bridge. Gully control benefits are minor at $2.11, yet considerably greater than the $1.47 amount for activity P_4 above.

A limited program comprised of the two activities at their 100 percent levels would reduce the watershed area annually in corn or its equivalent[20] from the predevelopment (or 1947) percentage of 53.06 to 52.91; increase the watershed area in oats to 19.66 from 19.52 percent; and increase the area in meadow to 29.00 from 27.42 percent. These cover changes combined with 1,013 feet (1.69 acres) of terraces on field 4-4, 2.8 acres of field 4-4 contoured, and the total 4.5 acre area of 4-4 fertilized moderately would reduce average annual predevelopment

[20]Cover conditions on farmsteads and roads are, for runoff determination and damage evaluation purposes, assumed equivalent to continuous corn cropping with no contouring or other practices.

gully damage of $101 in the main drainage by 3.54 percent; maximum floodplain crop damage of $2,803 by 7.40 percent; bridge damage of $385 by 12.78 percent; and off-site flood damage of $140 by only 0.02 percent. Annual damage reduction benefits of $265.48 added to $218.59 in increased crop income on the fields thus treated would total $484.07, annual costs would total $17.85, and net program benefits would be a maximum of $466.22 for the equivalent annual outlay of $17.85.

Floodplain treatment. If the two upland treatments (activities P_4 and P_{17}) discussed above were ignored as means of obtaining development benefits, a land use shift on the floodplain field 7-4 from a predevelopment rotation of CCCO to continuous meadow moderately fertilized (activity P_{47}, Table 19) would be the most critical treatment, by returning marginal discounted net benefits of $19.10 per unit of capitalized outlay. These benefits accrue from an adjustment to predevelopment overflow volumes rather than their reduction. Referring to Figure 8, average annual net income associated with a corresponding average annual overflow volume of 32 ac. ft. on the 41.6-acre area is -$284, or -$6.50 per floodplain acre with a predevelopment CCCO rotation (point A on the CCCO-F_o curve). Net income is about $1,060, or $25.00 per floodplain acre with permanent meadow (point A on the MMMM-F_1 curve). Shifting the floodplain to permanent meadow thus increases net income by about $1,344 ($1,060 + $284), or by $31.50 per floodplain acre, without any reduction in average annual overflow or acreages flooded to various depths. The equivalent annual outlay of $70.30 required to promote the adjustment on the 41.6-acre field is computed by amortizing a $1,287 present value of a $258 immediate and periodic (every 4 years) investment in pasture establishment over the 50-year project period at the private interest rate of 5 percent.

If the critical upland treatments were not ignored, however, the described floodplain shift to continuous meadow ranks as the third treatment activity given priority, since with average annual overflow reduced only 7.40 percent by upland treatment (or to 29.96 ac. ft. from 32.36 ac. ft.), no other floodplain cropping system is more profitable than permanent meadow. Figure 8 indicates that the average annual overflow volume would necessarily be reduced to 9 ac. ft. to justify a shift to heavily fertilized continuous corn rather than continuous meadow, and that overflow would necessarily all but be eliminated to justify retaining the predevelopment CCCO system or shifting to remaining alternatives in preference to continuous meadow.

The slightly expanded program comprised of the two upland treatments (activities P_4 and P_{17}) at their 100 percent levels and the floodplain shift to meadow (activity P_{47}) at its 100 percent level would then be described as reducing the watershed area annually in corn from the predevelopment percentage of 53.06 to 46.46, decrease the area in oats to 17.51 from 19.52 percent, and increase the area in meadow from 37.61 to 27.42 percent. No additional area would be contoured or terraced, and no additional reductions in gully damages, bridge damage, or off-site flood damage would result. If upland treatments are credited with their maximum benefits in reducing floodplain crop damage, annual damage-reduction benefits of $1,680.67 added to $218.59 in increased crop income on the three fields treated (2-1, 4-4, and 7-4) would total $1,898.43, annual costs would total $88.15, and net benefits would be a maximum of $1,810.28 for the outlay of $88.15.

Intermediate optimal programs

Though not described in detail for each farm or field these relate to optimal allocations of specified annual outlays ranging between $88.15 for the program above involving activities P_4, P_{17}, and P_{47}, and a maximum justified annual outlay of $5,716 approximated by the simplex method of programming.

Optimal land use conditions. The relation of Nepper Watershed cover conditions and adoption of conservation practices to the maximization of discounted net benefits is shown in Figure 15 with regard to any annual outlay. As the previous discussion of critical activities indicated, the watershed area in corn and oats would decline and the area in meadow increase if development capital were severely limiting. At higher capital levels also, however, optimal cover conditions are dependent on the optimal intensity of associated conservation practices or installation of structures. The programming analysis indicates in Figure 15 that if an annual outlay of $1,340 rather than $360 were being allocated to maximize aggregate net benefits at $3,913 rather than at $3,537, the watershed area in corn could be increased to 53 percent from 44 percent, the area in oats unchanged, and the area in meadow decreased to about 30 percent from 39 percent; with the increase in corn made feasible by construction of a 4-foot levee to protect the watershed floodplain from overflow volumes only partially reduced by upland treatment activities. The corn increase involves substitution of a protected continuous corn cropping system for the continuous meadow adjustment to the initial annual overflow of 32 ac. ft. Since neither terracing nor contouring are feasible treatment activities on the floodplain, and no added fertilization (in area terms) is involved in the change, the respective curves of Figure 15 evidence plateaus between annual outlays of $360 and $1,340.

As progressively higher outlays are assumed, further increases in the corn acreage are chiefly associated with increased application of fertilizer and additional terraces. Alternate increases and decreases in corn, oats, and meadow percentages between annual outlays of about $4,000 and the maximum justified outlay of $5,716 are in general explained by treatments yielding maximum benefits per acre being substituted for those yielding maximum returns to capital.

Optimal damage reduction. While Figure 15 describes the physical character of optimal programs in terms of watershed land use patterns, Figure 16 indicates the effectiveness of watershed treatment measures in treating specified classes of potential damage and, to some degree, the sources of maximum aggregate net benefits again plotted against annual outlays. The diagram is also useful in noting which watershed fields or sectors are 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 multi-purpose nature of the critical upland treatment activities reviewed above; and indicates

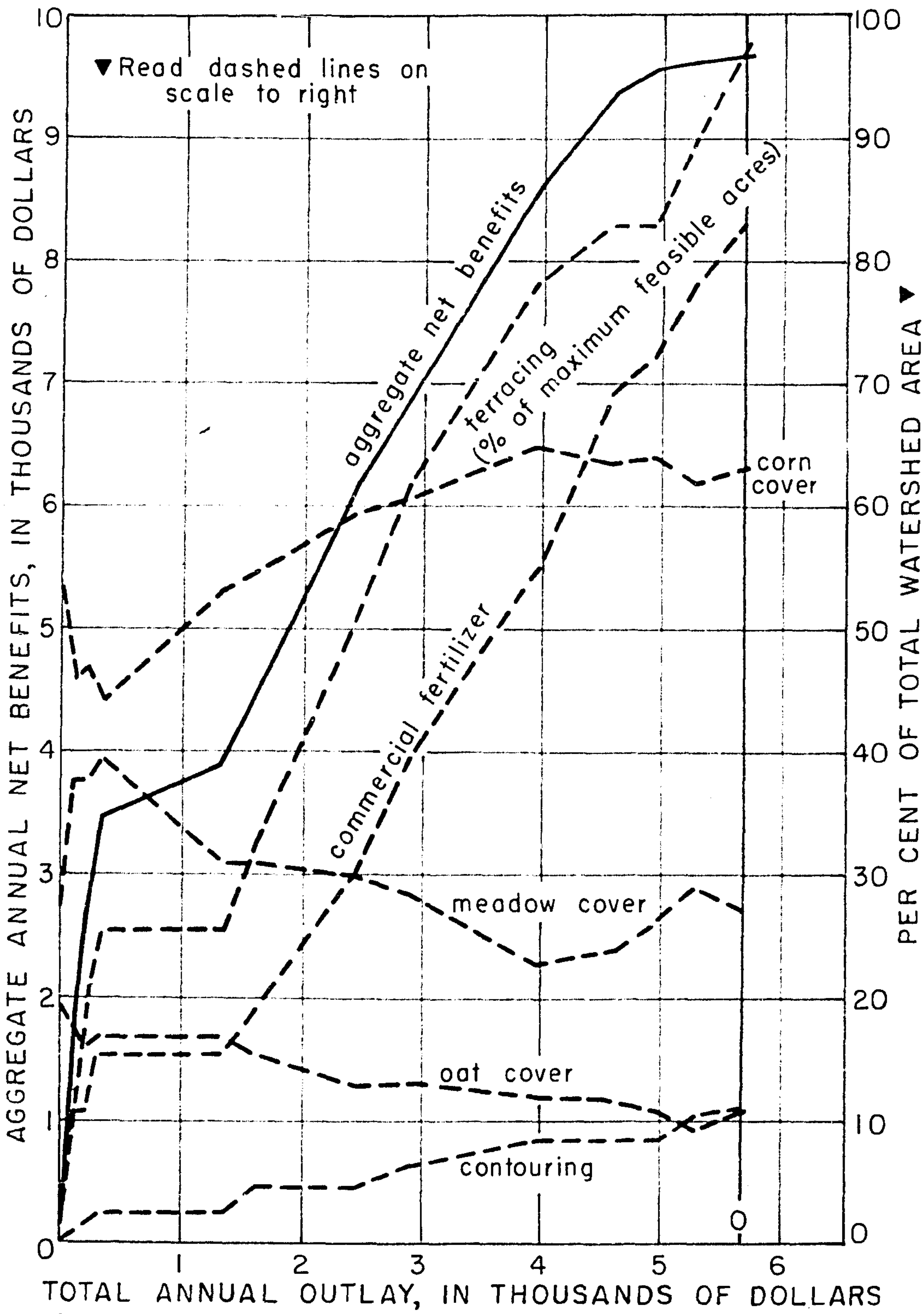

Figure 15. Watershed cover conditions and land use practices consistent with optimal development programs.

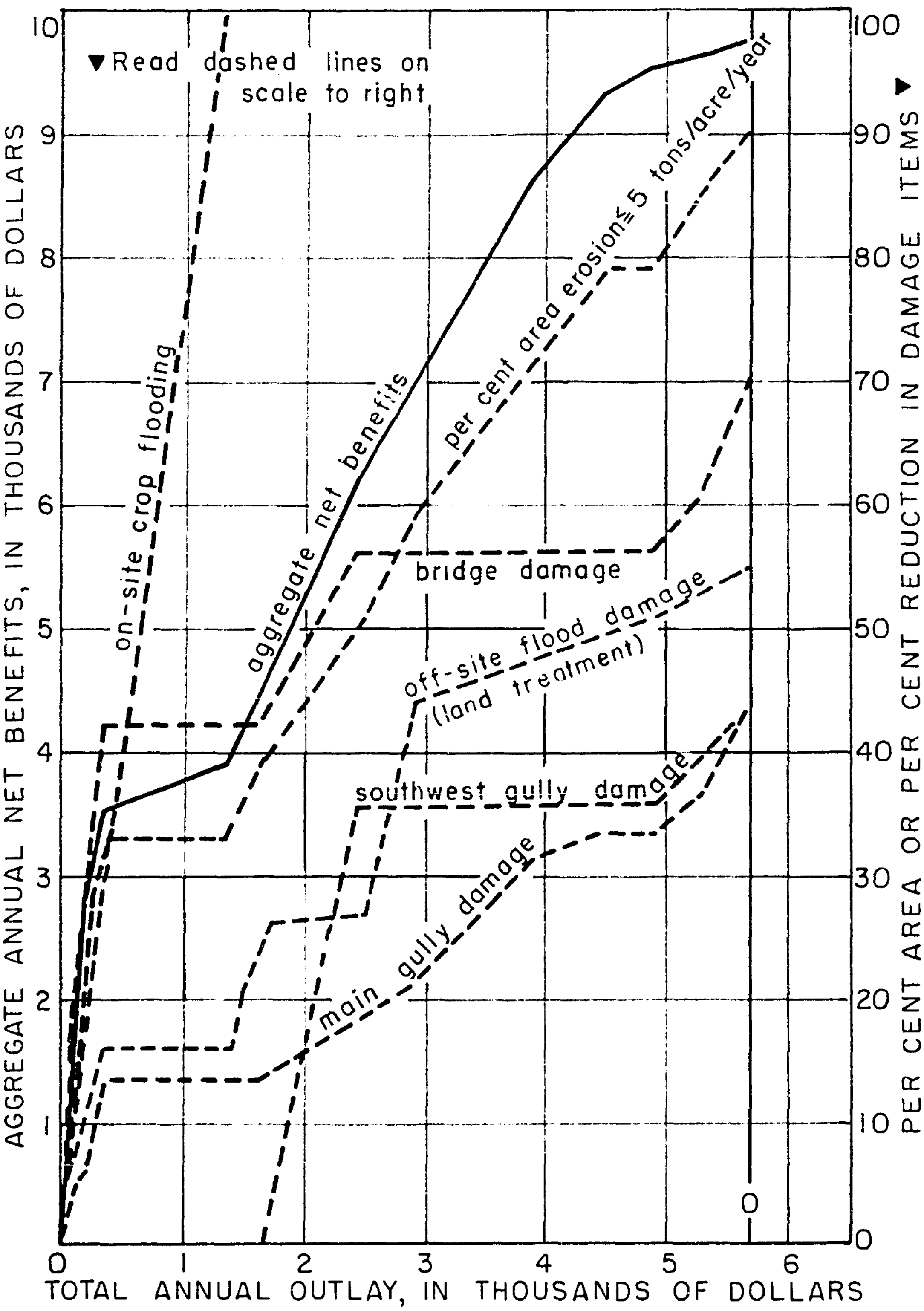

Figure 16. Reductions in damage consistent with optimal development programs.

that they must involve fields located within sector MFBO (in Figure 11 a source-area for all damages other than gully damage in the southwest drainage). Also, a minimum program expenditure of $1,600 required to provide any gully control benefits in the southwest drainage indicates that predevelopment land use systems would be retained on fields 5-2 and 6-7 (in Figure 11) if expenditure of any lesser amount were considered, since any treatment of these areas provides gully control benefits. For annual program outlays ranging between $2,460 and $4,907, gully control in the main drainage, off-site flood control, erosion control, and increased source-area productivity are purposes emphasized to the exclusion of gully control in the southwest drainage and control of flood damage to the Monona County bridge.

Figure 16 moreover establishes the dependence of critical treatment activities on benefits derived through control of on-site crop flooding. Floodplain crop damage is entirely eliminated with optimal allocation of a $1,340 program outlay, $982 of this amount ($1,340-$350)[21] financing construction and maintenance of the 4 ft. levees and a simultaneous shift in floodplain land use to continuous corn.

A final interpretation of Figure 16 considers degrees of hydrologic control corollary with economic allocations of available outlays. With the various classes of damages shown initially evaluated as directly proportional to selected hydrologic variables, damage reductions plotted as percentages of predevelopment amounts apply to these variables as

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[21] The latter amount ($350) is approximated in Figure 16 as the outlay corresponding to the point where control of main gully damages first reaches a temporary maximum, because levee construction provides no gully control benefits.

well as to corresponding monetary benefits. Allocation of a $3,000 annual outlay to provide maximum net benefits of about $7,100, for example, requires that the predevelopment runoff index of 52 in the main drainage (the index for A in Figure 3) be reduced by 23 percent to 40; and that in the southwest drainage by 36 percent from 46 (the index for A in Figure 4) to 29 to achieve the respective reductions of 23 and 36 percent in average annual gully damage. Similarly, average annual flood runoff damaging the bridge would necessarily be reduced 56 percent (from 18.71 ac. ft., Table 6) to 8.23 ac. ft.; and net watershed runoff associated with watershed land use and off-site flood damage by 45 percent (from 43.00 ac. ft., Table 6) to 23.65 ac. ft.[22] Sheet erosion would be controlled on about 60 percent of the watershed area and average annual overflow (32.36 ac. ft., Table 6) eliminated, the latter being achieved with a program outlay of $1,340 as noted above.

An optimal Nepper Watershed Little Sioux Program. In effect this involves programming the equivalent annual outlay of $3,706 estimated expended for Nepper Watershed improvements (Table 12) recommended or installed in 1948; with major features of such a program in terms of watershed land use and damage reduction determined from Figures 15 and 16. Whereas land treatment recommended in 1948 would reduce the watershed area annually in corn or occupied by farmsteads and roads from 46

[22] The off-site flood damage reduction curve of Figure 16 applies only to reductions attributable to land treatment activities. Net watershed runoff with an optimal allocation of $3,000 would actually be about 55 ac. ft., or increased by 27 percent over 43 ac. ft., because the 4-ft. levees would divert 38 ac. ft. of overflow otherwise flooding the on-site floodplain into the Maple River.

to 53 percent, the programming analysis suggests an increase to 64 percent (refer to Figure 15 for an outlay of $3,700). The watershed area annually in oats would be increased to 23 percent from 19 percent with the Little Sioux recommendations adopted, and decreased to 12 percent on the basis of the programming analysis. Contrasting meadow percentages are an increase to 31 percent from 29 percent with the Little Sioux recommendations, and a decrease to 24 percent suggested by programming. Also, Figure 15 indicates that programming the annual outlay of $3,706 would result in nearly 75 percent of the total watershed area feasibly terraced (295 acres) being terraced, 8 percent of the watershed cropland of 436 acres contoured and 52 percent of the cropland fertilized. Contouring of 62 percent of the watershed cropland was the major practice recommended in 1948.

While the program suggested in 1948 would have reduced annual sheet erosion rates to below 5 tons per acre on 27 percent of the watershed area, an optimal allocation of the $3,706 annual outlay involved would reduce sheet erosion to below a 5-ton level on 70 percent of the watershed area (see Figure 16), reduce gully damage in the main drainage by about 30 percent, gully damage in the southwest drainage by 36 percent, bridge damage by 56 percent, and on-site crop flooding by 100 percent. Despite watershed land treatment reducing off-site flood damage by 48 percent, average annual net watershed runoff of 43 ac. ft. and predevelopment off-site flood damage of $140 on balance would (by levee diversion of overflow) be increased 43 percent under an optimal allocation of $3,706. Largely because of extensive structural improvements (including levees) installed, all on-site flood and gully damage would be eliminated by the proposed 1948 Little Sioux Program, and off-site flood damage (again by levee diversion of overflow) increased about 11 percent. With reference to major program components, installation outlays, and annual benefit-cost data, the 1948 recommendations and results of programming an annual outlay of $3,706 are compared in sections III and IV of Table 12.

An optimal Nepper Watershed program with capital non-limiting

If 1947 planning in the Nepper Watershed could have proceeded without regard to capitalized outlays involved in promoting the various land treatment and structural activities of Table 19, a project formulated by the methods of this study would return aggregate annual gross benefits of $15,384, involve a comparable annual outlay of $5,716 and net $9,668 in the aggregate. Aggregate benefit-cost functions[23] generated by the variable capital programming procedure are shown in Figure 17. Reading vertically at $5,716 on line 0, the above estimates of annual costs and benefits are given on the left axis. Also plotted (on the right axis)

[23] The curves are plotted from observations at selected iterations in the programming solution. As the slopes of the aggregate benefit curves indicate, marginal benefits are not maximized in the outlay range from $360 to $1,340. This results from crediting upland treatment (at outlays less than $360) with maximum flood control benefits from reduction of floodplain overflow as if such benefits could be obtained independently of actual floodplain land use. Only in the outlay range from $360 to $1,340 (at a cost of $980) does floodplain use shift to the system otherwise subject to maximum flood damage. This is also the range where 4-ft. levees are built to eliminate remaining overflow. The corresponding marginal net benefit ratio curve of Figure 17 is drawn, however, to reflect the interdependence of upland overflow reductions and floodplain land use shifts in obtaining flood control benefits.

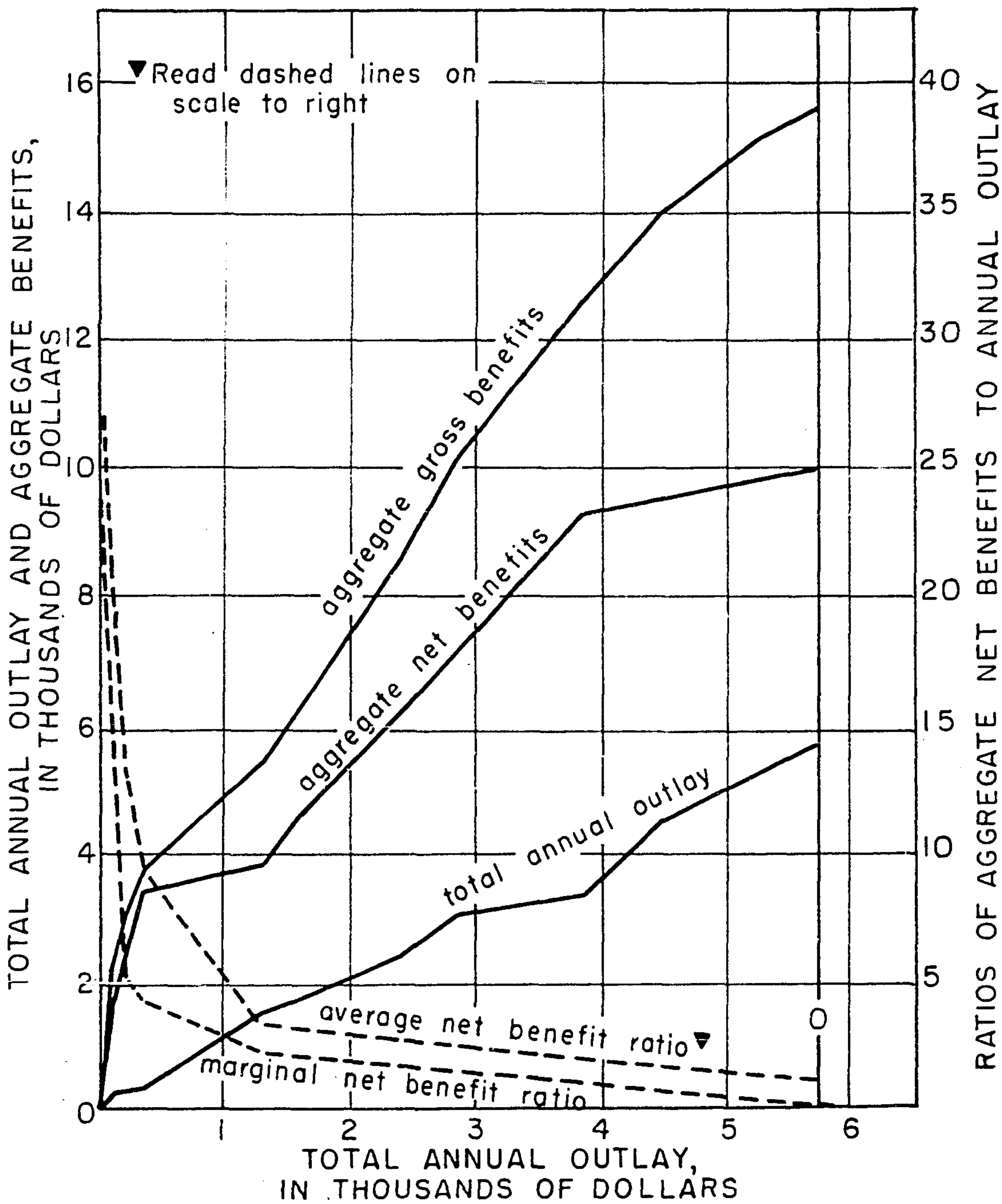

Figure 17. Benefit-cost aspects of optimal development derived through linear programming.

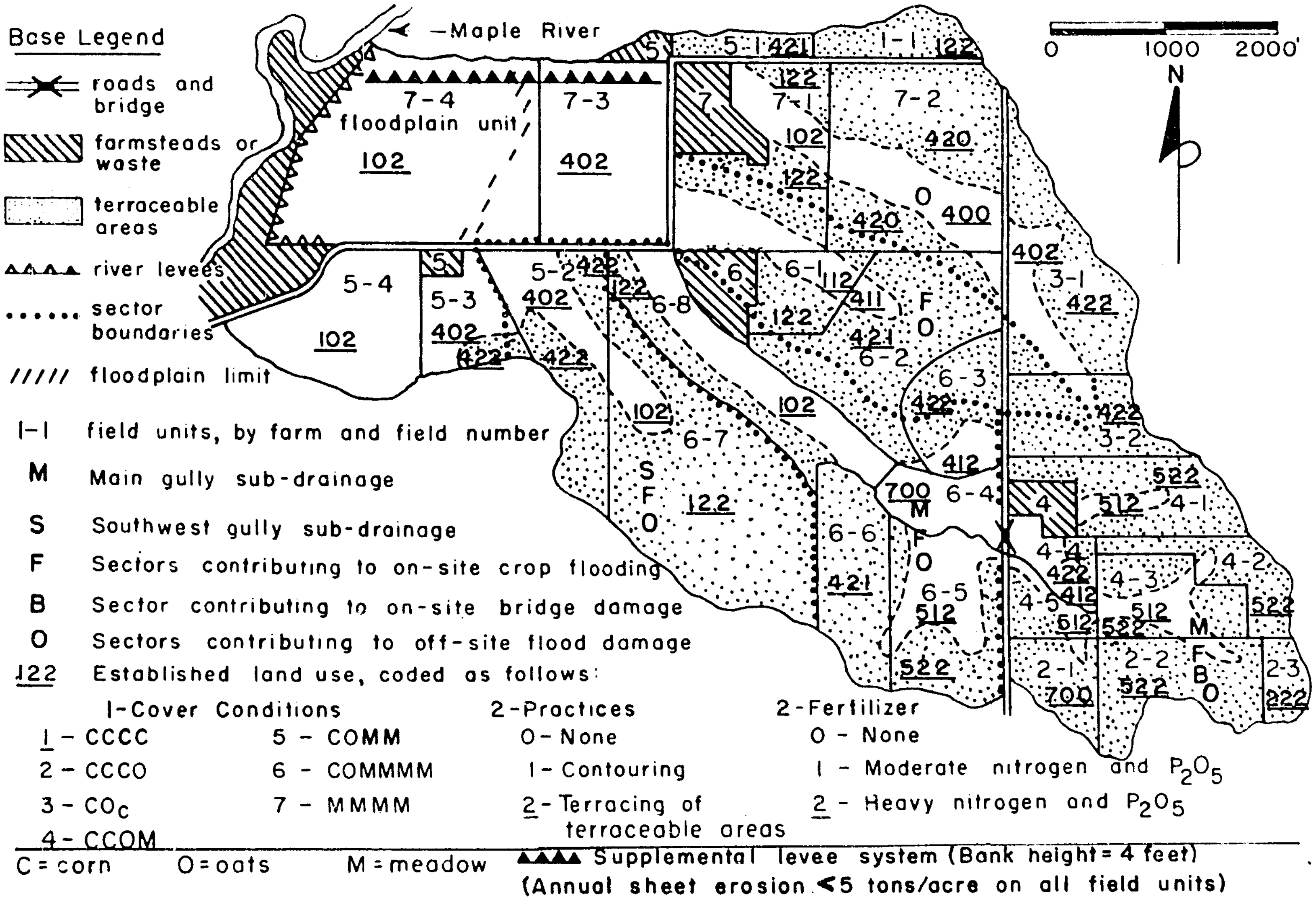

Figure 18. Optimal development in the Nepper Watershed; land use systems and supplemental levee construction.

are corresponding average net benefit ratios (discounted net benefit per dollar of capitalized cost), and marginal net benefit ratios (incremental discounted net benefit per incremental dollar of capitalized cost). At the maximum justified expenditure of $5,716, the average net rate of return on the present (1947) dollar value of committed resources is $1.69, and the marginal rate of return zero;[24] the latter indicating an optimal combination of the 50 treatment activities (P_j; j = 1, 2, . . . 50) of Table 19 with reference to non-capital planning restrictions. Additional net benefits are in effect not limited by the availability of capital, but by the availability of a larger watershed area (or more fields) susceptible of treatment, complete elimination of flood damage to on-site crops and, to some degree, by the limited range of treatment activities programmed.

Land treatment activities. The activities of Table 19 representing optimal land use in the Nepper Watershed corresponding with net program benefits of $9,668 and an annual outlay of $5,716 are mapped in Figure 18. Of the systems shown, only P_{42} (402 on field 7-3) and P_{43} (102 on field 7-4) would be adopted at less than their unit levels[25] or on less than

[24]Average net benefit ratios are converted to gross ratios of benefits to costs (the project ratio commonly given) by adding 1.00 to net ratios; and marginal net ratios are converted to gross ratios of marginal benefits to costs (ratios commonly not given) by adding 1.00 to net ratios. Thus at the optimal outlay of $5,716, total discounted benefits per unit of capitalized cost are $2.69 and incremental total benefits per incremental dollar of capitalized cost are $1.00.

[25]In cases where terracing or contouring are not necessary on certain field portions because of flat slopes, two systems may be **indicated.** The benefit-cost data of Table 19 are adjusted for these composite cases, however.

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 be required as the site of levees about 4 feet in height (activity P_{49} at 3.97 feet).

As indicated along 0 at an outlay of $5,716 in Figure 15, complete adoption of the land use pattern of Figure 18 over that given in Figure 11 for 1947 would increase the watershed area annually in corn to 63 percent from 53 percent; decrease oats to about 10 percent from 20 percent; and leave the proportionate area in meadow essentially unchanged at 27 percent. Also, level terraces of 2-inch runoff retention capacity per storm would be profitably installed and maintained on nearly 98 percent of the terraceable (stippled) watershed area; with about 11 percent of the 480-acre watershed contoured and 83 percent receiving applications of commercial nitrogen and phosphorus, 60 acres at moderate rates and 340 acres at heavy rates.

The cover changes combined with the 36 miles of terraces on 288 cropland acres, contouring of 52 acres, and fertilization of 400 acres would reduce predevelopment watershed damages in the proportions indicated along 0 at the $5,716 outlay in Figure 16; that is, sheet erosion controlled on 90 percent of the watershed or all cropland,[26] gully damage in both the main and southwest drainages reduced by 43 percent, flood damage to the Monona County bridge reduced by 70 percent, and off-site flood damage reduced 55 percent by on-site land treatment.

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[26] Erosion rates would remain at the predevelopment average of 29 tons per acre per year on farmsteads totaling 15.3 acres, and at 72 tons per acre per year on the road area of 29 acres.

About 24 percent of the flood control benefits accruing to the on-site floodplain (and farm 7) are also creditable to upland cover changes and related conservation practices. The same percentage reductions apply to the hydrologic variables modified by land use changes. Annual runoff of 18.71 ac. ft. previously affecting the Monona County bridge would be reduced by 70 percent, net watershed runoff reduced 55 percent by land treatment, and floodplain overflow by about 24 percent.

With particular reference to gully control, the effect of land treatment in the main drainage on the index of runoff characteristics, rate of peak 10-yr. flow, rate of land destruction, and average annual damage can be traced through Figures 3, 5, and 6. A 43-percent reduction in the runoff index from 52 (the index for A in Figure 3) to 30 (the index for the optimal program being discussed) reduces peak discharge rates of 10-yr. recurrence from 215 cu. ft. sec. to 66 cu. ft. sec. (line O). On the curve for the main drainage in Figure 5, the reduction of the index to 30 (and peak flow to 66 cu. ft. sec.) correspondingly reduces the average annual rate of land destruction from 0.133 acres to less than 0.04 (from line A to line O). And in Figure 6, reduction of the index from 52 to 30 is shown to reduce average annual damage in the main drainage from $101 to $57, a reduction of 43 percent (from line A to line O). The effect of a 43-percent reduction from 46 to 26 in the southwest drainage runoff index can similarly be traced through Figures 4, 5, and 6.

An initial outlay of $6,309 required to finance 36 miles (288 acres) of terrace construction and periodic re-establishment of 12 acres of permanent meadow is seen in Table 20 below to represent 55 percent of the funds required to install the program. On an annual basis, however, land treatment activities are by far the major program component, contributing 92 percent of aggregate benefits and involving 92 percent of all costs. Moreover, nearly 74 percent of annual program benefits (column 4) result from increased crop production on treated fields, aside from associated damage reductions there or elsewhere.

Structural improvements. The only structural component of an optimal Nepper Watershed project formulated by programming the activities of Table 19 is activity P_{49} at a program level of 3.97, designating supplemental levees (in Figure 18) built to a height of 3.97 feet. Though the main and southwest structural measures (activities P_{48} and P_{50}) are initially evaluated as respectively providing $53.46 and $68.90 in net benefits per installed 1,000 cu. yds. of earth fill, these benefits are largely of a flood control (for on-site crops) nature, and thus dependent on non-elimination of the damage by other activities. Consequently, with levees and effective upland treatments superseding the two remaining structural measures as program elements maximizing aggregate net benefits, the latter are re-evaluated ignoring flood control benefits properly credited if not already eliminated. On this basis, respective gully control benefits of $3.30 and $2.50 per installed unit of measures II and IV in Table 7 are far less than corresponding unit costs of $55.10 and $106.79 in Table 8, rendering the measures infeasible as means for obtaining additional net benefits.[27]

[27] Similar reasoning is applied in reappraising land treatment measures installed in sectors denoted by F in Figure 18, results

Table 20. Installation outlays, benefits, and costs of optimal development in the Nepper Watershed; distributed by major components

Benefit and cost items	Program components: Land treatment (dollars)	Program components: Structures (levees) (dollars)	Total program (dollars)	Program percent
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; on-site crops	2,523	1,141	3,664	23.80
Flood control; on-site bridge	273	0	273	1.77
Flood control; off-site	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; off-site	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 costs	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 off-site flood damage associated with diversion of on-site overflow into the Maple River by levees is included below as an annual cost.

Benefit-cost data pertinent to 4-foot levees as the only structural improvement required for optimal development in the Nepper Watershed are compared in Table 19 with the land treatment activities of Figure 18. While involving roughly 45 percent of initial outlays, levee construction contributes 8 percent of all benefits, 31 percent of the flood protection given the watershed floodplain, and 100 percent of the $125 only increase in annual damage (off-site flooding) permitted by the program. Despite its causing $125 in increased downstream damage charged to the benefiting on-site farmer (farm 7), the levees are a justified structural activity ranking equally with land treatment in terms of net benefits of $1.69 per unit outlay. Whereas the major factor in zero marginal net benefits to land treatment is complete treatment of all fields to maximize net benefits per acre, zero marginal net benefits to added levee heights are attributable to on-site crop flooding damage being completely eliminated.

Participant benefit-cost distributions. Consistent with the criterion that capitalized activity and project costs be shared by participants in proportion to capitalized benefits, Tables 21 and 22 indicate participant distributions of the benefits and costs incident to optimal development, with data other than initial installation outlays presented on an average annual equivalent basis. The predominantly on-site character of the project is shown in Table 21 by only 0.53 percent

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[27] (Continued from page 177)
indicating that flood control benefits for on-site crops are primarily creditable to treatment of the steep sector MFBO, plus field unit 6-2 with a mean slope degree of about 8 percent.

Table 21. Installation outlays, benefits, and costs of optimal development in the Nepper Watershed; distributed by private and public beneficiaries

Benefit-cost items	On-site			Off-site public	Total public	Total program
	Private[a] (dollars)	Public (dollars)	Total (dollars)	(dollars)	(dollars)	(dollars)
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; on-site crops	3,664	0	3,664	0	0	3,664
Flood control; on-site bridge	0	273	273	0	273	273
Flood control; off-site	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; off-site	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 the last column of Table 22.

Table 22. Installation outlays, benefits, and costs of optimal development in the Nepper Watershed; distributed by private beneficiaries

Benefit-cost items by watershed farms[a]	1 Cassidy (dol.)	2 Daley (dol.)	3 Engleke (dol.)	4 Rossel (dol.)	5 Means (dol.)	6 Nepper (dol.)	7 Ullrich (dol.)	Total Private[b] (dol.)
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; on-site 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; off-site	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 Figure 18 and identified by current (1957) owners.

[b]Transferred to the first column of Table 21.

[c]Includes $2,803 in maximum protection for intensive flood plain use and $861 in permitted intensive use.

of the total benefits ($77) and costs ($29) accruing or charged to downstream areas on the Maple River. Moreover, these result only from watershed land treatment measures; levee construction on balance causes a net decrease of only 1.52 ac. ft. in the net watershed runoff volume of 43.00 ac. ft. estimated under predevelopment conditions, though the increased annual damage of $125 associated with the levees alone is presumed compensated for by farm 7. Monona County as a participating on-site public entity would receive 1.77 percent ($273) of the total annual benefits of $15,384; an amount attributable to land treatment activities in the sector MFBO (see Figure 18) which reduce flood damage at the bridge site. Benefits and costs for the seven watershed farm units are aggregated in the column denoting on-site private beneficiaries, with the distributions for each farm comparably itemized in Table 22.

To emphasize the principle of proportionate sharing of costs, Tables 21 and 22 make no distinction between capitalized recurring expenses and initial installation outlays in arriving at total assignments among various beneficiaries and describing internal features of the program. The ratio of net benefits to costs is thus equivalent at $1.69 for all participants in Tables 21 and 22, and for the components shown in Table 20. Marginal net benefits are correspondingly zero, indicating that under conditions of proportionate cost sharing, net benefits cannot be increased either in the aggregate or for individual beneficiaries by varying the land use pattern of Figure 18 or by building structures other than levees 4 feet in height.

Table 23. Capitalized benefits and costs of optimal development in the Nepper Watershed; distributed by private and public beneficiaries

Benefit-cost items	On-site Private	On-site Public	Off-site public	Total program
	(dollars)	(dollars)	(dollars)	(dollars)
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; on-site crops	66,885	0	0	66,885
Flood control; on-site bridge	0	7,742	0	7,742
Flood control; off-site	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; off-site	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

By techniques illustrated in Table 15, the program data presented as annual equivalents in Table 21 are resummarized as capital values in Table 23, using a private discount rate of 5 percent and a public rate of 2 1/2 percent applied over the 50-year (1947-97) project period. The relative distribution of benefits and costs remains unchanged from Table 21.

In comparison with estimates of predevelopment returns and costs (Tables 10 and 42), the project as formulated would increase net farm incomes a minimum of 22 percent (farm 4) a maximum of 420 percent (farm 7), and a mean of 116 percent for all farms.[28] The major portion (75.23 percent) of the mean increase is attributable to increased crop values aside from related damage reductions, while flood control on farm 7 accounts for 24.38 percent and gully control (on farms 2, 3, 4, 5, and 6) for only 0.39 percent.

Similarly, the mean annual program cost of $798 per farm is largely the result of increased operating expense (86.53 percent) associated with the changed land use pattern of Figure 18; amortized installation costs of terraces and permanent meadow shown account for 5.85 percent, and amortized installation of the 4-ft. levees for 5.13 percent. Remaining proportions of costs assigned to farms are accounted for by compensated increases in off-site flood damage associated with levee construction (2.23 percent) and levee maintenance (0.26 percent).

For an equivalent annual outlay of $102 toward promoting land use changes indicated for the sector MFBO (Figure 18), annual benefits to Monona County are given in Table 21 as $273, the amount by which projected predevelopment average annual undue bridge maintenance expense is reduced from $385 (Table 10) to $112 by the land treatment activities. By substituting annual control costs of $102 for $273

[28] Incomes are gross only of income taxes but also refer only to portions of the total farm areas situated within watershed boundaries. The percentage increase for farm 4, for example, is given by (100) $524)/($1,193), where program net benefits are $524 (Table 22) and the predevelopment net crop value is $1,193 (Table 42).

in damages otherwise incurred, land-use-associated damages to Monona County are in effect minimized at $214 ($112 + $102) per year, thus reducing projected damages of $385 by 44 percent when costs of optimal control are considered.

For the downstream or off-site public interest, an equivalent annual outlay of $29 to finance land treatment activities indicated for fields within sector O in Figure 18 provides annual benefits of $77. This is the amount by which projected predevelopment average annual off-site floodwater-sedimentation damages are reduced from $140 (Table 10) to $63 by land treatment within the Nepper Watershed. As in the case given for Monona County above, by substituting annual control costs of $29 for $77 in damage annually averted, land-use-associated off-site damages are minimized at $92 ($63 + $29), thus reducing projected damages of $140 by 34 percent considering costs of control through watershed land treatment.

In relation to the predevelopment (1947) resource-use situation detailed in Tables 10 and 42, the over-all effects of an optimal development program involving a maximum justified annual expenditure of $5,716 beginning in 1948 are summarized in Table 24a. The major effect on the economy of the Nepper Watershed is a 57 percent increase (from $19,750 to $31,060) in the average annual gross value of primary agricultural production. Average annual costs associated with this output are increased by 21 percent (from $12,182 to $14,685) and annual net crop values by 127 percent (from $7,568 to $17,236). Average annual direct production expense on farms is increased 56 percent (from $8,717

Table 24a. Alternative programs of resource use in the Nepper Watershed in relation to predevelopment use and optimal changes

	Return and cost items	Alternative programs or adjustments: Program in 1947	Optimal changes in 1947	Optimal 1947 program	Program in 1957	Optimal changes in 1957	Optimal 1957 program
		(dollars)	(dollars)	(dollars)	(dollars)	(dollars)	(dollars)
	Equivalent annual returns						
1.	Gross value of crops produced	19,750	11,310	31,060	23,995	7,065	31,060
2.	Permitted intensive use of floodplain	0	861	861	0	861	861
3.	Total annual returns	19,750	12,171	31,921	23,995	7,926	31,921
	Equivalent annual costs						
4.	Direct production expense on farms	8,717	4,952	13,669	9,803	3,866	13,669
5.	Gully damage; main drainage	101	-44	57	0	0	0
6.	Gully damage; southwest drainage	36	-16	20	0	0	0
7.	Flood damage; on-site crops	2,803	-2,803	0	984	-984	0
8.	Flood damage; on-site bridge	385	-273	112	0	0	0
9.	Flood damage; off-site (land use)	140	-77	63	130	-67	63
10.	Flood damage; off-site (levees)	0	125	125	0	0	0
11.	Total gully and flood damage	3,465	-3,088	377	1,114	-1,051	63
12a.	Program installation; land treatment	0	339	339	8	333	341
12b.	Program installation; structures	0	287	287	3,155	0	3,155
13.	Program maintenance; structures	0	13	13	43	0	43
14.	Total annual cost decreases[a]	0	-3,213	0	0	-1,051	0
	Determination of net returns						
15.	Adjusted annual returns[a] (Item 3 less item 14)	19,750	15,384	31,921	23,995	8,977	31,921
16.	Total annual cost (increases)[a]	12,182	5,716	14,685	14,123	4,199	17,271
17.	Net value of crops produced (Item 15 less item 16)	7,568	9,668	17,236	9,872	4,778	14,650
18.	Net value per unit cost (Item 17 / item 16)	0.62	1.69	1.18	0.70	1.14	0.65

[a]Items 14, 15, and 16 not additive by columns.

to $13,669), all evaluated gully and flood damages associated with predevelopment land use are reduced about 89 percent (from $3,465 to $377), and damage control costs other than added farm production expense annually amount to $764 ($5,716-$4,952). The relative distribution of benefit classes and various cost items incident to the program is given by the final column of Table 20.

As indicated by Figure 17, and Tables 21 and 22, the program itself returns in the aggregate and for all participants $1.69 in discounted net benefits per unit of assigned capitalized outlays, and in the aggregate is sufficient to increase the predevelopment annual or capitalized net return on watershed resources from $0.62 per unit of $12,182 in annual costs (item 18, to Table 24a) to a post-development net return rate of $1.18 on annual costs of $14,685. With marginal net returns defined as additional discounted net returns per additional unit of capitalized program costs, predevelopment marginal returns of $29.26[29] are reduced to zero, indicating that the program exhausts all means (land treatment or structural activities) for increasing average annual discounted net crop values above a maximum of $17,236.

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[29]Taken as the discounted net benefit per unit of capitalized cost for activity P_4 in Table 19, the activity most critical in providing program benefits and involving a shift from continuous corn to continuous meadow cropping on field unit 2-1 (see Figures 11 and 18).

RECOMMENDATIONS AND REVIEW

Adjustments in the Current Land Use Program

Largely because of the uneconomic structures installed in the 1948 Little Sioux Program, the optimal resource-use program[1] for the Nepper Watershed specified by the foregoing programming analysis is hypothetical. But also because of the optional character of land use systems, possibilities currently remain for obtaining development benefits subject to the structures already eliminating all gully damage, all bridge damage, and returning about 65 percent of the maximum average annual flood control benefits to on-site crops. Remaining potential benefits are thus limited to increased outputs of corn, oats, and hay on upland areas or the floodplain; and to the reduction of off-site flood damage attributed to watershed land use. Concluding recommendations for the Nepper Watershed as the problem area studied concern the general effects of farmers shifting from current (1957) methods of land use shown in Figure 19 to the optimal pattern of Figure 18. The review of current conditions and recommendations are based on the same qualifications underlying the preceding benefit-cost and programming analyses; that is, a 50-year project period (1958-2008); respective corn, oats, and hay prices of $1.41 per bu., $0.74 per bu., and $15.70 per baled ton; similar cost projections; and the criterion that costs be shared to render total assignments proportional to benefit present

[1]Summarized in column 3 of Table 24a and mapped by watershed fields and farms in Figure 18.

values.

Current resource use and resultant returns

Although structural measures recommended for installation in 1948 were fully installed and are currently effective in damage reduction, land treatment activities intended to supplement these structures have been undertaken on few watershed fields. On the basis of input-output evaluations underlying this study, however, it appears that land use changes actually made by farmers over the period 1947-57 have been more profitable than the changes recommended in 1948 would have been. This judgment applies from either a farm or watershed viewpoint.

Under the present land use pattern of Figure 19, about 52 percent of the Nepper Watershed area is annually in corn or its erosion-runoff equivalent,[2] 23 percent is in oats, and 25 percent in meadow. Contouring and moderate fertilizing are the major special practices followed, with only about 11 acres (in fields 6-3 and 6-7) terraced. Contrasted with an annual sheet erosion rate of 42 tons per acre projected on 1947 land use, the current average approximates 25 tons per acre, ranging from about 5 tons on farm 7 to 58 tons on farm 4. A farm-by-farm summary of current cover conditions, labor use, sheet erosion, and fertilizer use is included in conjunction with related costs and returns in Table 46.

If existing structures shown in Figure 19 had not been installed, however, gully damages in both the main and southwest drainages, and

[2]Farmsteads and roads are presumed to have cover potentials for erosion and runoff equivalent to continuous corn cropping.

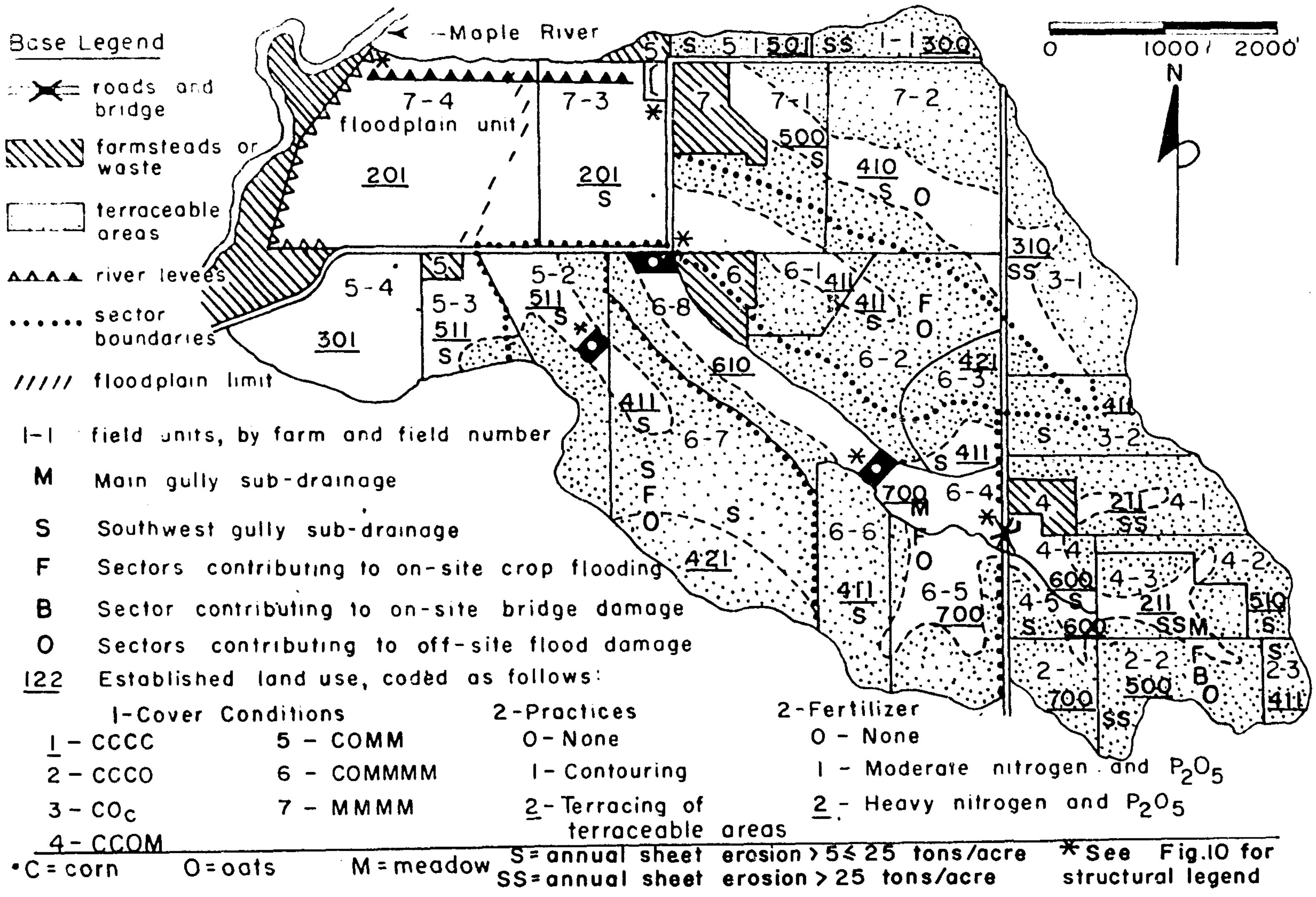

Figure 19. Current (1957) land use and existing structures in the Nepper Watershed.

damage to the Monona County bridge would be reduced by only negligible amounts from their 1947 levels. Average annual floodplain overflow would be reduced by about 15 percent from the 32.36 ac. ft. based on 1947 land use, and net watershed runoff would be reduced by about 7 percent from the 43.00 ac. ft. projected from 1947 conditions. With particular reference to the main gully drainage, Figure 3 indicates that reduction of the runoff index from 52 to 51 by land use changes over the period 1947-57 has reduced the 10-yr. recurrence peak discharge rate from 215 cu. ft. sec. (point A) to 201 cu. ft. sec. (point C). A corresponding reduction in a projected rate of land destruction from 0.133 acres per year (point A) to 0.122 acres per year (point C) is shown on the main drainage curve of Figure 5; while the 3 percent reduction of potential annual damage from $101 (point A) to $98 (point C) is given along the upper curve of Figure 6. The negligible effects of a reduction in the runoff index to 45 from 46 in the southwest drainage are likewise determined by comparison of points A and C in Figures 4, 5, and 6.

While adoption of the Little Sioux land use recommendations would have reduced, on the basis of input-output evaluations of this study, net crop incomes on farms 4, 5, and 6 (Table 44), the current systems of Figure 19 increase net incomes on all farms (except farm and field 1) above 1947 levels. Current net incomes in Table 46 range between $124 for farm 1 and $5,558 for farm 6 in terms of input-output evaluations.[3]

[3]These presume average rainfall and crop yields (as agronomically estimated) for the land use systems of Figure 19 on each field. Field surveys conducted in 1957 and covering the 1956 crop year of sub-normal rainfall estimated net incomes of from $62 (farm 1) to $4,198 (farm 6).

Production costs similarly range from $71 for farm 1 to $4,166 on farm 7, and include amortized farmer contributions toward structures installed in 1948.

The current cost-return position of Monona County with respect to the Nepper Watershed is an annual cost of $112 (Table 47), representing amortization of the $3,174 contributed in 1948 toward construction of the chute-spillway eliminating $385 in extra expense of bridge maintenance. The annual net benefit to Monona County of the chute-spillway[4] is $273 (or $385-$112), the amount by which annual damages of $385 based on 1947 land use (Table 10) exceed annual control costs, since the current average annual flood runoff volume (18.86 ac. ft.) affecting the location approximates the 18.71 ac. ft. computed volume based on 1947 land use. With annual costs fixed at $112 and damages eliminated, land treatment in sector MFBO (Figure 19) reducing average annual flood runoff below 18.86 ac. ft. cannot be credited with damage-reduction benefits at the bridge site.

As indicated above, average annual net watershed flood runoff under current land use conditions is estimated at 40 ac. ft. and associated average annual downstream damages at $130. Off-site public costs currently totaling $2,711 (Table 47) include these damages and amortized

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[4]The chute spillway provides net benefits to Monona County because the County's contribution of $3,174 toward installation of the structure in 1948 represented only 17 percent of the total installation cost of $18,255 (Table 39), with the remaining $15,051 Federally advanced. About 91 percent of the benefits accrue to Monona County in the form of reduced maintenance expense of $385, and 9 percent as gully control benefiting farms 2, 3, and 4. In the aggregate, however, and on the principle of proportionate beneficiary cost sharing applied in Table 8, benefits of the structure are less than costs.

Federal contributions toward installation of existing terraces on farm 6 as well as the structures installed in 1948. While current installation costs are not reducible below $2,581 (or $2,711-$130), off-site damages of $130 can be further reduced by land treatment activities promoted on fields within sectors designated by O in Figure 19.

The final column of Table 47 summarizes the current situation in the Nepper with regard to the collective interest of on-site farmers, Monona County, and the downstream area. The data indicate that the aggregate average annual gross crop income of $23,995 on farms is being obtained at a cost of $14,123 and has a net value of $9,872. In Table 24a these data are compared with corresponding amounts[5] of $31,921, $14,685, and $17,236 resulting if an optimal development program had been initiated in 1948. The current gross output, while 25 percent under the optimal gross output, involves essentially the same total cost, with the current net crop value consequently only 48 percent of that obtainable under optimal resource use.

Optimal adjustments in current land use

Despite possibilities for obtaining limited flood control benefits, a shift in the current Nepper Watershed land use pattern (Figure 19) to that suggested by the linear programming analysis (Figure 18) is recommended. The justification for the adjustments is that the values of increased crop yields alone, aside from nominal flood control benefits, would exceed increased production costs on all fields. The

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[5] See items 15, 16, and 17 in column 3.

adjustments require $6,108 in capital, however, to finance terrace installation on practically all terraceable areas. Cost-benefit aspects of the adjustments (column 5, Table 24a) are derived as changes in costs and returns induced by shifting from the 1957 program of resource use (column 4) to a program (column 6) most closely approximating the optimum (column 3) specified by linear programming.

Deviations in costs and returns between the optimal programs of 1947 and 1957 are explained by the installation in 1948 of uneconomic structures and/or structure capacities for damage control. For example, while linear programming suggested that average annual gully damage in the main drainage be reduced from $101 by $44 to $57 (item 5, Table 24a), the existing structures eliminate all gully damage as shown by items 5 and 6 in column 4. Similar considerations relevant to flood damage apply to items 8 and 10. Amortized installation costs of land treatment (item 12a) are about equal at $340 under the optima of columns 3 and 6, but structure installation and maintenance are held at their $3,155 and $43 amounts in columns 4 and 6 to indicate the fixed character of existing structures.

Annual benefits of $8,977 (column 5, item 15) resulting from an optimal adjustment program are derived in Table 24a as $7,926 in increased crop values on uplands and the floodplain, added to $984 in complete floodplain protection and $67 in reduced off-site damage. These are obtained at a cost increase of $4,199; $3,866 in increased production expense on farms, and $333 as the amortized installation expense of required terraces and permanent meadow. Net benefits are

$4,778, or $1.14 per unit of the added $4,199 in annual cost. Distributions of benefits and proportionally assigned costs among watershed farmers and the downstream public interest are given in Tables 48 and 49; Monona County as the on-site public interest neither gains nor loses by the adjustments in land use.

Since the initial installation costs given as the first item in Tables 48 and 49 apply almost exclusively to terraces, the amounts indicate justified investments of $6,023 by watershed farmers and $85 by off-site interests. Particular areas terraced within each field are shown in Figure 18; footage requirements by each farm are tabulated in the lower section of Table 50.

Despite costs of present optimal adjustments being $4,199 rather than the $5,716 amount for the optimal adjustments possibly made in 1948, cover conditions and conservation practice intensities are equivalent to those shown vertically from $5,716 in Figure 15, and by Figure 18. The watershed area in corn, farmsteads, or roads would increase to 63 percent from the current 52 percent,[6] the area in oats would decrease to 10 percent from the current 23 percent, while the meadow area would increase slightly to 27 percent from the current 25 percent. Terraces would be installed on 98 percent (288 acres, 36 miles) of the total terraceable cropland area of 295 acres; with about 11 percent (52 acres) of the 480-acre watershed area contoured and 83 percent commercially fertilized, 12 percent at moderate rates and

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[6]Percentages at the zero outlay in Figure 15 apply to benchmark conditions prevailing in 1947 rather than a benchmark based on current (1957) land use.

71 percent at heavy rates. Sheet erosion would be reduced to rates not exceeding 5 tons per acre per year on all watershed areas other than farmsteads and the road system.

As Table 24a indicates, the only element of damage remaining with the program of column 6 (and Figure 18) substituted for that of column 4 (and Figure 19) is $63 in average annual off-site flood damage, representing a 52 percent reduction from the $130 amount based on current land use. Cost and return data pertaining to the optimal 1957 program are detailed in Table 50 for watershed farm units; also included are a farm-by-farm summary of resulting cover conditions based on Figure 18, plus labor use estimates and corresponding quantities of terraces, contouring or commercial fertilizer. Aggregate data pertaining to watershed farmers as a group, Monona County, and the downstream interest are given in Table 51.

Although the program resulting from optimal changes made in 1957 represents maximum improvement over the current program in the Nepper Watershed, it must be emphasized that it remains sub-optimal with respect to the situation resulting from an optimal program possibly installed in 1948. This is shown by a simple least-cost comparison. In Table 24a, total annual returns including gross crop values and enhanced floodplain use add to $31,921 (item 15) under both the optimal postdevelopment situations of column 3 and 6. Comparative associated costs are $14,685 and $17,271, however, and net returns respectively $17,236 and $14,650. The difference of $2,586 in costs and net returns can be termed the minimum opportunity cost (or net return foregone) of the structural components of the 1948 Little Sioux Program being completely installed (in Figure 19) rather than just the system of 4-ft. levees suggested by the linear programming analysis (in Figure 18).

An estimate of the maximum annual opportunity cost of installing unneeded structures is given as $7,364, the annual net benefit of $4,778 foregone by not undertaking currently optimal changes (item 17, column 5), added to the foregoing minimum of $2,586. The effect of current changes in minimizing opportunity costs of prior uneconomic planning thus justifies shifting Nepper Watershed land use to the pattern of Figure 18 from the 1957 pattern of Figure 19. Benefits and costs of the shift itself are detailed by participants in Tables 48 and 49; resultant program returns and costs are similarly given by Tables 50 and 51.

Conclusions, Limitations, and Research Implications

General conclusions

A first inference drawn from this study is that, while devices such as the linear programming model employed here can expedite formulation of resource development projects maximizing net benefits, specific input-output relationships of alternative activities examined are necessarily determined by procedures often criticized as faulty or inadequate. The Nepper analysis indicated, for example, that ratios of capitalized benefits to capitalized costs as conventionally calculated by Federal resource agencies are usable indicators of relative activity profitability if concern is with the efficient allocation of specified total expenditures, rather than simply with initial capital investments.

The programming methods of this study are adaptable to the basing of planning decisions either on the conventional benefit-cost ratio or on the marginal efficiency of initial capital computed as some internal rate of return. If projects are planned without reference to limited installation funds (the common practice), but still to requirements for capitalized benefits exceeding capitalized costs by a maximum, the question of capital productivity as such is immaterial. Competitive activities (or activity combinations) included will be those with maximum capitalized net benefits, with all supplementary activities producing positive net benefits included. With one objective of this study being demonstration of planning refinements possible even under the constraints of current general procedures or assumptions, the benefit-cost ratio is taken as the measure of relative return.

A related conclusion is that prescriptions for improved agency practices are generally built around the simple case of activities being mutually exclusive, in that one activity or another must either be feasible or preferred with reference to a specified outlay. The more usual situation in watershed planning is that many possibilities exist for utilizing specified outlays to partially sustain one or more activities. Figure 13 illustrated the possibility of different land treatment activities being proportionately undertaken on the same field to maximize net benefits. Figure 14 indicated how a portion of a given farm field might be utilized as a structure site and the remainder either not treated, partially treated, or entirely treated by cropping changes or fertilizer application, the particular choice being determined by the outlay available.

The major conclusion warranted is, however, that mathematical programming is primarily a problem-solving rather than an analytical technique; it thus will best supplement rather than replace present methods of project formulation based on extensive benefit-cost comparisons but indirect regard for resource availability. The application of linear programming to the problem of devising optimal development programs for the Nepper Watershed was preceded by detailed input-output and cost-benefit appraisals, plus an explicit listing of resource or technological restrictions; these preliminaries are essential to the method.

Special limitations

Approximate hydrologic-economic relations. Aside from initially stated qualifications concerning price levels, discount rates, and the range of alternative activities considered, the study has other limitations. Important among these is the utilization of single-valued estimates of the average and marginal benefits from hydrologic control of flooding and gullying (Table 6). In reality these have multiple values, both with respect to given uses and all alternative uses determining damage potentials on affected areas. In uniformly crediting land treatment or structural activities with maximum floodplain benefits of reduced overflow, the floodplain was presumed to be in heavily fertilized continuous corn, the land use system of Figure 9 under which damage would be greatest for any overflow volume. And with regard to this system alone, each acre-foot reduction in annual overflow was uniformly valued at $86.59 as evaluated under predevelopment conditions (Table 5). The effects of this inconsistency on the optimal combinations of treatment activities at various outlay levels are probably not serious, however. In Figure 16, control of on-site flooding appears as the over-riding damage-reduction purpose of Nepper Watershed treatments.

Uncertainty aspects. Weaknesses of this nature are 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 34); and the extension of these results to flood producing storms occurring in the Nepper Watershed from 1950-54 (Table 37). There is neither assurance that antecedent moisture conditions prevailing at Castana at the time of each recorded storm are typical, nor that the short flood-storm record in the Nepper Watershed even approximates the frequency distribution of flood producing rainfall that might be observed over an infinite period. Benefit-cost appraisals and the subsequent formulation of optimal programs are doubtless in error on these considerations as well as other aspects of uncertainty relating to projected prices, production costs, and crop yields. The study illustrates planning only within the constraints of the best available estimates of likely future conditions, and all results are qualified by the adequacy of the estimates.

Farmer preferences and management skills. In delimiting the range of land use changes selected for benefit-cost analysis and possibly considered as development activities, the criteria applied (page 39) with reference to each field are perhaps too objective. Some farmers are averse to certain erosion control practices regardless of estimated benefits and, to some extent, regardless of liberal cost sharing assistance. An example is terracing, often objected to simply because field operations might be a little more difficult. The Nepper study did not eliminate terracing possibilities on this account because required farmer capital contributions (about 30 percent) toward terrace construction under the Agricultural Conservation Program appeared to be a greater obstacle to additional terracing than subjective factors. The latter, however, could have been considered more thoroughly.

A related limitation pertains to management capabilities. The land treatment activities indicated on each farm by alternative optimal programs have differing management requirements, and the requirements may exceed expected performance of some farmers. One way to account for less-than-average management skills would be to adjust net benefits of all activities as economically feasible on concerned farms downward, although a rational basis for establishing the magnitude of such adjustments is not clear. An alternative would be the exclusion from planning consideration of otherwise feasible and profitable activities (in Table 19, for example) having management requirements known to exceed capabilities of particular operators. The latter seems preferable to the arbitrary adjustment of either activity or program benefits. The Nepper study, however, was concerned only with indicating maximum net benefits obtainable from land treatment activities, without reference to contrasting management capabilities of watershed farmers.

Partial farm planning. In concentrating on the problems of determining optimal land use patterns the study did not consider as land-supply limitations those farm fields or field portions beyond boundaries of the Nepper Watershed. Optimal land treatment undertaken on portions of farms within watershed boundaries is not independent of treatment possibilities on outlying areas, in that all farm fields compete for limited resources available for treatment. Farm areas outside Nepper Watershed boundaries could have been included in this analysis by also evaluating possibilities on them for increased crop yields or reduced flooding and gully damage, but for completeness the analysis would then have necessarily involved portions of other watersheds draining into the Maple River. The non-coincidence of farm and drainage boundaries poses a special problem in defining the areal scope of watershed planning; delineations on a farm basis may be inadequate from the hydrologic viewpoint, and those on a watershed basis inadequate from a farm viewpoint.

Income-distributive aspects. Watershed development projects can doubtless result in redistributions of income, either among watershed residents or between residents compared as a group with off-site interests. Particular redistributions desired can easily be effected by controlling the manner in which development costs are shared.

No judgments were made here as to what absolute or relative income distribution should prevail subsequent to implementation of watershed programs in the Nepper Watershed. 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 operative 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 thus assigned, the implied judgment is that programs are neither intended to maintain nor achieve given income distributions, but that any prospective increases in income should be shared proportionately (by thus sharing program costs). This is the position recommended as a general policy by at least one important review group (page 36). This study merely illustrated how such a policy would be carried out by planners and suffers from the limitation of not illustrating other possible policies.

One alternative policy, for example, might be that the predevelopment income distribution among watershed farmers should be unaffected by development, or that both benefits and costs be shared proportionately with the predevelopment distribution of income. Planning could just as easily proceed on this basis but the particular activities recommended might differ considerably from those based on a policy of not tampering with the incidence of benefits except to compensate for negative benefits or damages.

Research implications

Physical research. Being primarily economic, this project was not directly concerned with pointing out precise relations between Nepper Watershed land use and resulting effects on watershed hydrology. Several implications for the collection and use of physical input-output data follow, however, particularly as these data support benefit-cost appraisals.

First, data collection should be specific to the sectors as well as variables with which evaluation and planning are concerned. Gaging flood-producing runoff from entire watersheds may be unnecessarily expensive if particular drainages are known to contribute a major portion of flood flows. Second, a single hydrologic variable can possibly be related to a number of distinct economic problems and thus reduce the complexity of evaluations that attempt integration of many physical relationships, thereby simplifying planning within a multi-purpose framework. Third, a frequent approach of calibrating entire watersheds under predevelopment conditions, while reasonable from the standpoints of experimentation and complete evaluation, can delay obviously desired programs. In these situations limited programs might be planned and installed on the basis of apparent physical and economic relationships; continued gaging would then indicate the further adjustments needed.

Socio-economic research. While the major implication for economic research is correcting stated weaknesses of the study bearing on assumptions and procedures used in economic analysis, an additional problem is the relating of results of economic analysis to alternative institutional arrangements under which programs might be implemented. Research into the organizational aspects of watershed planning has been emphasized almost to the exclusion of economic investigations since passage of the Watershed Protection and Flood Prevention Act in 1954. This may be attributed to the Act's special provisions under which localities can qualify for Federal assistance in project installation. The present effort is at another extreme, in that development possibilities are evaluated, programs are formulated to maximize net benefits, and cost-sharing requirements are indicated, but the details of actually working out the latter through a formal organization or other types of cooperative endeavor are ignored.

In addition to continued improvement of techniques for economic planning, an objective of future economic research could be the trial formulation of programs under alternative institutional arrangements, rather than considering such arrangements apart from economic planning. For example, the Watershed Protection and Flood Prevention Act, while allowing discretion for localities to organize as Conservancy Districts, Soil Conservation Subdistricts, or some other legally constituted body, clearly defines the conditions under which the Federal government will provide technical and financial assistance to any organization. Such conditions will pervade economic evaluation of development possibilities and the selection of development activities included in programs planned under the Act. An advantage of this approach is that benefit-cost appraisals based on known cost-sharing requirements could be made more understandable to project participants than appraisals based on hypothetical requirements subject to considerable modification. This could also be the direction of continuing research in the Spring Valley Creek Watershed of southwest Iowa; objectives of the project in obtaining improved physical and economic data have been stated earlier (page 22).

Possibilities for Field Application

The relevance to actual planning of the framework illustrated here for the Nepper Watershed depends on the willingness of technicians, within the limitations of planning funds and time, to consider each proposed land treatment or structural measure as an alternative measure only and to consider a number of such alternatives for each different area likely treated. The fact that a measure shows a favorable ratio of benefits to costs (greater than 1) merely indicates that its adoption will in the aggregate produce a net gain. Without compensation arrangements, it could result in significant losses to some project participants and off-project areas. The objective of planning is not simply to select activities yielding net benefits, but to extend the range of selection and combine activities to render net benefits a maximum, subject to any restrictions imposed by resource availability and requirements for ensuring that projects not leave anyone damaged and uncompensated. Linear or other forms of mathematical programming are designed to meet this objective.

A second argument for the adoption of linear programming is that it provides for land and water interrelations unique to given areas. By defining each field within the Nepper Watershed as a possible treatment area, input-output coefficients were derived that applied to each field, and thus accounted for both physical and locational factors in the evaluation of watershed damages. Related to this argument is the scope of programming for multi-purpose planning. Each land treatment activity could be credited with gully control, flood control, and crop-yield benefits according to its location; and each structure could similarly be credited with damage-reduction benefits according to its design. In relation to costs, all identifiable benefits determined the absolute and relative profitability of each activity. This principle dominates multi-purpose planning.

Programming recommends itself most strongly to field application, however, in simultaneously resolving planning questions involving program feasibility, combination of activities, program scale, and project priorities.[7] With feasibility defined here as an excess of aggregate benefits over costs and no net losses to any participant, Table 19 lists those activities feasibly considered in planning programs for the Nepper Watershed. And since a program is given by any combination of feasible activities, any combination of the activities of Table 19 including at least one of the activities P_1 through P_{50} at greater than zero level would provide net benefits and be feasible.

Because the remaining questions commonly involve the maximization

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[7] The precise criteria applied in making the decisions are given by Timmons, op. cit., pp. 1173-1179.

of net benefits, Table 24b reviews how net benefits were maximized by programming the Nepper Watershed. For an equivalent annual outlay limited to \$9.60, activity P_4 provided a maximum net benefit of \$280.95, returning more (\$29.26) at the margin than any other activity of Table 19. Activity P_4 in step 1 of Table 24b displaced the artificial activity P_{52} denoting non-treatment of field 2-1.[8] The marginal return of \$29.26 for activity P_4 is the benefit-cost ratio familiar to technicians, but was computed here on a net basis. It coincided with the cumulative program ratio only in step 1, because activity P_4 alone at its unit level was the program.

The activity with the next highest benefit-cost ratio or incremental return (\$22.35) was P_{17}, displacing P_{60} or non-treatment of field 4-4 in step 2 of Table 24b. Activity P_{17} increased the annual program cost (\$9.60) of step 1 by \$8.25; \$17.85 was required, however, to permit also adding P_{17} at its unit level and increasing net program benefits to \$465.39. The over-all benefit-cost ratio of \$26.07 (column 10) is an average or cumulative rather than a marginal ratio, but is still a maximum with respect to a given outlay of \$17.85 and thereby resulted in maximum net benefits. Steps 1 and 2 thus indicate how activities can be combined to maximize net benefits on the basis of data presently collected by field parties. But selecting combinations by the linear programming method made the planning procedure more deliberate and pointed out possible internal revisions in programs as greater outlays might be

[8]The displacement means that a cropping system of continuous meadow (P_4) was substituted for the predevelopment system of continuous corn (P_{52}) on field 2-1.

Table 24b. 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)
Steps	Program formulation			Marginal activities			All program activities			
and programs	Activity added	Activity deleted	Added intensity	Cost	Net benefits	Net / cost	Cost	Net benefits	Net / cost	Total benefits
	(Table 19)	(Table 19)	(units)	(dollars)	(dollars)	(dollars) (6)/(5)	(dollars) Σ(5)	(dollars) Σ(6)	(dollars) (9)/(8)	(dollars) (8)+(9)
1	4	52	1.00	9.60	280.95	29.26	9.60	280.95	29.26	290
2	17	60	1.00	8.25	184.44	22.35	17.85	465.39	26.07	483
3-17	...	...	...	...	...	...	2591.15	6428.44	2.48	9019
18	9	55	1.00	324.91	570.35	1.75	2916.06	6998.79	2.40	9914
19	26	25	1.00	315.21	523.52	1.66	3231.37	7522.31	2.33	10753
20	40a	74	1.00	449.68	670.60	1.49	3680.95	8192.91	2.23	11873
21	35a	70	1.00	180.06	262.85	1.46	3861.01	8455.76	2.19	12316
22	36a	71	1.00	121.11	175.53	1.45	3982.12	8631.29	2.17	12613
23	42	76	.97b	208.22	289.34	1.39	4190.34	8920.63	2.13	13110
24	32a	68	1.00	214.15	270.56	1.26	4404.49	9191.19	2.09	13595
25	19	62	1.00	21.45	23.04	1.07	4425.94	9214.23	2.08	13640
26	30	29	1.00	148.56	158.90	1.06	4574.50	9373.13	2.05	13947
27	24	23	1.00	130.56	127.45	0.97	4705.06	9500.58	2.02	14205
28	7	6	1.00	30.13	21.06	0.69	4735.19	9521.64	2.01	14256
29	8	9	1.00	164.21	45.98	0.28	4899.40	9567.62	1.95	14467
30	20	19	1.00	7.85	2.21	0.28	4907.25	9569.83	1.95	14477
31	16	17	1.00	47.82	12.23	0.26	4954.07	9582.06	1.93	14536
32	14a	59	1.00	173.07	37.09	0.21	5127.14	9619.15	1.88	14746
33	22a	63	1.00	236.03	35.29	0.10	5363.17	9644.44	1.80	15007
34	13a	58	1.00	116.35	11.65	0.10	5479.52	9656.09	1.76	15135
35	12a	57	1.00	237.25	11.73	0.05	5716.77	9667.82	1.69	15384

[a]Data in Table 19 have been adjusted to eliminate flood control for on-site crops as a benefit of these activities because prior activities eliminate all such damage.

[b]Approximately 3 percent of field 7-3 in Table 19 and Figure 18 is occupied by activity P_{49}, the levee system.

available. In step 19 of Table 24b, for example, net benefits were increased by $523.52 by substituting activity P_{26} for P_{25} at an incremental cost of $315.21.[9] This substitution was the most profitable program revision if a $3331 rather than $2916 outlay (column 8) were being optimally allocated to maximize cumulative or aggregate net benefits. No subsequent steps would produce a marginal return equal to $1.66 or increase aggregate net benefits to $7522. Moreover, the substitution is the sort of program revision that could easily escape planners proceeding intuitively.

The field interpretation of optimal project scale relates simply to the maximization of net benefits with no restriction on total expenditure, rather than to proportional variations in all factors. Net benefits were maximized at step 35 in Table 24b, with P_{12a} as the last activity added having a benefit-cost ratio of $0.05 and the cumulative program ratio being $1.69. Any additional activities or activity substitutions would yield no additional net benefits. The maximum program expenditure justified on the criterion of maximizing net benefits was $5716. And this program consisted of all the steps of Table 24b at the intensities given in column 4.

The final question, that of assigning priorities, involves the competition among proposed projects for available funds; it is the

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[9] Incremental data of columns 5 and 6 are differences between relevant items for activities P_{25} and P_{26} in Table 19. In this case the substitution means that, in addition to a continuous corn cropping system being adopted in place of the predevelopment corn-corn-corn-oats notation on field 5-4 (Figure 11), the continuous corn system would be heavily fertilized.

intra-watershed planning problem restated on an inter-watershed basis. If each of the 27 land-supply limitations of Table 19 (P_{51} through P_{77}) had been considered as competing watersheds and the activities P_1 through P_{50} as alternative treatment activities evaluated for each watershed, Table 24b also indicates how each watershed would have been treated or not treated to maximize the net benefits of general development. Watershed P_{52} would be given top priority and be treated by activity P_4. All of the 27 watersheds would be treated only if $5716 were available to finance any project selections and maximize net benefits.

The Watershed Protection and Flood Prevention Act and other legislation impose requirements for considerable refinement of field appraisals, both as the appraisals are related to cost-sharing and to program formulation. The requirements have been summarized as (1) the development of procedures for identifying beneficiaries with greater accuracy; and (2) a shift from the present emphasis of planners on total project values to schedules relating both benefits and costs to varying degrees of project scale.[10] This research was largely an attempt to show how these requirements might be met.

[10] Harry A. Steele. Economics of small watershed development. Agricultural Economics Research 8, No. 1: 17-23. Jan. 1956.

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APPENDIX A: INPUT-OUTPUT DATA FOR VARIOUS LAND USE SYSTEMS

Table 25. Annual per-acre basic labor requirements for selected rotations and fertilizer treatment in the Nepper Watershed

Rotation and treatment	Relative frequency of crops (%)			Man-hrs. per rotation[a]	
	Corn(C)	Oats (O)	Meadow(M)	F_0	F_1 or F_2
CCCC	100	0	0	7.00	7.20
CCCO	75	25	0	6.50	6.72
CO_c	50	50	0	6.00	6.25
CCOM	50	25	25	7.65	7.90
COMM	25	25	50	8.81	9.08
COM_4	17	17	66	9.69	10.00
MMMM	0	0	100	11.62	11.92
Treatment[a]	Man-hrs. per crop[1]				
F_0	7.00	5.00	11.62		
F_1 or F_2	7.20	5.30	11.92		

[1]Crop requirements are from Ross Baumann. Farm input-output data for budgeting and linear programming. Mimeo. report. Ames, Iowa. Iowa State College. Department of Economics and Sociology. 1956.

[a]No fertilization is denoted by F_0, while F_1 and F_2 respectively denote moderate and heavy fertilizer recommendations for various crops, soils, and tillage practices. Labor requirements for rotations are computed from crop frequencies and single crop requirements.

Table 26. Annual capital requirements for selected rotations in the Nepper Watershed[a]

Rotations	Relative frequency of crops (%)			Dollars per acre
	Corn(C)	Oats(O)	Meadow(M)	
Per crop (dollars)	16.23	13.28	6.63	--
CCCC	100	0	0	16.23
CCCO	75	25	0	15.50
CO_c	50	50	0	14.76
CCOM	50	25	25	14.01
COMM	25	25	50	11.08
COM_4	17	17	66	9.33
MMMM	0	0	100	6.63

[a]Requirements are based on 1955 Iowa custom rates adjusted to long-term price levels.

Table 27. Estimated production effects of conservation practices and fertilization under selected rotations; Monona silt-loam, 3-6% slope (non-eroded)[2]

Rotations	Practices	F_0-No Fertilization			F-1 Fertilization			F-2 Fertilization		
		Corn (bu.)	Oats (bu.)	Hay (tons)	Corn (bu.)	Oats (bu.)	Hay (tons)	Corn (bu.)	Oats (bu.)	Hay (tons)
C or CCCO	None	38	32	-	60	35	-	65	40	-
	Fertilizing rate, No.N-No.P				60-20	10-20	-	80-30	10-30	-
	Contouring	40	32	-	65	35	-	70	40	-
	Fertilizing rate, No.N-No.P				60-20	10-20	-	80-30	10-30	-
	Terracing	40	32	-	65	35	-	70	40	-
	Fertilizing rate, No.N-No.P				60-20	10-20	-	80-30	10-30	-
CO-sc	None	45	35	-	60	35	-	65	40	-
	Fertilizing rate, No.N-No.P				30-20	0-20	-	60-30	0-30	-
	Contouring	48	35	-	65	35	-	70	40	-
	Fertilizing rate, No.N-No.P				30-20	0-20	-	60-30	0-30	-
	Terracing	48	35	-	65	35	-	70	40	-
	Fertilizing rate, No.N-No.P				30-20	0-20	-	60-30	0-30	-
CCOM[3]	None	55	38	2.6	65	35	2.7	70	40	2.8
	Fertilizing rate, No.N-No.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, No.N-No.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, No.N-No.P				30-20	0-20	0-20	45-30	0-30	0-30

[2]Source: W. D. Shrader, Ames, Iowa. Information on crop yields and fertilizer applications for Nepper Watershed land use systems. Private communication. 1955.

[3]Similar data for COMM, COM_4, and continuous meadow omitted. For complete data on all watershed soils see Iowa State College. Departments of Agronomy, Agricultural Engineering, and Economics and Sociology. op. cit., pp. 20-29.

Table 28. Design, construction, and maintenance data for level terraces of 2-inch retention capacity

Construction and maintenance items	Units	Soil types by percent slope phases						
		Ida silt loam			Monona silt loam			
		4-8	9-15	16-25	3-6	7-9	10-14	15+
Design and construction								
Mean slope (S)	%/100	.06	.11	.20	.04	.08	.12	.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 ft. 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[4]	hrs.	na	.37	.19	na	na	.37	.17

[4]Computed from percent replowed and 1.1 man-hours of labor required for a complete plowing operation with a 2-14" moldboard plow. Man-hours of 1.1 are based on 0.9 acres per hour as the effective field working capacity for such a plow as estimated by D. Hunt. Farm power and machinery management. Ames, Iowa, the Iowa State College Press. 1956. p. 13.

[a]Vertical interval (V.I.) computed from 60 S + 2.

[b]Horizontal interval (H.I.) computed from (V.I.)/S.

[c]Feet per acre computed from 43560/(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]na indicates additional plowing is unnecessary regardless of land use.

[h]Computed from percent replowed and a variable plowing cost of $2.25 per acre.

Table 29. Terrace depreciation by soil types and land use

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	48	0	0	(Zero for remaining soil types and rotations in Table 28)	
	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 and rotations in Table 28)	
	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 and rotations in Table 28)	
	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 is considered as field length.

[b]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 28 for construction cost).

Table 30. Annual terrace maintenance requirements in relation to soil types and land use

Silt loam soils	Percent slope	Number of added plowings[a] for complete maintenance: CCCC	CCCO	CO_c	CCOM	Per added plowing[b]: Silt removal	Requirements: Capital	Labor
						(tons)	(dollars)	(man-hrs.)
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 28)		
	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 28)		
	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 28 by corresponding silt-removal estimates under column 7.

[b]Transferred from Table 28.

[c]Computed as products of capital per added plowing and numbers of added plowings given in the first section.

[d]Computed as products of labor per added plowing and numbers of added plowings.

Table 31. Annual capital requirements per acre for complete maintenance of level terraces of 2-inch retention capacity[a]

Silt loam soils	Percent slope	Rotations with terraces					
		CCCC	CCCO	CO_c	CCOM	COMM	COM_4
		($)	($)	($)	($)	($)	($)
Ida	4- 8[b]	0.21	0.21	0.21	0.21	0.28	0.42
	9-15[c]	1.87	2.91	0.21	0.21	0.28	0.42
	16-25[c]	3.41	2.71	1.32	0.68	0.28	0.28
Monona	3- 6[b]	0.21	0.21	0.21	0.21	0.28	0.42
	7- 9[b]	0.21	0.21	0.21	0.21	0.28	0.42
	10-14[c]	1.01	1.38	0.21	0.21	0.28	0.42
	15+[c]	0.59	0.76	0.21	0.21	0.28	0.42

[a]Includes the cost of replacing one-way with two-way 2 x 14" moldboard plows for normal plowing operations, plus the variable cost of repeated plowing operations to restore design cross-sections.

[b]No repeated plowing necessary. Costs given are simply the annual per-acre expense of replacing one-way plows with two-way plows.

[c]Costs of repeated plowing for silt removal are represented by differences between any row indicated by c and rows indicated by b.

APPENDIX B: DAMAGE EVALUATION METHODS AND HYDROLOGIC DATA

Table 32. Projected average annual gully damage in the main drainage with predevelopment land use continued 50 years

Field ident.[a] (code)	Total area[a] (acres)	Susceptible area[b] (acres)	Susceptible area[c] (percent)	Susceptible system: Ident.[d] (code)	Susceptible system: Net per acre per year (dollars)	Area lost per year[e] (acres)	Annual damage increase[f] (dollars)	Average annual damage[g] (dollars)
2-1	6.0	1.0	3.31	122	47.37	.00440	0.20842	3.56276
2-2	10.5	0.4	1.32	522	27.97	.00176	0.04922	0.84137
3-2	11.7	0.2	0.66	422	34.06	.00088	0.02997	0.51231
4-1	16.6	1.5	4.96	522	29.72	.00660	0.19615	3.35301
4-3	13.9	4.4	14.56	522	34.32	.01936	0.66443	11.35786
4-4	4.5	2.8	9.27	422	42.33	.01233	0.52192	8.92177
4-5	5.6	2.3	7.61	522	35.97	.01012	0.36401	6.22244
4-f	2.9	0.5	1.65	h	0.00	.00219	0.00000	0.00000
6-3	15.5	2.3	7.61	422	40.24	.01012	0.40722	6.96107
6-4	6.2	5.2	17.21	122	62.70	.02289	1.43520	24.53352
6-5	19.0	3.5	11.58	522	31.28	.01540	0.48171	8.23442
6-6	17.1	1.5	4.96	421	38.04	.00660	0.25106	4.29165
6-8	12.2	4.6	15.30	122	64.69	.02035	1.31644	22.50342
Totals	141.7	30.2	100.0	-	-	.13300	5.92575	101.29565

[a]Field codes and acreages from Figure 2 in text.

[b]Includes Napier soil units of 3-5 percent slope within affected fields.

[c]Percent of total affected area of 30.2 acres.

[d]Systems identified in text, Figure 11; net incomes are in projected long-term prices.

[e]Column 4 x 0.133 acres per year from Figure 5.

[f]Column 6 x column 7.

[g]Column 8 x $312 (the present value of an increasing annuity of $1 at 5 percent for 50 years) x 0.05478 (amortization factor for 5 percent and 50 years).

[h]Non-income use assumed for farmstead.

Table 33. Average annual gully damage in the main drainage allocated by contributing fields and land use

Field ident.[a] (code)	Field area[a]: Total (acres)	Field area[a]: Proportionate (%/100)	Established land use: Ident.[b] (code)	Established land use: Runoff index[c] (W_i)	Weighted index (2)x(3)x(5)	Allocated damage (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	300	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
Totals or means	213.10	157.50[f]	-	52.2[g]	8,218.95	101.29

[a]Field codes, acreages, and proportionate acreages from text Figure 2.

[b]Established land use from Figure 11.

[c]Runoff indexes from reference in note 7, p. 64 of text.

[d]Total damage from Equation 1 and Table 32 allocated by weighted indexes.

[e]Assume the equivalent of continuous corn and no practices on farmsteads and roads.

[f]Total 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.

Table 34. Effect of cover conditions and conservation practices on runoff for the 12 most erosive storms at the Western Iowa Experimental Farm, Castana, 1948-56[1]

Storm record			Runoff in a CO_c rotation				Runoff in a COMM rotation			
Date	Rain-fall	Maximum intensity	Corn no practices	Corn contoured	Corn listed	Oats disked	Corn listed	Corn disked	Meadow year 1	Meadow year 2
	(in.)	(in./hr.)	(in.)	(in.)	(in.)	(in.)	(in.)	(in.)	(in.)	(in.)
7/25/48	1.97	1.39	0.36	0.46	0.37	0.33	0.29	0.24	0.34	0.21
7/29/48	2.07	1.28	0.57	0.36	0.31	0.16	0.24	0.13	0.19	0.08
8/10/48	1.90	1.21	0.86	0.70	0.74	0.30	0.48	0.25	0.27	0.18
8/26/48	1.51	0.18	0.72	0.43	0.68	0.13	0.46	0.15	0.10	0.04
6/15/50	0.97	0.97	0.68	0.36	0.02	0.42	0.39	0.08	0.03	0.52
6/17/51	3.11	2.84	1.58	1.58	0.88	1.48	0.25	0.44	0.09	0.51
7/ 3/51	0.89	0.77	0.45	0.27	0.16	0.23	0.14	0.05	0.08	0.24
7/ 6/52	2.95	1.56	1.01	0.96	0.64	0.23	0.11	0.00	0.00	0.00
6/19/54	1.68	1.30[2]	0.74	0.88	0.37	0.87	0.11	0.89	0.10	0.04
6/21/54	1.91	0.83	0.49	0.83	0.39	0.77	0.13	0.59	0.00	0.00
5/10/56	1.73	0.68	0.41	0.45	0.00	0.39	0.00	0.47	0.20	0.00
7/11/56	2.06	1.46	0.43	0.43	0.48	0.48	0.33	0.43	0.42	0.07
All storms	22.75	14.47	8.30	7.71	5.04	5.79	3.03	3.72	1.82	1.89
Av. per storm (in.)	1.90	1.22	0.82	0.78	0.49	0.62	0.26	0.33	0.16	0.20
Av. per storm (%)			42.94[a]	41.44	25.87[a]	32.66	13.74[a]	17.51	8.36	10.65

[1]Source: W. E. Larson and F. W. Schaller. Spacing of level terraces in western Iowa. Agricultural Engineering. 39: 20-23. 1958.

[2]Intensity estimated from U. S. Department of Commerce. Weather Bureau. Rainfall-intensity-duration frequency curves. Technical Paper 25. Wash., D. C. Author. 1955. p. 16.

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

Table 35. Annual flood 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 averages		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 34.

[b]Cropping conditions are identified as follows:

1. Continuous corn and 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 34. Percentages for each cropping condition are 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 34.

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

Table 36. 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[3]			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[4]		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

[3]Runoff percentages for degree of field slope are from the U. S. 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. Technical Bulletin 973. Wash., D. C., U. S. Govt. Print. Off. 1949. p. 28. Data given were observed on Fayette silt loam plots 72.6 feet in length planted to grain with slopes shown.

[4]Runoff percentages for slope length are from the U. S. 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. Technical Bulletin 959. Wash., D. C., U. S. Govt. Print. Off. 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.

[a]Runoff percentages for cover conditions and conservation practices other than terracing are from Tables 34 and 35. Runoff is assumed to be zero upon installation of level terraces designed to retain up to 2 inches of runoff per storm.

Table 37. Adjustment of experimental plot runoff percentage with runoff observed from Nepper Watershed flood storm records[5]

Storm record: Date	Rainfall (in.)	Watershed[a] runoff (ac.ft.)	Floodplain[a] overflow (ac.ft.)	Net off-site runoff (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
6/27/54	3.87	50.71	21.48	29.23
6/20/54	2.06	29.43	10.22	19.21
Total for record:				
April 1-May 31	6.54	97.65	35.64	62.01
June 1-September 30	24.77	330.85	116.12	214.73
Seasonal	31.31	428.50	151.76	276.74
Average per storm:				
April 1-May 31	2.18	32.54	11.87	20.66
June 1 -September 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 -September 30	4.95	66.17	25.41	42.95
Seasonal	6.26	85.70	32.36	55.36
Average percent runoff:	Record	Period weight	Plots	Watershed weight
April 1-May 31	37.30	1.09	17.40[b]	2.14
June 1 -September 30	33.34	0.96	17.40	1.91
Seasonal	34.16	1.00	17.40	1.96

[5]Source of storm record and runoff data: Howard P. Johnson. Flood-producing storms and associated runoff in the Nepper Watershed. Private communication. 1957.

[a]Watershed runoff is from the entire 480-acre watershed area under 1950-54 land use conditions; while floodplain overflow originates under similar land use from the 293-acre sector contributing to on-site crop flood damage.

[b]Runoff percentages approximated from 1950-54 watershed land use conditions and 1948-56 plot runoff studies at the Western Iowa Experimental Farm (see Table 34 for plot results).

APPENDIX C: INPUT OUTPUT DATA FOR ALTERNATIVE STRUCTURES

Table 38. Detailed design specifications and construction outlays for Nepper Watershed structures installed in 1948[1]

Specifications and construction outlays	Units	Main drainage: Chute-bridge	Drop inlet	Drop inlet	Drop spillway	Levees	Total	Southwest drainage drop inlet	Watershed total
Structure location[a]	00+00	66+97	57+00	34+93	20+00	(20+00 to river)	---	33+49	---
Site area[b]	acres	1.79	6.20	1.95	0.14	2.10	12.18	2.65	14.83
Drainage area	acres	89	125	157	157	293[c]	157	57	350
Height or drop	feet	33	31	14	7	6	85[d]	25	---
Detention capacity	ac.ft.	0	14	0	0	0	14	8	22
Maximum inflow[e]	cfs.	full-flow	440	full-flow	1,100	full-flow	1,100	165	---
Maximum outflow[e]	cfs.	full-flow	16	full-flow	660	full-flow	660	34	---
Peak flow reduction[e]	cfs.	0	424	0	440	0	432	131	---
Earth fill	cu.yds.	10,500	36,000	4,000	850	14,212	65,562	14,400	79,962
Construction outlay	dollars	15,261	18,565	9,000	14,600	4,929	53,510[f]	10,600[g]	64,529

[1]Source of data other than site areas: Little Sioux Flood Control Office, Sioux City, Iowa. Private communication. 1957.

[a]Refer to Figure 10 in text for locations.

[b]Site areas of structures other than levees are approximated as being proportional to earth fill volume represented by the drop inlet at Station 57+00, or by 0.17 acres per 1,000 cu. yds. of earth fill volume. Site area of levees is estimated with reference to 80 feet in total base width and 1,143 feet in length, measured from Station 20+00 to the Maple River.

[c]Levees are assumed to drain all sectors designated by F and O in Figure 10. The area of the main drainage proper, however, is limited to the sectors designated by M in Figure 10.

[d]Drainage total excludes levee height.

[e]Peak flow data applicable to storms of 50-year recurrence intervals.

[f]Includes $1,159 in structure-related channel improvement between Stations 57+00 and 20+00.

[g]Includes $419 in structure-related channel improvement above Station 33+49.

Table 39. Capital outlays for Nepper Watershed structural measures as installed in 1948

Outlay items by measures	Main drainage			Southwest drainage group	Watershed total
	Road chute	Drainage group	Levees		
	(dollars)	(dollars)	(dollars)	(dollars)	(dollars)
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 38. Units for measures I, II, and IV are in 1,000 cu. yds. of earth fill; units for measure III are feet of bank height.

[b]Estimated from site area requirements (Table 38) and the present value of maximum annual net income per acre, capitalized over 50 years at 5 percent.

[c]From Table 38.

[d]Maintenance costs for measures I, II, and IV are estimated as being proportional to earth fill volumes, and are based on a $400 farmer contribution in 1948 toward continued maintenance of measure II. Maintenance costs for measure III are estimated as being equivalent to a similar farmer contribution of $360.

Table 40. 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
Measure designations	--	I[b]	II[c]	III[d]	IV[e]
Site area	acres	1.79	8.29	2.10	2.65
Drainage area	acres	88.95	157.53	293.14	48.00
Height or drop[f]	feet	33.00	52.00	6.00	25.00
Flood control; per storm[g]	ac.ft.	--	31.00	20.82	13.30
per season	ac.ft.	18.70	49.80	33.50	21.30
Flow reductions; 10-yr.[h]	cfs.	0	286	0	98
Fill volumes; earth	cu.yds.	10,500	40,850	14,212	14,400
Installation increment	1.00	1,000 yds.earth	1,000 yds.earth	1 ft. height	1,000 yds.earth
Installed increments[i]	--	10.50	40.85	6.00	14.40

[a]Design data for each measure based on data for individual structural improvements given in Table 38.

[b]Road chute located at station 66 + 97; see Figure 10 in text for this and following locations.

[c]Includes a dry-pond drop inlet at station 57 + 00, a drop inlet at station 34 + 93, a drop spillway at station 20 + 00, and necessary channel improvement.

[d]Levees extend 1,143 feet, from station 20 + 00 to the Maple River.

[e]Includes a drop inlet at station 33 + 49 and necessary channel improvement.

[f]Effective height refers to vertical drop for measures I, II, and IV; and to levee bank height for measure III.

[g]Floodwater control refers to prevention of bridge undermining by the full-flow chute for measure I and detention capacity for other measures. Floodwater control per season is approximated as the product of control per storm and the average number (2.8) of flood-producing storms occurring in the Nepper Watershed from April 1 through September 30 over the period 1950-54. See Table 37 for storm record.

[h]Flow reductions are computed as the difference between average design inflow and outflow for storms of the given recurrence interval.

[i]For measures I, II, and IV refer to item 8; for measure III refer to item 4.

Table 41. Incremental design and cost data for Nepper Watershed structural measures installed in 1948[a]

Design specifications and cost items	Units	Road chute	Drainage group	Levees	Southwest drainage group
Designated measures[b]		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-yr.[c]	cfs.	0	7.00	0	5.00
Site requirements; total	acres	0.170	0.023	0.350	0.184
By field units[d]	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[e]	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 39 and 40 on a per unit installed basis.

[b]Structure types and locations are as indicated in footnotes b through e in Table 40.

[c]Measures are designed for storms of 50-year recurrence, but 10-year recurrence interval reductions are utilized to estimate effectiveness of gully control features.

[d]Refer to Figure 2 in text for field unit locations.

[e]Site acquisition costs are based on maximum net returns obtained from utilizing field units 7-3, 7-4, and 6-7 for crop production; and an actual payment of $370 for necessary right-of-way from farmstead unit 4-f. No alternative use is assumed for field unit 6-4 because it included part of the area voided by the main gully prior to installation.

APPENDIX D: COST AND RETURN DATA APPLICABLE TO ALTERNATIVE TREATMENT ACTIVITIES AND WATERSHED PROGRAMS

Table 42. Predevelopment returns and costs distributed by potential private participants

Items by private participants[a]	1 Cassidy	2 Daley	3 Engleke	4 Rossel	5 Means	6 Nepper	7 Ullrich	Total private[b]
	(dol.)	(dol.)	(dol.)	(dol.)	(dol.)	(dol.)	(dol.)	(dol.)
Annual returns								
Gross value of crops produced	247	513	1,152	2,004	2,152	7,616	6,066	19,750
Annual costs[c]								
Direct production expense	95	367	763	781	881	3,408	2,422	8,717
Gully damage; main drainage	0	4	1	30	0	66	0	101
Gully damage; southwest drainage	0	0	0	0	22	14	0	36
Flood damage; on-site crops	0	0	0	0	0	0	2,803	2,803
Total annual costs	95	371	764	811	903	3,488	5,225	11,657
Net value of crops produced	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-hrs.)	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]Farm units numbered as in Figure 11 and identified by current (1957) owners.

[b]Transferred to column 1 of Table 10 in text.

[c]Cost items included in Tables 10 and 43 but omitted here are uniformly zero.

[d]Farmstead cover, for damage evaluation purposes only, is assumed equivalent to continuous corn with no supplemental practices.

Table 43. Post-Little Sioux returns and costs distributed by private participants

Items by private participants[a]	1 Cassidy (dol.)	2 Daley (dol.)	3 Engleke (dol.)	4 Rossel (dol.)	5 Means (dol.)	6 Nepper (dol.)	7 Ullrich (dol.)	Total private[b] (dol.)
Annual returns								
Gross value of crops produced	260	565	1,176	1,746	2,112	7,051	5,629	18,539
Annual costs[c]								
Direct production expense	95	369	786	969	960	3,444	2,594	9,217
Land treatment installation	0	0	0	0	0	4	0	4
Structure installation	0	0	0	0	0	299	167	466
Structure maintenance	0	0	0	1	1	22	19	43
Total annual costs	96	369	786	970	961	3,769	2,780	9,730
Net value of crops produced	165	196	390	776	1,151	3,282	2,850	8,809
Initial installation; land treatment	0	0	0	0	0	80	0	80
Initial installation; structures	0	0	0	17	11	5,871	2,712	8,611
Watershed area in corn (percent)	50	100	50	41	44	25	52	46
Watershed area in oats (percent)	25	0	50	19	32	22	22	23
Watershed area in meadow (percent)	25	0	0	40	24	53	36	31
Labor use (man-hrs.)	33	132	253	406	354	1,393	940	3,511
Rates of sheet erosion (tons per acre)	13	103	41	40	12	8	10	23

[a]Farm units numbered as in text Figure 12 and identified by current (1957) owners.

[b]Transferred to column 1 of Table 12.

[c]Cost items included in Table 42 but omitted here are uniformly reduced to zero.

Table 44. Benefits and costs of the Little Sioux Program in the Nepper Watershed; distributed by private participants[a]

Items by private participants	1 Cassidy	2 Daley	3 Engleke	4 Rossel	5 Means	6 Nepper	7 Ullrich	Total private[b]
	(dol.)	(dol.)	(dol.)	(dol.)	(dol.)	(dol.)	(dol.)	(dol.)
Changes in annual returns								
1. Gross value of crops produced	13	52	24	-258	-40	-565	-437	-1,211
Changes in annual costs[c]								
2. Direct production expense	0	2	23	188	79	36	172	500
3. Gully damage; main drainage	0	-4	-1	-30	0	-66	0	-101
4. Gully damage; southwest drainage	0	0	0	0	-22	-14	0	-36
5. Flood damage; on-site crops	0	0	0	0	0	0	-2,803	-2,803
8. Land treatment installation	0	0	0	0	0	4	0	4
9. Structure installation	0	0	0	0	0	299	167	466
10. Structure maintenance	0	0	0	1	1	22	19	43
11. Total cost decreases	0	-4	-1	-30	-22	-80	-2,803	-2,940
12. Total program benefits (Item 1 less item 11)	13	56	25	-228	-18	-485	2,366	1,729
13. Total program cost (increases)	0	2	23	189	80	361	358	1,013
14. Net benefits (Item 12 less item 13)	13	54	2	-417	-98	-846	2,008	716
15. Ratio of total benefits to costs	d	28.00	1.08	-1.20	-0.225	-1.34	6.60	1.70

[a]Data derived from Table 43 less Table 42.

[b]Transferred to column 1 of Table 13 in text.

[c]Cost items 6 and 7 included in Table 14 but not here are uniformly non-applicable to private participants.

[d]Infinitely large because of zero costs.

Table 45. Annual per-acre erosion rates and on-farm returns of selected erosion-controlling land use systems on field unit 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				
412	2.57				
420	1.16				
421	0.89				
422	0.63				
500	4.10				
501	3.15	(Computations for remaining systems obviated by infrequent corn)			
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 Figure 11 for code explanations.

[b]Returns and costs computed only for systems involving the three most corn-frequent rotations controlling erosion, excepting system 700 below.

[c]On-farm returns to land are maximized by system 122 and returns to capital by system 700; while maximum erosion control from corn-frequent systems is obtained from system 322.

Table 46. Returns and costs of the current (1957) resource-use program in the Nepper Watershed; distributed by private participants

Benefit-cost items by watershed farms[a]	1 Cassidy	2 Daley	3 Engleke	4 Rossel	5 Means	6 Nepper	7 Ullrich	Total private[b]
	(dol.)	(dol.)	(dol.)	(dol.)	(dol.)	(dol.)	(dol.)	(dol.)
Equivalent annual returns								
Gross value of crops produced	195	708	1,508	2,433	2,640	9,291	7,220	23,995
Equivalent annual costs								
Direct production	71	308	782	1,123	1,115	3,408	2,996	9,803
Flood damage; on-site crops	0	0	0	0	0	0	984	984
Land treatment installation	0	0	0	0	0	4	0	4
Structure installation	0	0	0	0	0	299	167	466
Structure maintenance	0	0	0	1	1	22	19	43
Total annual costs	71	308	782	1,124	1,116	3,733	4,166	11,300
Net value of crops produced	124	400	726	1,309	1,524	5,558	3,054	12,695
Initial installation; land treatment[b]	0	0	0	0	0	80	0	80
Initial installation; structures[c]	0	0	0	17	11	5,871	2,712	8,611
Watershed area in corn (percent)	50	20	51	59	38	42	61	49
Watershed area in oats (percent)	50	18	42	21	34	19	24	25
Watershed area in meadow (percent)	0	62	7	20	28	39	15	26
Labor use (man-hrs.)	26	183	274	370	372	1,342	894	3,461
Rates of sheet erosion (tons per acre)	28	29	38	58	5	11	11	25
Grade commercial fertilizer (cwt.)[d]	0	4	18	77	47	18	14	178
Percent nitrogen - percent P_2O_5[d]	0	10-14	10-14	20-10	10-20	10-12	20-10	--

[a]Farm units numbered as in Figure 19 and identified by current owners.

[b]Includes farmer contributions toward installation of terraces on fields 6-3 and 6-7 in Figure 19.

[c]Includes farmer contributions toward existing structures installed in the 1948 Little Sioux Program.

[d]Applications of available nitrogen and P_2O_5 per cropland acre are converted to equivalent commercial grades and amounts by farms.

Table 47. Returns and costs of the current (1957) resource-use program in the Nepper Watershed; distributed by private and public participants

Items by participants	On-site Private[a] (dollars)	On-site Public (dollars)	On-site Total (dollars)	Off-site public (dollars)	Total public (dollars)	Watershed total (dollars)
Equivalent annual returns						
Gross value of crops produced	23,995	0	23,995	0	0	23,995
Equivalent annual costs						
Direct production expense	9,803	0	9,803	0	0	9,803
Flood damage; on-site crops	984	0	984	0	0	984
Flood damage; on-site bridge	0	0	0	0	0	0
Flood damage; off-site	0	0	0	130	130	130
Land treatment installation	4	0	4	4	4	8
Structure installation	466	112	578	2,577	2,689	3,155
Structure maintenance	43	0	43	0	0	43
Total annual costs	11,300	112	11,412	2,711	2,823	14,123
Net value of crops produced	12,695	-112	12,583	-2,711	-2,823	9,872
Initial installation; land treatment[b]	80	0	80	113	113	193
Initial installation; structures[c]	8,611	3,174	11,785	71,105	74,279	82,890
Total initial installation	8,691	3,174	11,865	71,218	74,392	83,083

[a] Transferred from Table 46.

[b] Includes installation of terraces on fields 6-3 and 6-7 in Figure 19.

[c] Includes existing structures installed in the 1948 Little Sioux Program.

Table 48. Benefits and costs of optimal 1957 adjustments in the Nepper Watershed; distributed by private participants

Benefit-cost items by watershed farms[a]	1 Cassidy (dol.)	2 Daley (dol.)	3 Engleke (dol.)	4 Rossel (dol.)	5 Means (dol.)	6 Nepper (dol.)	7 Ullrich (dol.)	Total private[b] (dol.)
Initial installation; land treatment	163	222	815	265	804	1,958	1,796	6,023
Percent initial installation	2.66	3.63	13,34	4.34	13,16	32.05	29.82	99.00
<u>Equivalent annual benefits</u>								
Increased crop values	241	329	1,206	393	1,190	2,895	811	7,065
Permitted intensive floodplain use	0	0	0	0	0	0	861	861
Flood control; on-site crops	0	0	0	0	0	0	984	984
Total annual benefits	241	329	1,206	393	1,190	2,895	2,656	8,910
Percent annual benefits	2.69	3.66	13.43	4.37	13.25	32.24	29.61	99.25
<u>Equivalent annual costs</u>								
Increased production expense	103	141	519	169	512	1,249	1,144	3,837
Amortized installation	9	12	45	15	44	107	98	330
Total annual costs	112	153	564	184	556	1,356	1,242	4,167
Percent annual costs	2.69	3.66	13.43	4.37	13.25	32.24	29.61	99.25
Annual net benefits	129	176	642	209	634	1,539	1,414	4,743
Net benefits per unit cost	1.14	1.15	1.14	1.14	1.14	1.14	1.14	1.14
Marginal net benefits	0	0	0	0	0	0	0	0

[a]Farm numbered as in Figure 18 and identified by current (1947) owners.

[b]Transferred to first column of Table 49.

Table 49. Benefits and costs of optimal 1957 adjustments in the Nepper Watershed; distributed by private and public participants

Benefit-cost items	On-site			Off-site public	Total public	Total program
	Private[a]	Public	Total			
	(dollars)	(dollars)	(dollars)	(dollars)	(dollars)	(dollars)
Initial installation; land treatment	6,023	0	6,023	85	85	6,108
<u>Equivalent annual benefits</u>						
Increased crop values	7,065	0	7,065	0	0	7,065
Permitted intensive floodplain use	861	0	861	0	0	861
Flood control; on-site crops	984	0	984	0	0	984
Flood control; off-site	0	0	0	67	0	67
Total annual benefits	8,910	0	8,910	67	67	8,977
Percent annual benefits	99.25	0	99.25	0.75	0.75	100.00
<u>Equivalent annual cost</u>						
Increased production expense	3,837	0	3,837	29	29	3,866
Amortized installation	330	0	330	3	3	333
Total annual costs	4,167	0	4,167	32	32	4,199
Percent annual costs	99.25	0	99.25	0.75	0.75	100.00
Annual net benefits	4,743	0	4,743	35	35	4,778
Net benefits per unit cost	1.14	0	1.14	1.14	1.14	1.14
Marginal net benefits	0	0	0	0	0	0

[a]Transferred from last column of Table 48.

Table 50. Returns and costs in an optimal 1957 resource-use program in the Nepper Watershed; distributed by private participants

Items by private participants	1 Cassidy	2 Daley	3 Engleke	4 Rossel	5 Means	6 Nepper	7 Ullrich	Total private[b]
	(dol.)	(dol.)	(dol.)	(dol.)	(dol.)	(dol.)	(dol.)	(dol.)
<u>Equivalent annual returns</u>								
Gross value of crops produced	436	1,037	2,714	2,826	3,830	12,186	8,892	31,921
<u>Equivalent annual costs</u>								
Direct production expense on farms	174	449	1,301	1,292	1,627	4,657	4,140	13,640
Installed structures	0	0	0	0	0	299	167	466
Structure maintenance	0	0	0	1	1	22	19	43
Land treatment installation	9	12	45	15	44	111	98	334
Total annual costs	183	461	1,346	1,308	1,672	5,089	4,424	14,483
Net value of crops produced	253	576	1,368	1,518	2,158	7,097	4,468	17,438
Initial installation; land-treatment	163	222	815	265	804	2,038	1,958	6,023
Initial installation; structures	0	0	0	17	11	5,871	2,712	8,611
Total initial installation	163	222	815	282	815	7,909	4,670	14,634
Watershed area in corn (percent)	100	21	50	32	70	68	84	64
Watershed area in oats (percent)	0	20	25	34	15	12	8	17
Watershed area in meadow (percent)	0	59	25	34	15	20	8	19
Labor use (man-hrs.)	31	184	333	438	352	1,165	907	3,410
Miles of 2-inch level terraces	0.344	1.334	4.071	4.107	1.641	20.581	4.281	36.359
Acres contoured	0	1	4	11	10	17	9	52
Grade commercial fertilizer (cwt.)[a]	12	24	105	80	150	403	256	1,030
Percent nitrogen - percent P_2O_5[a]	30-10	10-20	10-16	5-20	16-10	16-10	24-10	--

[a]Applications of available nitrogen and P_2O_5 per cropland acre are converted to equivalent commercial grades and amounts by farms.

Table 51. Returns and costs in an optimal 1957 resource-use program for the Nepper Watershed; distributed by private and public participants

Items by participants	On-site			Off-site public	Total public	Watershed total
	Private[a]	Public	Total			
	(dollars)	(dollars)	(dollars)	(dollars)	(dollars)	(dollars)
Equivalent annual returns						
Gross value of crops produced	31,060	0	31,060	0	0	31,060
Permitted intensive floodplain use	861	0	861	0	0	861
Total annual returns	31,921	0	31,921	0	0	31,921
Equivalent annual costs						
Direct production expense on farms	13,640	0	13,640	29	29	13,669
Gully damage; all drainages	0	0	0	0	0	0
Flood damage; on-site bridge and crops	0	0	0	0	0	0
Flood damage; off-site	0	0	0	63	63	63
Installed structures	466	112	578	2,577	2,689	3,155
Structure maintenance	43	0	43	0	0	43
Land treatment installation	334	0	334	7	7	341
Total annual costs	14,483	112	14,595	2,676	2,788	17,271
Net value of crops produced	17,438	-112	17,326	-2,676	-2,788	14,650
Initial installation; land treatment[b]	6,023	0	6,023	286	286	6,309
Initial installation; structures[c]	8,611	3,174	11,785	71,105	74,279	82,890
Total initial installation	14,634	3,174	17,808	71,391	74,565	89,199

[a]Transferred from Table 50.

[b]Includes installation of the terraces and permanent meadow shown in Figure 19.

[c]Includes existing structures installed in the 1948 Little Sioux Program.