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H. P. Johnson
Iowa State University

K. E. Saxton
Iowa State University

D. W. DeBoer
Iowa State University

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The Effect of Man on Water Yield,[1] Peak Runoff and Sedimentation

H. P. JOHNSON[2], K. E. SAXTON[3] AND D. W. DEBOER[4]

Abstract. Man can alter several facets of the hydrologic cycle appreciably. Those facets most easily altered are related to vegetative cover and surface geometry either on the land or in the drainage system. Changes brought about by man affect surface runoff and base flow, timing and peak discharges of flood flows, and water yields. Cover changes and more efficient drainage systems increase sediment delivery to streams. This paper attempts to define evidence of changes, and to comment on our present understanding of the extent of changes.

In recent years, much emphasis has been placed on management of resources in view of growing populations and affluence, coupled with reduced resources. Wise planning of resource use requires knowledge of the physical aspects of the resource system involved as they relate to the economic and social aspects.

Our ability to quantitatively describe the effect of man on water and land resources is increasing. However, many facets of natural systems such as the hydrologic cycle are yet poorly defined. It is difficult to prove that man can increase or decrease the total runoff of the Nishnabotna River, although there is evidence that he can. It is not always possible to distinguish clearly between natural and man-induced erosion even though we are certain man has been an influence.

There is little evidence that man has had a profound effect on the earth's energy balance and the accompanying transfer of moisture over the earth. He has primarily altered the cover and configuration of the earth's surface. In so doing, he has changed the quantity and rate of runoff and the rate of erosion and sedimentation.

Stream flow and erosion are the result of complex processes. The relative effect of factors defined in the hydrologic cycle varies from one location to another. For example, stream flow from the sand hills of Nebraska is derived primarily from the underground aquifers. In contrast, the claypan areas of Missouri primarily provide surface runoff because little water percolates to the ground water to reappear as stream flow.

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[2] Professor, Iowa State University, Ames.

[3] Hydraulic Engineer, Iowa State University, Ames.

[4] Research Associate, Iowa State University, Ames.

In this paper, we will limit the discussion to Iowa and to selected activities of man. Our objectives are to (1) define the facets of the hydrologic cycle that man alters, (2) describe and provide quantitative examples of these alteration effects, and (3) provide an understanding of the processes involved.

IOWA—AREA OF CONSIDERATION

The primary factors of interest that relate to stream flow and erosion are climate and soil. Iowa's climate is subhumid, and the precipitation normally exceeds evaporation and falls primarily as rain during the growing season. Iowa's renewable water resources are derived from an average annual precipitation of about 31 inches, of which about 80% is consumed through evaporation and transpiration. Average annual natural runoff is about 6 inches, although variations of more than 50% of the average are commonly recorded at gaging stations on large Iowa streams (U.S. Water Resources Council, 1968).

The parent material for about 40% of Iowa soils is glacial drift; loess-derived soils also account for about 40%. Most of the others are alluvial soils. Much Iowa land is relatively flat; nearly 75% has slopes of less than 10%. The portion of North Central Iowa within the region affected by the Wisconsin glacial intrusion is relatively level and drainage systems are poorly defined. Western Iowa, a region of deep loess, and Southern Iowa have a high percentage of sloping-to-steep topography (Oschwald, et al., 1965).

PROCESSES INVOLVED

Before discussing the effect of man's specific activities, the primary phenomena contributing to the generation of stream flow, peak rates, and sediment yield under Iowa conditions should be considered. It will then be possible to delineate and discuss those processes that man can alter by his activities.

Water yield is the total water passing a given point in a stream per unit of time. The source of this water can usually be divided into two phases—that from direct surface runoff during and soon after rainfall and that seeping from ground water storage. Direct runoff results when rain falls at a rate faster than the soil infiltration rate. Thus, water is accumulated on the soil surface and, once all small depressions are filled, water is transported on the surface toward the streams.

Seepage flow, or ground water outflow, is derived from infiltrated water that continues to percolate vertically until it joins the ground water, where it moves on some gradient toward the stream. This vertical movement through the soil is quite complex and is not well understood. We do know that, in Iowa, once water is infiltrated into the soil, it is usually stored in the root zone until it is returned to the atmosphere by evaporation or transpiration. Only when this soil root zone is quite wet does any appreciable amount of water percolate downward toward the ground water.

In this summary of water yield generation, we have mentioned several processes—precipitation, infiltration, depressional storage, overland flow, root zone storage, percolation, and aquifer seepage. From these processes, we must sort out those which man can affect. Since our major activity is at the soil surface, a few feet above, and a few inches below, this largely limits the region of our effect.

We can start by noting that man has little or no control or effect on precipitation. It is difficult to make a direct statement for the other processes. For example, man usually does not directly alter the percolation rate; however, the percolation rate is dependent upon the infiltration and root zone storage processes, which man does alter. Perhaps a logical separation might be achieved if one asks, "Does man alter the potential (flow or storage) of the process?" Let us define direct effects as those in which the potential is altered and the other effects as indirect. Thus, of the processes listed, man would have no effect on precipitation; indirect effects on root zone storage, percolation, and aquifer seepage; and direct effects on infiltration, depressional storage, and overland flow.

The peak rate of stream flow is primarily the result of the amount of surface runoff generated, the time distribution of this generation, and the channel system through which it is delivered from the point of generation to a specific point of the stream. The rate and amount of runoff generation is a function of the rainfall rate, infiltration rate, and depressional storage which were previously considered. Stream channels are often altered. These alterations vary from the channel systems of contour farming and graded terraces to large reservoirs and dredged channels. The delivery system can be described in terms of channel slope, roughness, cross section, storage, and drainage density.

The sediment transport of a stream is closely related to the processes of hydrology we have considered. The movement of a soil particle from a field to a point in a river can be divided between detachment and transport, but those have not usually been isolated on a field basis. The major effects governing field sediment yield have been described (Wischmeier and Smith, 1965) as rainfall, soil erodibility, length of slope, slope gradient, cropping and management, and erosion control practices. Of these variables, man has no effect on rainfall, some effect on soil erodibility and slope gradient, and a direct effect on the length of slope, cropping and management, and erosion-control practices.

Little is known of the erosional process from field to stream. A complex and highly variable interrelation of deposition, redetachment, and transportation is involved. These processes all occur at the land surface and are therefore subject to man's interferences. Once the sediment has been delivered to a stream channel, channel transport is dominant but, again, little is known of the principles involved. Channel transport is dependent on the sediment characteristics, channel geometry, and rate of flow. Man influences these processes by such actions as dam construction, channel straightening and dredging. Thus, man directly affects several phases of sedimentation from field erosion to channel transport.

THE EFFECTS OF MAN

We have defined the characteristics of the area considered; looked at the major processes influencing water yield, peak rate, and sediment yield; and taken special note of those processes that were either directly or indirectly affected by man's activities. The effect of these activities will now be related to water yield, peak rates, and sediment yield through the processes considered.

Water Yield. As previously defined, water yield is the total water moving past any point in the drainage system. For upland areas, this water is derived solely from surface runoff. At points downstream, ground water discharge is usually intercepted and added to the surface flow.

Vegetation is probably the most influential variable in the hydrologic cycle and is the variable most manipulated by man. Infiltration is largely dependent upon vegetation. Plants with dense canopies protect the soil surface and increase infiltration, as opposed to a bare soil where direct rainfall puddles the soil surface. Soil moisture content has a significant effect on infiltration and percolation, but soil moisture is a function of infiltration and evapotranspiration (ET), which are both dependent on vegetation.

The surface of bare soil will soon dry. This reduces the amount of water returning to the atmosphere, whereas the plant root system extends to a large volume of soil and continues to withdraw water so long as the atmosphere is demanding water from the plant and there is water available in the root zone. Most lush vegetation under wetted conditions will have similar ET rates. Differences of annual ET amounts result because of growing season length; for example, grasses use water from early spring until late fall compared with corn, for instance, which has lush growth for only 2 to 3 months. Since grasses have shallower roots but use more water, the soil beneath grass often is drier, which causes higher infiltration rates.

These vegetative effects on water yield have been documented by several researchers. Average results of 5 years, 1964-1968, from experimental watersheds near Treynor, Iowa, as shown in figure 1, indicate the decrease of water yield from the grass watershed compared with the corn watersheds (Saxton and Spomer, 1968). Lysimeters and small plots at research stations near Clarinda, Iowa, and Bethany, Missouri have also shown decreased water yield and increased ET from grass compared with corn (Browning et al., 1958.; Smith et al., 1945).

Similar research at McCredie, Missouri, on 1/50-acre plots for 12 years, 1954-1965, shows not only a significant change in water yield with crop but also with fertility level, as shown in Figure 2 (Saxton and Whitaker, 1969).

Each bar height represents the ratio of the observed water yield over that observed on full-fertility meadow. The soils at the McCredie Station are similar to some in South Central and Southeastern Iowa. The fertility effect is undoubtedly the result of increased ET and infiltration because of crops with better canopies and deeper rooting systems.

Terrace and diversion conservation practices have various effects on downstream water yield. Level terraces trap all runoff water and hold it until percolated or evaporated unless their capacity is exceeded. Graded terraces and diversions convey the water to streams but at a slower pace than natural drainageways and with some extra losses from infiltration and evaporation. As shown in Figure 1, the level-terraced corn watershed had total stream flow nearly equal to the other watersheds in corn; however, most of the water came from ground water seepage. There is evidence that the water trapped by the level terraces percolated to the ground

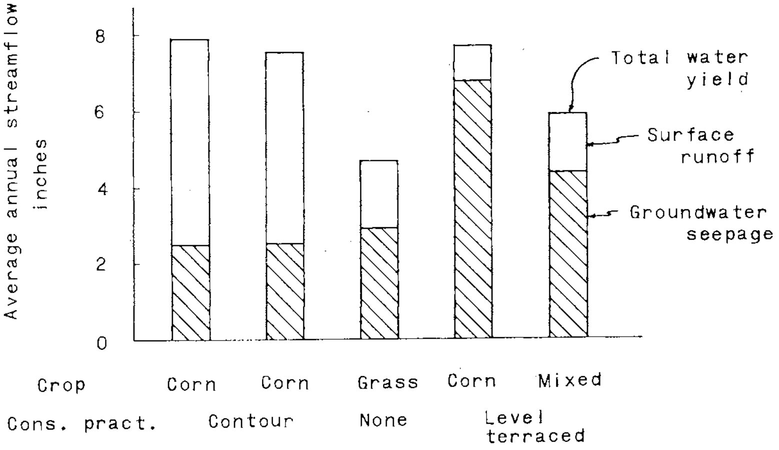

Figure 1. Effect of cover and practices on water yield

water and increased seepage flow. Research on the Clarinda, Iowa, and Bethany, Missouri, research stations showed that graded terraces decrease water yield, but this effect decreased as the terrace slopes increased. However, for large rains or wet soil conditions, graded-terrace systems only slightly reduce water yield (Baird and Potter, 1950).

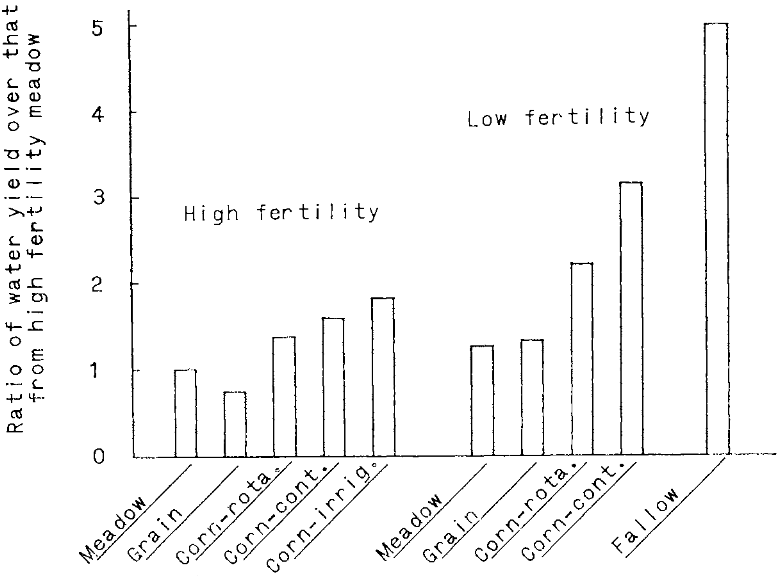

Figure 2. Effect of fertility on water yield

Some farm management practices will affect water yield. Contour rows trap and infiltrate water that otherwise would have run off, particularly for low-to medium-intensity rains. Plant residues on the soil surface and minimum tillage are other management principles that can increase infiltration and reduce stream flow. The effect of management practices is usually less than vegetation changes or terraces; yet, they can be significant.

Peak Rates of Steam Flow. Peak rates of stream flow are primarily the result of the amount of surface runoff, the time distribution of this generated runoff, and the channel system through which the runoff must flow. The amount and time distribution of the runoff is the result of the rainfall rates minus the infiltration rates. The flow systems on upland areas vary from overland flow in thin sheets to small rills or channels to well-defined channels and waterways.

Dense vegetation, conservation practices, and good farm management practices will reduce the runoff volumes, which cause a similar reduction in peak rates. Since level terraces store most surface runoff, they drastically reduce the peak-rates—for all but the unusual storms. Examples of vegetation and level terrace effects on peak rates have been observed on the Treynor, Iowa, loessal watersheds (Saxton and Spomer, 1968). For 82 comparable storms, peak rates from the grass and level-terraced watersheds have been less than 10 percent of those from the contoured-corn watersheds.

Graded terraces do not prevent runoff from reaching the streams, but they do convey it over a longer distance and at a slower rate; thus, water reaches the downstream point more slowly and at reduced peak rates. Good examples of this effect have been shown in Missouri (Hale and Beasley, 1964) and Texas (Baird and Potter, 1950). The effect often is negligible on large watersheds.

Channel Effects. The movement of excess water from a watershed is often separated into overland and channel phases. Recent studies have been made of the channel phase in which features of artificial drainage systems such as drainage ditches, subsurface tile lines, and land grading were related to flood flow changes (Haan and Johnson, 1967). The recently glaciated North Central region of Iowa under study is characterized by shallow, saucer-shaped depressions and has been extensively drained since the early 1900's. Preliminary results indicate that low-intensity rainstroms result in higher peak flows from drained watersheds, while high-intensity rainstorms tend to result in higher flood flows from wet, undrained watersheds. Available storage is an important consideration. Flood discharges on the basis of flow per square mile are small whether the land is drained or undrained compared with steeper watersheds.

The effect of river channelization or river straightening and diking is also an activity that affects flood flows. The Boyer River in Western Iowa has been the center of recent litigation concerning benefits to drainage districts along the river as a result of channel maintenance (Dague et al., 1968). Figure 3 shows a section of the river near Dow City as it appeared in 1938 after channelization. The old river meanders and the new channel are clearly visible. Elimination of the meanders reduced the river length by about 50% and, in turn, doubled the slope of the river. Figure 4 shows the relative size and shape of the natural (1852), constructed (1913), and existing (1968) channels.

The channelization and associated channel degradation of the Boyer River has significantly affected the movement of flood waters down the valley, as shown in Figure 5. The inflow hydrograph is a typical discharge-time relationship which can be expected near Wall Lake approximately 63 miles above the gaging station at

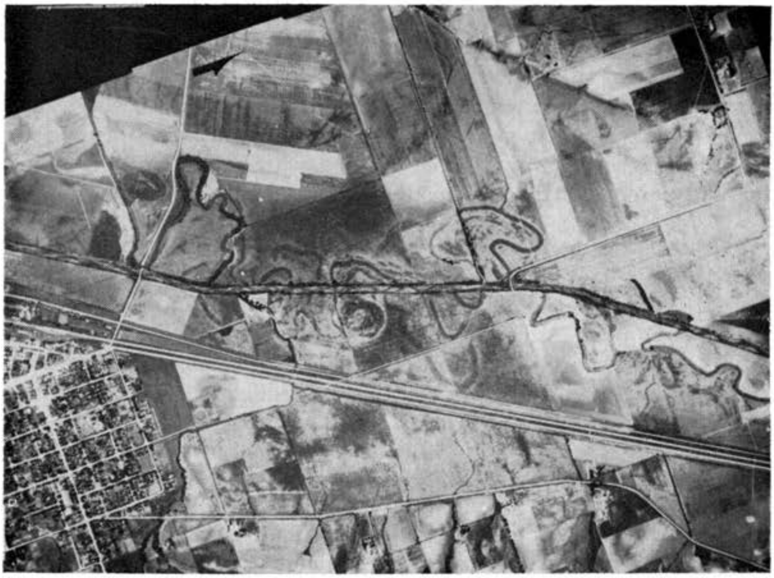

Figure 3. Aerial view of straightened Boyer River

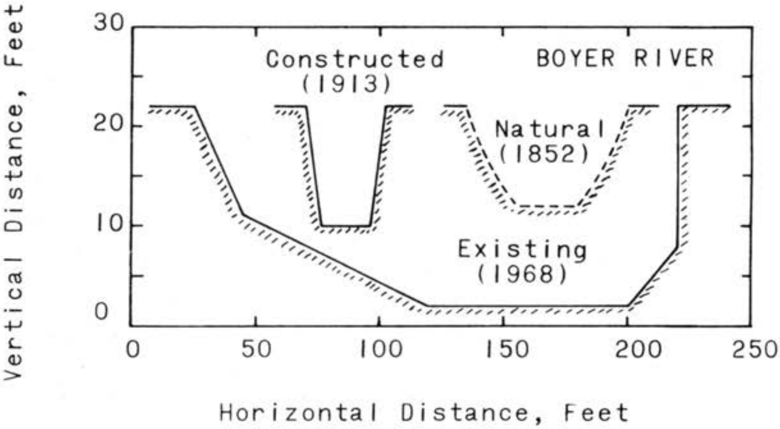

Figure 4. Entrenchment of Boyer River

Logan. The two outflow hydrographs are for the existing channel and the estimated natural channel and flood plain before construction. These hydrographs show that the channel improvement has caused the peak discharge to be greater and reach the downstream point sooner. This effect may cause increased downstream flooding but reduces the upstream flood hazard.

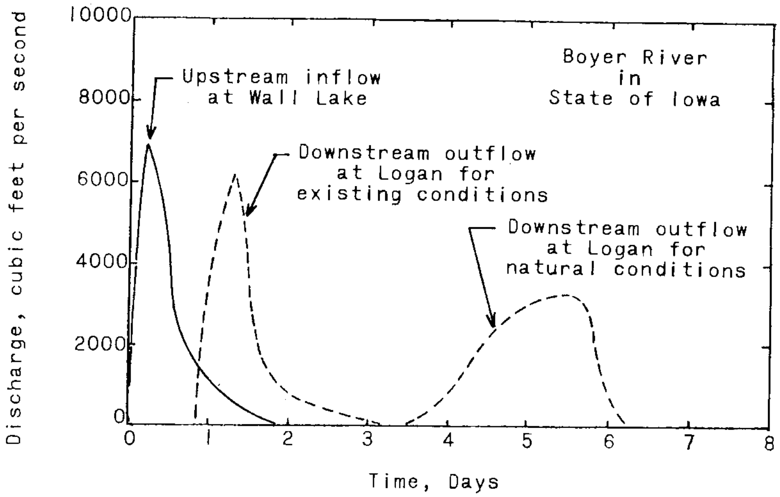

Figure 5. Effect of straightening streams on flood flows

Degradation and widening of a river often accompanies straightening. The associated flow capacity increase may nearly eliminate flooding. For example, the West Fork of the Des Moines River flows through a dredged channel in Palo Alto County. A channel cross section below Emmetsburg which carried flow from 2,200 square miles increased in cross section about three times from the time of construction in 1918 until 1932. While the bottom elevation remained the same, the bank-full capacity increased from 1,700 to about 6,300 cubic feet per second (Schlick, 1939).

Flood control reservoirs can also have a significant effect on flood flows. Iowa has several large reservoirs in existence or under construction, such as the Coralville, Red Rock, Saylorville, and Rathbun reservoirs, plus many smaller reservoirs on upland watersheds. An example of the influence of reservoirs on flood flows is shown in Figure 6, in which the discharge-time relationship for a flood entering and leaving the reservoir is illustrated. Basically, the flood control reservoir stores the flow volume of high rates and releases it at a slow rate. The effect of a given reservoir on flood flows decreases with distance downstream from the reservoir because the percentage of watershed area controlled by the reservoir at points in question decreases with distance downstream. Reservoirs will often reduce the peak river discharge by 50% or more just below the dam. (Pickels, 1941) indicated that the capacity of a reservoir should reduce the flood discharge by at least one-third.

Erosion and Sedimentation. The amount of sediment in streams per unit of contributing area varies greatly in Iowa. The Clarion-

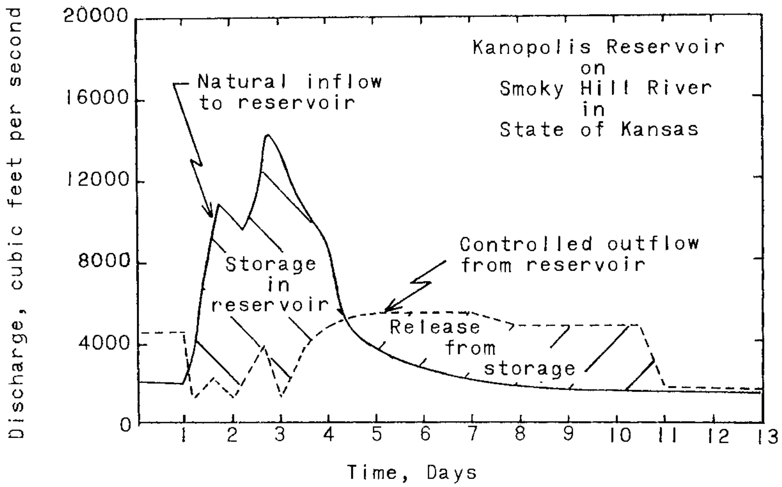

Figure 6. Effect of reservoirs on flood flows

Nicollet-Webster soil association area of North Central Iowa produces very small quantities of sediment. The annual sediment yield for a 100-square-mile watershed in that area is about 50 tons per square mile. This increases to about 500 tons per square mile per year in Northeast Iowa and to about 1,000 tons per square mile in Southeast Iowa (Interagency Task Force on Sedimentation, 1968). Sediment yields are greatest in the deep loess area of Western Iowa where watersheds of similar size contribute 6,000 tons per square mile per year. An average of 12 years of record on the Soldier River gaged at Pisgah, Iowa, indicated an average of more than 10,000 tons per square mile per year for a watershed of 417 square miles—about 15 tons per acre per year.

In general, as the size of the watershed increases, the sediment yield per unit area for a given period for the same physiographic area decreases. Although the relationship is approximate, it may be defined by the exponential equation, $Y = KA^{-n}$, where Y is sediment yield, K is sediment yield for 1 square mile, A is area in square miles, and n is the exponent indicating the decrease with increasing area. Another term, delivery ratio, is sometimes used to express the ratio of sediment delivered, to total erosion on a watershed. The term is used in reservoir design and is often expressed through multiple regression equations which contain factors related to delivery of sediment (Maner, 1968).

The major portion of sediment transported by streams in Iowa is derived from sheet erosion. A study of 36 watersheds by Glymph indicated that gully erosion exceeded 10% of total erosion in only four watersheds (Glymph, 1954). The watersheds with high gully erosion were in Southwest Iowa.

It is well documented that on-site sheet and rill erosion is profoundly affected by cover. Data showing effects of cover and management and conservation practices on several soils are available from 10,000 plot-years of runoff and soil loss data assembled from 47 research stations in 24 states. (Wischmeier and Smith, 1965) present erosion for various covers as a percentage of erosion on a bare, fallow soil. The following table shows the effect of cover.

EFFECT OF COVER ON SOIL LOSS

Cover and Management	Soil Loss, Percentage of that from Fallow
Fourth-year corn; low fertility; conventional tillage	65
Fourth-year corn; high fertility; conventional tillage	50
Moderately productive grass-legume	0.6
Highly productive grass-legume	0.4

Ten years of data from plots near Castana, Iowa, show that average-yielding corn in a corn-oats-sweet clover rotation lost 25 tons per acre per year for tillage up and down the hill and only 10 tons per acre for corn planted on the contour. Second-year meadow (alfalfa-brome) showed only a trace (0.1 ton per acre) of erosion with good management. Similar results were reported by (Piest and Spomer, 1968) for small, single-crop watersheds. Average annual soil loss under corn for 3 years of data was 20 tons per acre; under grazed meadow the loss was less than 1 ton per acre. Thus, erosion from row-cropped areas is approximately 100 times that of good grass cover.

Contouring on short, gentle slopes will reduce erosion to about half that for straight rows. However, contouring alone is not effective for steep or long slopes. Terraces are very effective for erosion control because they reduce slope length and trap most of the eroded soil. A value of 20% of that from contour practice and a slope length equal to the terrace spacing is often used for sediment yield prediction. Thus, erosion from a contoured, terraced field with an average slope of 7% and slope lengths of about 400 feet would be about 10% of that for a similar field under straight-row, unterraced conditions. Sediment losses would be even less for level-terraced or tile-outlet terraced land. It has been shown that well-managed, terraced land will produce little more sediment than grazed pasture. For example, soil loss from a terraced watershed under continuous corn was less than 1 ton per acre as compared with 20 tons per acre on an unterraced watershed (Piest and Spomer, 1968).

The effects of channel improvement on sediment yield are more difficult to define quantitatively because natural and man-induced factors cannot be isolated easily. However, man sometimes removes vegetation and increases erodibility, straightens streams and increases velocity, reduces roughness, enlarges cross sections, and further increases velocity—usually to hasten the removal of water.

The hydraulically efficient channels tend to erode unless carrying heavy sediment loads relative to the stream slope. Tributary channels crossing flat flood plains to larger streams are often clogged by sediment carried from steeper uplands. Ditches on the Missouri River flood plain are good examples. On the other hand, stream channels often increase in cross section, as discussed previously. A well-documented study of Willow Creek in Harrison County (Daniels and Jordan, 1966) describes a channel which widened and degraded after dredging and straightening in 1918. At a point 2½ miles north of the Monona-Harrison County line, the creek was about 11 feet deep and 40 feet wide in 1920. Measured bed slopes were about 10 feet per mile. In 1960, the channel was about 45 feet deep and 120 feet wide. The decreased bed elevation has resulted in the development of deep gullies in the small upland watersheds because their depths are primarily controlled by the bed elevation of Willow Creek. Natural and man-induced erosion cannot be separated, but man has played a prominent part in the valley trenching in the deep loess of Iowa.

Reservoir sedimentation, largely man-induced, is a severe problem in Iowa. The trap efficiency—that is, the ratio of sediment trapped in the reservoir to the sediment delivered to the reservoir—is usually 80 to 100%. Thus, a fairly accurate estimate of the life of a reservoir can be made from knowledge of stream sediment load and particle size. An annual storage loss of 0.3% to 3% is common for large reservoirs. The trap efficiency of the Coralville Reservoir is about 94%. About 6% of the upper-level conservation pool was occupied by sediment 5 years after construction. At the present rate of sedimentation, the reservoir will be seriously impaired in 75 years.

The gross erosion and delivery ratio are critical aspects of small reservoir design. Ponds below watersheds heavily row cropped without conservation practices may lose their recreational value in 10 to 20 years. The permanent pool of a small reservoir in the Mule Creek Watershed, Mills County, was filled in 12 years; surveys of similar reservoirs in Honey Creek Watershed, Lucas County, where better conservation practices were used, showed annual storage losses of from less than 1 to 2½% of the permanent pool (Economic Research Service and Soil Conservation Service, 1965).

CONCLUSION

As the demand for food increases, the better Iowa land will probably be planted to clean-tilled crops. About 26 million acres of the total (36 million acres) in the state is cropland. Nearly two-thirds of the cropland has been in row crops in recent years. The rate of fertilizer application has increased, insuring lush growth when water is available.

There is evidence that switching from a well-managed, deep-rooted grass cover to row crops would increase annual water yields by at least 2 inches in Iowa. Grass cover would considerably reduce peak flows from severe storms in the deep loess and would, in most instances, reduce peak flows from other soil areas. Good cover, in contrast to row crops, reduces erosion by about 100 times. On terraced cropland, erosion is less than one-tenth that of unterraced cropland. Higher peak discharges from cultivated, contributing land areas and channel diking and straightening enlarge cross sections of streams in which there is no sediment deposition.

The construction of reservoirs alters sediment transport. In addition to the obvious deposition in the reservoir, there is reduced sediment concentration in the water discharged from the reservoir. Small Iowa reservoirs often become useless for recreation within 20 years; evidence indicates that larger reservoirs will be seriously impaired in less than 100 years.

Human needs require that we use our water and land resources. However, we must preserve these resources by recognizing and understanding man's effect on them, insuring that these effects are not detrimental. By further study and implementing our best practices, we will be able to maintain the quality of our land and water resources.

REFERENCES

BAIRD, R. W. & W. D. POTTER. 1950. Rates and Amounts of Runoff for the Blacklands of Texas. USDA Tech. Bull. No 1022.

BROWNING, G. M., R. A. NORTON, A. G. MCCALL, & F. G. BELL. 1948. Investigation in Erosion Control and Reclamation of Eroded Land at the Missouri Valley Loess Conservation Experiment Station, Clarinda, Iowa, 1931-42. USDA Tech. Bull. No. 959.

DAGUE, RICHARD R., E. ROBERT BAUMANN, & PAUL E. MORGAN. 1968. Interdistrict apportionment of flood-control costs. Amer. Soc. of Civil Eng. Proc. 94. IR4: 441-454.

DANIELS, R. B., & R. H. JORDAN. 1966. Physiographic History and the Soils, Entrenched Stream Systems and Gullies, Harrison County, Iowa. USDA Tech. Bull. No. 1348.

GLYMPH, L. M. 1954. Studies of Sediment Yields from Watersheds. Intern. Association of Hydrology, International Union of Geodesy and Geophysics, Tenth General Assembly, Rome, Publ. No. 36: 178-191.

HAAN, C. T. 1967. Hydraulics of Watersheds Characterized by Depressional Storage. Unpublished PhD Thesis. Ames, Iowa, Library, Iowa State University.

HAAN, C. T. and H. P. JOHNSON. 1968. Hydraulic Model of Runoff from Depressional Areas. Trans. Am. Society Agr. Engineers 11:364-367.

HALE, D. D. & R. P. BEASLEY. 1964. Hydrologic Investigations of the Burge Branch Watershed, Univ. of Mo., Agr. Expt. Station Research Bull. No. 863.

INTERAGENCY TASK FORCE ON SEDIMENTATION. 1968. Fluvial Sediment in the Upper Mississippi River Basin. Draft No. 3, Appendix 6, U.S. Dept. of Army.

MANER, S. B. 1968. Factors Affecting Sediment Delivery Rates in the Red Hills Physiographic Area. Trans. Am. Geophysical Union 39:669-675.

OSCHWALD, W. R., F. F. RIECKEN, R. I. DIDERIKSEN, W. H. SCHOLTES, & F. W. SCHOLLER. 1965. Principal Soils of Iowa. Special Report No. 42. Cooperative Extension Service, Iowa State University of Science and Technology.

PICKELS, GEORGE W. 1941. Drainage and Flood-Control Engineering. McGraw-Hill Book Company, Inc., New York.

PIEST, R. F. & R. G. SPOMER. 1968. Sheet and Gully Erosion in the Missouri Valley Loessal Region. Trans. Am. Society Agr. Engineers 11: 850-853.

SAXTON, K. E. & R. G. SPOMER. 1968. Effects of Conservation on the Hydrology of Loessal Watersheds, Trans. Am. Society Agr. Engineers 11: 848-849, 853.

——————— & F. D. WHITAKER. 1969. The Hydrology of a Claypan Watershed. (Unpublished manuscript of a Missouri Expt. Station Bull. Bulletin in process).

SCHLICK, W. J. 1939. Rainfall and Discharge Records for Northern Iowa Drainage Districts. Iowa Engineering Expt. Station Bull. No. 141.

SMITH, D. D., D. M. WHITT, A. W. ZINGG, A. G. MCCALL, & F. G. BELL. 1945. Investigations in Erosion Control and Reclamation of Eroded Shelby and Related Soils at the Conservation Experiment Station, Bethany, Mo 1930-42. USDA Tech. Bull. No. 883.

USDA. 1966. The Cooperative Water Yield Procedures Study. Development of a Procedure for Estimating the Effects of Land and Watershed Treatment on Streamflow. USDA Tech. Bull. No. 1352.

ECONOMIC RESEARCH SERVICE AND SOIL CONSERVATION SERVICE. 1965. Watershed Program Evaluation, Honey Creek, Iowa. Bull. ERS-204.

U. S. WATER RESOURCES COUNCIL. 1968. The Nation's Water Resources. Supt. of Documents, U. S. Govt. Printing Office, Washington, D.C.

WISCHMEIER, W. H. & D D. SMITH. 1965. Predicting Rainfall-Erosion Losses from Cropland East of the Rocky Mountains, Agr. Handbook No. 282, Agr. Research Service, USDA.