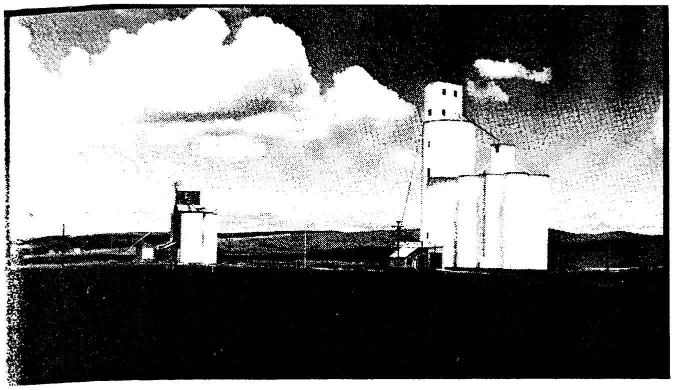
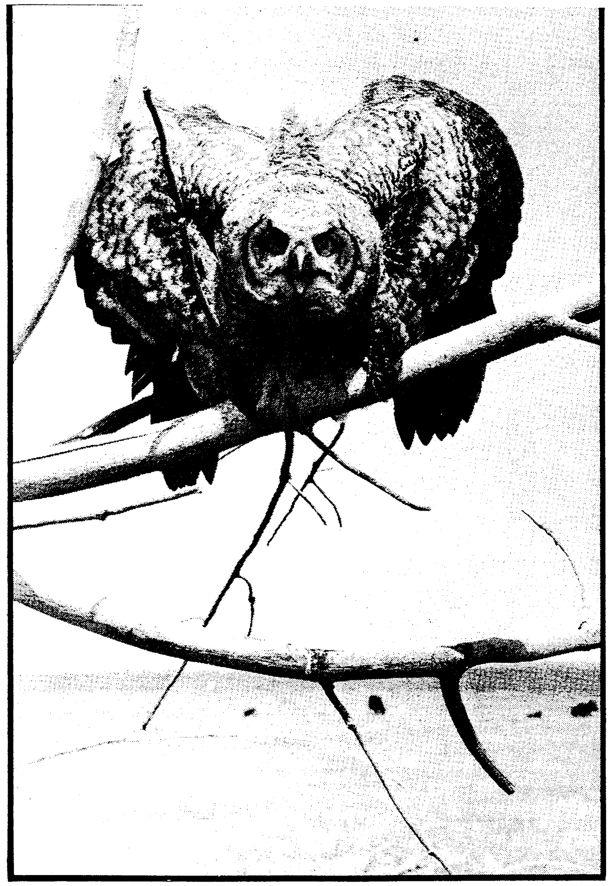
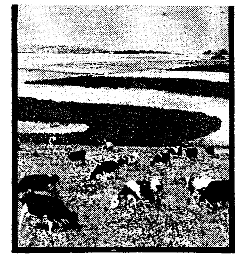
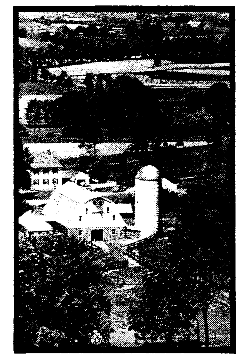
National Agricultural Lands Study

Interim Report Number Four

Soil Degradation: Effects on Agricultural Productivity

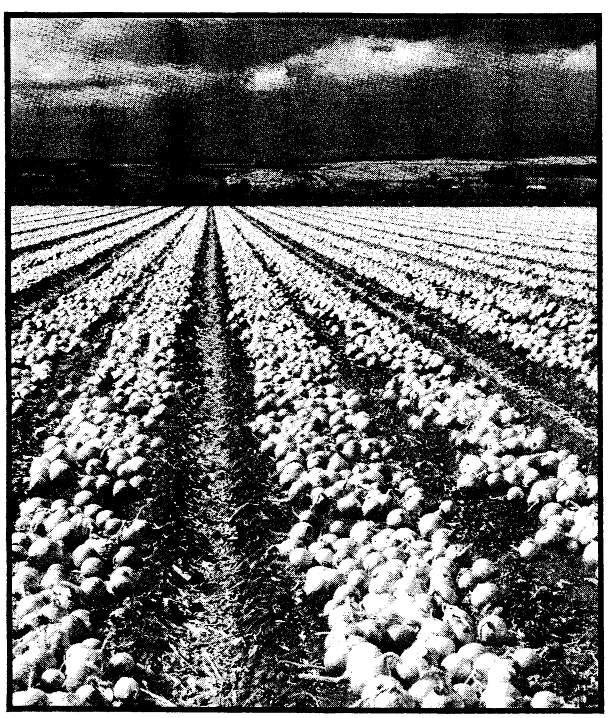




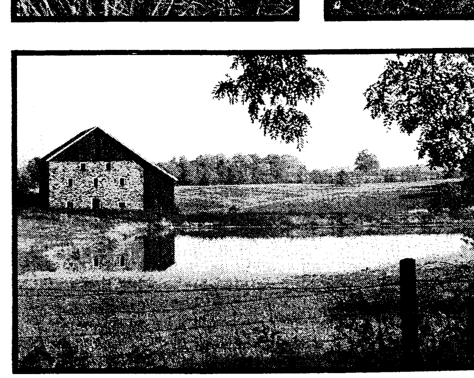










National Agricultural Lands Study

Soil Degradation: Effects on Agricultural Productivity

Prepared by
National Association of Conservation Districts
Washington, D.C.

PREFACE

In the early 1700's — only a scant eighty-five years after the Pilgrims landed on New England's shores — much of Connecticut's rich crop and pasture land was already exhausted by over-grazing and other wasteful farming practices.

Jared Eliot, a Connecticut minister and farmer, was one of the first to question the wisdom of a practice common in his day: farming until the soil wore out, abandoning the land and moving on. In 1787, in the first American book on agriculture, Eliot called attention to soil washing and its dangers. *Save the soil,* he said, with deep plowing and proper drainage.

A generation later, Samuel Deane, a Massachusetts minister and farmer, admonished his neighbors to "toss their dung with an air of majesty" — for agriculture is a noble calling. Deane's book on agriculture had great influence in New England, but more than 150 years would pass before the soil conservation practices he recommended — terracing, stripcropping and contour plowing — gained widespread national acceptance.

The phrase "American soil" was much more than a figure of speech to Thomas Jefferson. At Monticello, Jefferson noticed that rain on bare slopes caused soil to wash away from the hills, leaving them sterile. He recommended countour plowing to prevent gully and sheet erosion wherever sloping lands were cultivated.

Our debt to these and other early American agriculturists is great, for through their observations and teachings an American conservation ethic was born.

In more recent times, the name that stands above all others in the field of soil conservation is Hugh Hammond Bennett, first chief of the USDA Soil Conservation Service. Bennett's timely message during the Dust Bowl Days opened a whole new chapter in the history of natural resource conservation.

In the 1930's, in the Great Plains States, prolonged drought, reckless farming and over-grazing had conspired to damage agricultural land and to impoverish the people. Our croplands were ravaged, farmers were homeless, and Bennett spoke with a prophet's fire and a scientist's conviction: "Poor lands make poor people," he said, "and soil conservation is a basic step in alleviating rural poverty.

"Conservation is possible," Bennett stressed, "only if we use every acre according to its capability, and treat every acre according to its need. You can't farm a flat Indiana field like you would a rolling Georgia slope, or a Vermont mountainside like a Texas River bottom. It is that simple, and that complex."

Fifty years ago, these were revolutionary teachings. Today, they are as fundamental to conservation as the saved soil itself is to the well-being of our nation.

How well have American farmers, environmentalists and the public-at-large responded to Bennett's message?

Certainly progress has been made. Today, there are nearly 3,000 locally-governed conservation districts — one in nearly every county in the U.S. — established under state law to protect and develop soil and water resources within their boundaries. Many of these districts have their own technical staffs.

Today, also, within the USDA Soil Conservation Service that Bennett helped to create, there is a cadre of highly-trained soil conservationists who work through conservation districts in giving direct, on-site help to rural and urban land owners and users who need technical assistance in solving a host of land and water management problems. Soil surveys and soil conservation plans are valuable tools in helping prevent erosion, a work further enhanced by the efforts of agricultural engineers, agronomists, foresters, economists and others.

Yes, our progress has been real. *But much greater progress is needed.*

William J. Brune, state conservationist for the Soil Conservation Service in Iowa, points out that his state is losing two bushels of soil for every bushel of corn produced on unprotected, sloping cropland. "We need to accelerate our soil conservation work in Iowa immediately," he says. "We've lost half of our topsoil in the last hundred years, and if erosion continues at the present rate, vast acreages that are now producing corn and soybeans will be completely lost to these crops within twenty years.

"Erosion-control is never-ending," Brune adds. "We need more food for more people. But the problem is this: every time we help one farmer protect an acre of sloping cropland, a second Iowa farmer may be bringing additional acres of marginal cropland into production. And these marginal acres usually require even more intensive soil conservation."

Brune speaks not only for Iowa, but for many other parts of the nation.

The National Agricultural Lands Study's central concern is the conversion of agricultural land to non-agricultural use. However, as this NALS Interim Report Number Four indicates, we address ourselves as well to the effect of soil erosion upon our present and future ability to produce food for ourselves and for our hungry world.

A recent editorial in the *Northern Illinois Farmer* reflects our concerns. It is entitled, *Learning from the Past.* It reads:

"'Those who do not learn from the past are doomed to repeat it.' said historian George Santayana in one of humanity's most enduring aphorisms. One key lesson to be learned from history is that a civilization maintains its greatness only so long as it is able to feed itself, and it is able to feed itself only so long as it maintains its rich, food-producing soil. The once proud and mighty civilizations of ancient Egypt, Babylon and Greece were literally washed away.

"The 8.5 million acres of cropland in the Palouse region of the U.S. Pacific Northwest, an area that includes parts of eastern Washington, northwestern Idaho, and northeastern Oregon, features some of the world's most fertile and productive topsoil. It has been boasted by agricultural experts in the area that no place in the world, under dryland conditions, grows more wheat per acre...

"Each year, more than 110 million tons of topsoil responsible for this splendid production are lost to erosion. It is estimated that during the last 100 years, erosion has removed more than forty percent of the original topsoil, a loss of an inch of topsoil every fifteen years — an inch that took nature at least 800 years to form. The land beneath this topsoil is drastically less productive, and increasingly more erosive. Unless the soil erosion in the Palouse is checked, one day, in the not too distant future, food production (there) may simply stop.

"Complicating the problem of soil erosion is the difficulty in drumming up public support for efforts to control it. Erosion is insidious."

In conclusion, I quote an excerpt from a recent editorial written by North Carolinian Bob Colver in the *Charlotte News.* Colver writes: "We have in this country a resource of land and water greater than any on earth. And we have had the genius to develop it. The question now is, do we have the wisdom to keep it?"

The question rests.

November 1980

Robert J. Gray
Executive Director
National Agricultural Lands Study
Washington, D.C.

Acknowledgement

The initial draft of this paper was prepared by the staff of the National Association of Conservation Districts as a contribution toward clarifying the current status and condition of America's agricultural lands. We are indebted to the many people who assisted in its writing and review.

Many members of the National Office staff of the USDA Soil Conservation Service were most helpful in providing data and background information, and assisting with the location of source documents. The initial data and materials for the study were assembled, and the first draft of the paper was written by Thomas H. Clarke, Jr., consultant.

Contributors on the NACD staff included Robert E. Williams, Director, Special Projects; Charles Boothby, Executive Secretary; and James E. Lake, Water Quality Specialist. Word Processing was done by Donna K. Smith.

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Final revisions to the paper were made by Dr. Charles M. Benbrook of the Council on Environmental Quality, Washington, D.C. and the NALS staff based on agency review and comment.

Cover design, page layout and print production are the work of Shirley Foster Fields, NALS Director of Information.

Dallas Fields of Falls Church, Virginia edited the manuscript.

R. Neil Sampson
Executive Vice President
National Association of
Conservation Districts

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"There is a limit to the extent to which applied science can temporarily force up soil productivity, but there is no limit except zero to the extent which erosion permanently reduces it."[1]

In the United States, there is growing concern about the ability of our agricultural land to continuously produce the levels of food, fiber, and other materials needed nationally and by our foreign trade partners in the indefinite future.

This concern might seem unwarranted since the United States contains the largest body of prime farm land in the world and feeds a relatively small number of people. In fact, this nation's capacity to dramatically expand production has been a recurring concern. During most of the years since World War II, American agricultural productivity has far exceeded the demand for food and fiber. Accordingly, a principle policy goal has been to restrict agricultural production in order to keep commodity prices within acceptable ranges.

This past preoccupation with excessive production notwithstanding, scientists, in a number of agricultural fields now are expressing concern over the nature and magnitude of current and prospective losses in agricultural productivity. These losses stem, in part, from reductions in quantity and quality of the land resource base. Deterioration of agricultural land quality is viewed as especially serious, given the possible magnitude of future domestic and export demand, as well as the possible slowing of technological advances that enhance farm land production.[2]

Physical processes that degrade soils do not necessarily lead to immediate loss of agricultural production. Different management techniques, genetic improvements, and fertilizer may compensate for some physical soil changes that result from erosion, compaction, salinization, etc. In the past, such "compensating technology" has generally increased production costs. Consequently, soil stabilization, protection of organic matter, etc. have been among the major agricultural goals of the federal government — since creation of the Soil Erosion Service in 1933.

The National Agricultural Lands Study (NALS) is examining a variety of complex and dynamic mechanisms that affect the agricultural land base of the United States, especially its conversion to permanent nonagricultural uses.[3] This paper examines the physical processes of soil degradation, not the technological capability to offset the consequence of these processes.

Land does not have to be covered with concrete or asphalt to become economically unusable for agriculture. Soils can be eroded away, until little is left behind but bedrock or other infertile or untillable materials. Gradually, but over wide areas, erosion can diminish the fertility of the soil. The loss of productivity eventually may become as complete and permanent as a conversion to urban and built-up uses. Natural processes of landscape evolution and soil formation, particularly in humid environments, also result in the loss of potential soil productivity through weathering and leaching of plant nutrients. It is a natural, irreversible process.

In addition to erosion, there can be adverse impacts on soil productivity from imbalances in soil-water relationships. Another fairly new phenomenon is soil damage from air pollution. All these factors are important in assessing the potential productivity of the nation's agricultural land base.

To the extent that soil degradation reduces the natural productivity of agricultural soils, the range of future options is narrowed. Added inputs of fertilizer, energy and other technology will be needed to replace the lost productivity or else more land will need to be farmed. The loss caused by soil erosion and other soil degradation processes must be added to the amount of farm land lost to other land uses in order to get the full picture of productivity loss currently being sustained by American agriculture.

This paper examines the following factors:

- Natural loss of soil productivity
- Soil erosion from water and wind
- Soil compaction and deterioration of soil structure
- Soil-water problems, including:
  diminishing water supplies
  increasing salinity and alkalinity
  water-logging of productive soils
- Air pollution and its impact on soils
- Soil problems in urbanizing areas.

The paper's objective is two-fold: first, to present in nontechnical terms what we know about the whole process of soil degradation, and second, to indicate there is much we don't know.

Despite many years of dedicated study and research, natural resource scientists have much to learn about the long-term effects of modern cultivation on the internal mechanisms of the soil. There is considerable debate over the adverse effect of soil erosion on crop yields, and what level of soil erosion can be tolerated indefinitely. Different soils, farming systems, and climates combine in literally thousands of ways — each with its own consequences for soil productivity and quality.

The relationship between erosion and productivity can only be quantified with one soil, in one place, and with given climatic conditions. The same relationship may or may not occur elsewhere when one or more of these factors change.

Modern U.S. soil surveys are generally considered the most comprehensive in the world, but they are not yet available for the entire nation because of limitations of budget and technical staff. Monitoring programs that can tell us how much soil erosion or other land damage is occurring, and where and when, are still in their infancy.

The decision-making process rarely enjoys full information or complete understanding of natural resource systems. Nonetheless, decisions must be made. The prudent decision-maker with limited information responds by exploring available data and determining the cost of reaching conclusions which may later turn out to be erroneous. These considerations may lead to deferral, but more typically lead to phased resource management programs that can be modified as additional information becomes available.

The subject of soil degradation is relevant to any appraisal of policy options for agricultural land. If policies and programs are to effectively reduce current rates of soil loss and associated declines in agricultural land productivity, additional information about the processes of soil degradation will be required.

Two: SOIL EROSION

Definitions

Soils are the natural terrestrial bodies on which plants grow. They comprise living ecosystems in which millions of micro-organisms carry out biological functions in complex cycles resulting in the conversion of minerals, dead plant and animal remains, and water and air into organic compounds which nourish plants.

The size of the mineral particles determines the "texture" of the soil. Clay is the smallest particle, being composed of microscopically fine particles, while silts and sands comprise larger particles. Organic matter can be in the form of the dead plant or animal material, or in a decomposed form called humus. The size and quantity of the mineral particles and quantity of organic matter influence the aggregation of particles and the resulting pore space within the soil. This affects the soils' ability to absorb, hold, and freely circulate air and water. Pore space, and soil-and-water relationships also are affected by soil structure — the manner in which the soil particles are grouped together in larger aggregates.[4]

Soil formation requires water to assist in weathering the mineral particles. The weathering product, including the essential plant nutrients, may be leached out of the soil in humid areas, or transported and accumulated in low places in arid areas. The changes in chemical and physical features occur naturally without any intervention by man. This steady removal of soluble components leads to a progressive long-term decline in soil productivity. Vegetation temporarily recycles part of the nutrients, and ecosystems adjust to the prevailing conditions.

Our concern, therefore, is with accelerated losses of productivity on a generation time-scale and with other forms of induced soil degradation that reduce or impair soil productivity.

Erosion is the movement of soil or its component parts. Energy for this soil movement comes mainly from wind, the impact of raindrops, or moving water. Soil erosion occurs in all natural ecosystems, especially where steep slopes result in rapid water runoff. Greater amounts of erosion usually occur from cropland than from grassland or forest ecosystems because of the exposed soil surface.

As might be expected, the smaller and lighter components of the soil generally are dislodged more easily and are carried the farthest before being deposited. Because organic matter erodes more easily and moves farther, soils lose beneficial physical and chemical characteristics as the erosion process continues over time. In general, an eroded soil will absorb and hold less water, have a lower organic matter content, and be less fertile as a result.[5]

Types of Soil Erosion

Erosion caused by moving water is characterized according to the type of soil movement, its location, and pattern. Soil science has adopted the terminology: *sheet, rill, gully, and streambank erosion.*

Sheet and rill erosion are caused by water moving across the surface of the land. Sheet erosion removes soil fairly uniformly in a thin layer over a given area. Rills are small channels which form when running water concentrates and flows in small rivulets down a slope or ridge that may have been created by tillage practices.

Gully erosion involves the formation and/or enlargement of existing ravines or channels. Streambank erosion refers to the soil moved from the banks of established streams, creeks, or rivers.[6]

The most common forms of soil erosion adversely affecting agricultural land — particularly cropland — are sheet and rill erosion. Although it is often difficult to see the damage caused by these types of soil movement, they can transport tremendous amounts of soil every year. Farm fields can lose 10 to 20 tons per acre (0.03 to 0.06 inches per acre) during winter and spring runoff from small rills that are obliterated by the first spring cultivation. Thus, a major type of erosion loss remains largely unnoticed and the consequent soil impairment is rarely monitored.

Virtually all of the data used in this paper to evaluate the extent of soil erosion by water are for sheet and rill erosion. Only those two types of soil erosion losses were estimated in the first phase of the 1977 National Resource Inventories conducted by the USDA Soil Conservation Service (SCS National Resource Inventories)[7], and no other systematic data sources exist on the other types of erosion in the United States.

Gullies have seriously damaged soils in some regions such as the Midwest and Southeast. Pictures of huge gullies scarring the lay of the land were instrumental in sparking public concern for the problems of soil erosion during the 1920's and 30's.

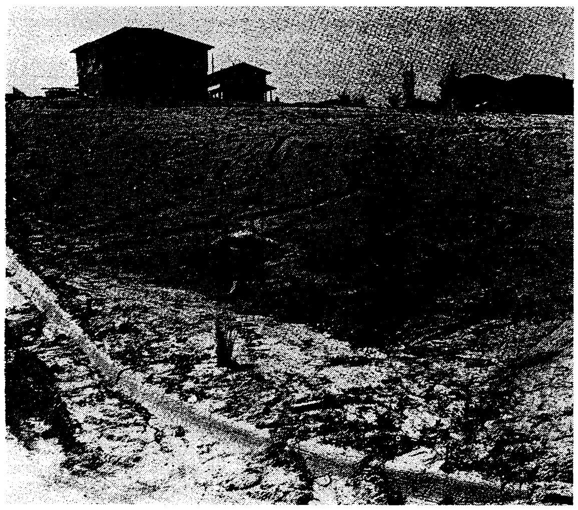
Today gully control methods are fairly well known and widely used. However, severely gullied land still exists in many parts of the nation.

Rolling hills cut by gullies become more difficult to farm, and it is almost impossible to restore the land back into its previous state. National estimates of the extent and location of gully erosion were made for the second phase of the SCS-NRI, but these data are not available at this time.

Streambank erosion, caused by the meandering actions of streams, is not believed to be comparable to the other forms of soil erosion in terms of national impact on soil productivity. Aquatic environments may be seriously impaired by stream bank erosion. Information about this type of soil loss is extremely limited. However, data from Phase 2 of the SCS-NRI will help to fill this void.

Wind erosion can be a very destructive form of soil loss. Soils are most susceptible to wind erosion when they are devoid of plant cover, have a fairly smooth surface, and are composed of very fine soil particles that can be lifted and moved by the wind.

Soil Erosion



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One and Two: Sheet and rill erosion damage millions of cropland acres every year.

Three: Roadside erosion results in expensive costs for maintenance and repair.


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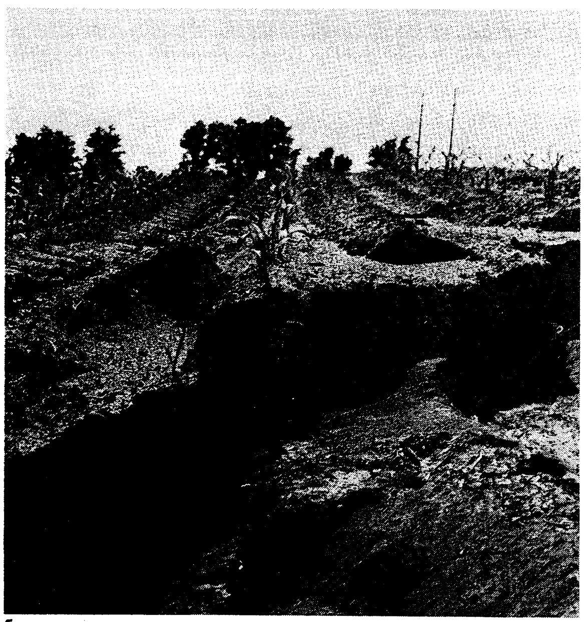
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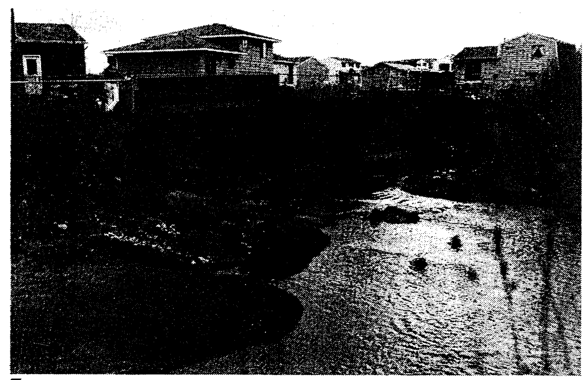
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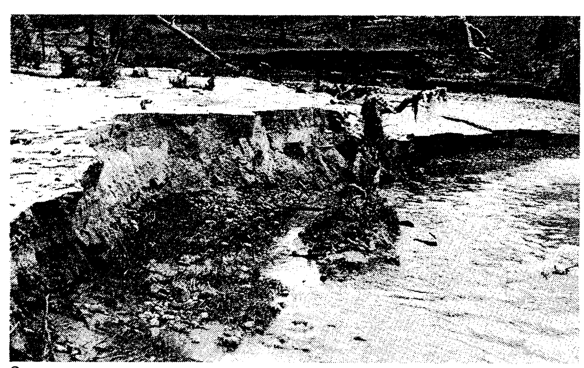
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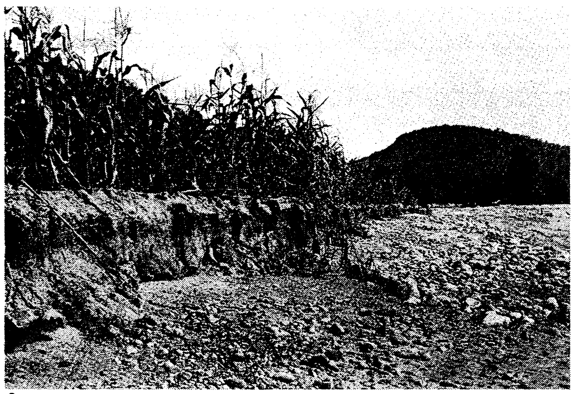

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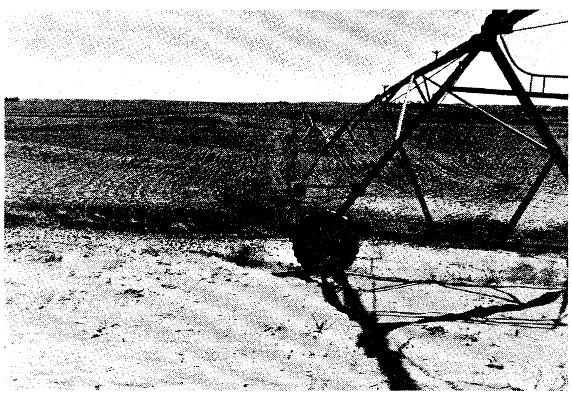

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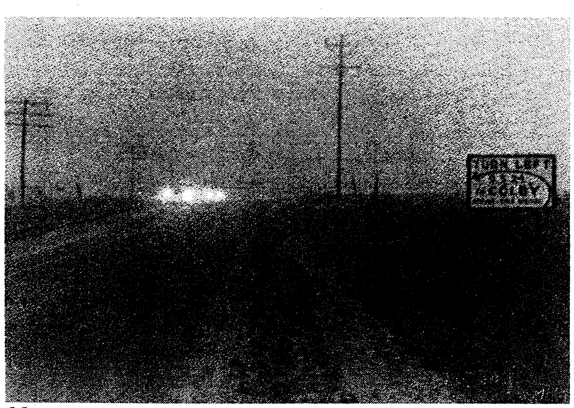

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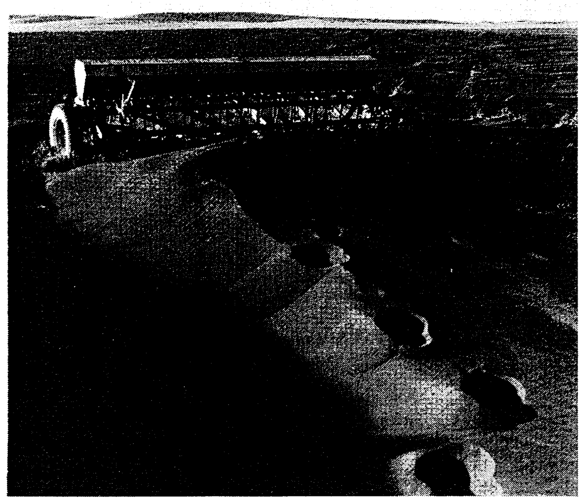

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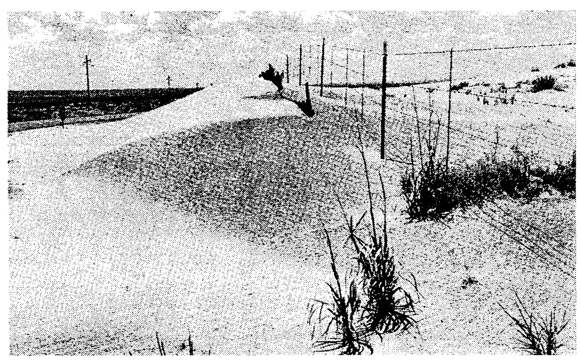

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Four through Six: Gully erosion is one of the more dramatic forms of soil degradation.

Seven through Nine: Stream bank erosion is a critical problem in both urban and agricultural regions.

Ten through Thirteen: Wind erosion is most destructive in the Great Plains States.

Although dust clouds often rise thousands of feet in the air, most of the actual soil movement takes place within a few inches or feet off the ground.

Soil particles are "bounced" along by the wind when they are too large to be carried aloft, and their energy in striking and dislodging other soil particles on the surface of the soil further increases soil loss.

The practice of removing trees to facilitate machine cultivation eliminates windbreaks, thereby intensifying wind erosion.

The "Dust Bowl" remains a poignant chapter of American history, a time when the red soils of Oklahoma blew over Washington, D.C., and 300 miles out to sea. This striking phenomenon galvanized the first national efforts to control soil erosion.

Factors Affecting Soil Erosion

Since soil erosion occurs when wind or water pick up soil material and move it, a major factor is the force of the wind or water. For wind, it is mainly a matter of wind speed and turbulence. For water, the situation is a little more complex.

The erosive force of water starts with the raindrop. The larger the drop the more force it has when it strikes the soil, and the more soil particles are dislodged and washed away.[8] Larger raindrops usually are associated with higher-intensity rains. The more rapidly the rain falls, the less the soil is able to absorb the water, and the more the water will run off the surface of the land.

The total amount of rain fall in any given storm and the storm's intensity are important factors in determining the amount of erosion resulting from a given rainstorm.

As water gathers on the soil's surface and begins to flow downhill, its force is affected by the steepness of the slope. The steeper the hill, the more rapid the flow of water, and thus the more energy generated for dislodging and moving soil particles. The length of the slope also is important.

As water begins to move down a slope, small rivulets form, later collecting into larger channels as the small rivulets come together. This produces the familiar candelabra pattern of erosion on a hillside, with the rills — or gullies — becoming larger and larger as they come further down the hill. Large volumes of water collect on long slopes, greatly increasing the total amount of soil per acre that will be moved in a given storm.

A major factor in determining the degree of soil erosion is the soil itself. Its physical characteristics, including texture, structure, organic matter, and pore space are critical. Soils range from very erosion-resistant to very susceptible.[9] In general, soils made up of a large percentage of silt (the medium-sized soil particle) will be highly erodible. When these soils exist on steep slopes, in regions where frequent, high-intensity rains are common, and when appropriate conservation methods are not practiced, excessive rates of erosion can be expected.

Growing crops shield the soil from the direct impact of raindrops. The plants' root system helps open the surface of the soil water, increasing its penetration and slowing runoff. Living plants and decaying vegetable matter bind soil particles together, and provide an important source of replenishment for the soil's organic matter.

Cropping systems have an important influence on the rate of soil erosion. Table 1 indicates that grass or legume cover can reduce soil losses substantially.

Depending on how the land is managed, erosion on forestland and pasture is generally less than that on rangeland and cropland. Well-managed forests represent a minimal risk of soil losses from sheet and rill erosion.[10] Likewise, pastures normally do not lose much soil, unless overgrazed.[11] While all land uses can be managed to limit excessive erosion, current estimates indicate that crop and rangeland sustain the bulk of the sheet and rill erosion today.

Most rangelands are in arid and semiarid regions where rainfall is infrequent but often intense. Native plant cover in arid regions, even in good condition, is sparse, and much of the erosion is natural. Research indicates, however, that differences in soil movement on rangelands are primarily due to the kinds and amounts of vegetation present, a factor indirectly influenced by the kind of livestock management practiced.[12]

The 1977 SCS-National Resource Inventories data also show how the kind of

Table 1.
Cropping Systems and Soil Erosion

Cropping System or Cultural System	Average Annual Loss of Soil Per Acre *(tons)*	Percentage of Total Rainfall Running off the Land
Bare, cultivated, no crop	41.0	30
Continuous corn	19.7	29
Continuous wheat	10.1	23
Rotation, corn, wheat, clover	2.7	14
Continuous bluegrass	0.3	12

Average of fourteen years of measurements of runoff and erosion at Missouri Experiment Station, Columbia, Mo. From cropping systems in relation to erosion control, by M.F. Miller, Missouri Agric. Exp. Bull. 366, 1936.

soil, slope length, and gradient affect the rate of erosion. For example, more than seventy percent of cropland erosion takes place on the erosion-prone soils.[13]

Estimating the Rate of Soil Erosion

The Soil Conservation Service uses a Land Capability Classification System (see Appendix A) to group soils into capability classes on the basis of their susceptibility to erosion. In general, Class I lands have few, if any, limitations and can sustain intensive cultivation without soil damage. As the Capability Class numbers (expressed as Roman numerals) rise from I to VII, conservation practices must become progressively more complex and effective in order to keep soil losses at tolerable levels.

Class IV is considered to be the upper limit for safe cultivation, and then only with extensive conservation treatment. Thus, the capability class of the land provides an initial reference for estimating the severity of soil erosion which may be anticipated under a particular set of management practices.

Soil erosion is usually measured or estimated in tons of soil moved per acre per year (t/a/y). A ton of soil is roughly equivalent to a cubic yard. An inch of topsoil covering an acre would weigh in the neighborhood of 165 tons. Six inches of topsoil, the depth that normally is cultivated in modern agriculture, weighs about 1,000 tons per acre.

Thus, an estimate that a given field is losing 10 t/a/y means that it will lose an inch of topsoil every fifteen to twenty years, and the whole plow layer in about 100 years.[14]

A method of estimating the amount of sheet and rill erosion expected to occur under a given set of climate, soil, vegetation, and management conditions has been developed by the Department of Agriculture (see Appenix B). The estimation method, called the Universal Soil Loss Equation (USLE), has been widely used by the SCS, and was the basis for estimating the soil loss in the 1977 SCS-National Resource Inventories.[15]

Thus, while the 1977 inventories give us the most current estimates of the extent of soil erosion in America, the results must be used cautiously. Some variables in the USLE cannot be measured with full precision. For example, a major factor in the equation is the rainfall factor "R." It provides a mathematical approximation of the importance of rainfall, raindrop size, and storm intensity in causing sheet and rill erosion. Because it is only an approximation, the formula may be inadequate for predicting erosion in certain areas.

For example, there are some fifty-eight million acres of irrigated cropland in America, much of it in dry climates. Rainfall is a negligible part of the water that is applied to the land, and soil erosion under irrigation can be serious on erodible soils, or under poor management.

In the Northwest, significant soil loss occurs due to spring snowmelt. Erosion rates in excess of 100 tons per acre have been measured in localized areas from a single snowmelt, when the soils are frozen and begin to thaw under the snow.[16] Such extreme events are difficult to predict, and can not easily be captured by a probabilistic equation like the Universal Soil Loss Equation.[17]

A major hazard in using the erosion data, however, lies in the use of "average" soil erosion estimates. A state might be experiencing an average rate of soil loss from cropland of five t/a/y. Is that serious or not? Studies of average annual soil loss tolerance (T-values)[18] help answer the question.

T-values are estimates of a soil's tolerance of erosion and serve as a reference point in assessing the seriousness of actual rates of erosion. Ranging generally from one to five tons per acre per year for most soils, this value represents an estimate of the amount of soil loss that can be permitted without serious reduction of future agricultural productivity. Ideally, it should reflect the rate of new top soil formation from the various physical and biological processes. The average soil loss may reflect thousands of acres that are losing no soil and other thousands of acres losing fifteen t/a/y.

In short, the real erosion problem may be hidden by the misuse of averages.

Finally, it must be remembered that Phase 1 of the 1977 SCS-National Resource Inventories did not measure gully or streambank erosion. It measured wind erosion only in the ten states comprising the Great Plains area. This is the only region of the country for which such data are available. Therefore, current SCS National Resource Inventory estimates of national soil erosion are only partial estimates. They probably catch most of the soil erosion affecting cropland.[19/20]

Soil Erosion Damage in the Past

Soil erosion is neither a new phenomenon nor one limited to the United States. As a natural part of environmental dynamics, it has been occurring since the first water struck the surface of dry earth, and erosion will persist as long as that process goes on. *Man's actions have, however, drastically accelerated the erosion process. Entire civilizations have succumbed to its ravages.*[21]

In America, pioneer conservationists such as Jared Eliot warned of the dangers posed by soil erosion. Eliot carried out experiments on how to stop soil erosion, and in 1748 published a series of essays on his methods. In the mid-1800's, the practice of "horizontal plowing" was a topic of wide discussion and debate. In 1894, USDA's *Farmers Bulletin No. 20* discussed eroded soils and how to reclaim them.[22] This subject did not, however, attract widespread public attention until the mid-1930's. In 1934, the first national survey of soil erosion damage was completed.[23]

By 1939, Dr. Hugh Hammond Bennett, first chief of the Soil Conservation Service, gave the following estimate to a Congressional Committee:

> "In the short life of this country we have essentially destroyed 282,000,000 acres of land-crop and rangeland. Erosion is destructively active on 775,000,000 additional acres. About 100,000,000 acres of cropland, much of it representing the best cropland that we have, is finished in this country. We cannot restore...We are losing every day as the result of erosion the equivalent of two hundred forty-acre farms.[24]"

It has been estimated that we have lost one-third of the topsoil from U.S. cropland in use today.[25] The significance of today's erosion rate must be measured in light of the depth and quality of soil remaining in the nation. As topsoil resources are lost, the seriousness of a given rate of national soil erosion increases. *More stringent techniques for erosion reduction are required to deal with these problems.*

Soil Erosion Today: The 1977 SCS National Resource Inventories

Despite a significant investment in conservation practices by the federal government and private landowners, erosion from agricultural lands continues at a disturbing rate, though certainly less than that which would have occurred in the absence of the present soil conservation programs.[26]

The 1977 National Resource Inventories show a national 1977 average annual loss from sheet and rill erosion of about four billion tons. Average annual losses are

Table 2.
Sheet and Rill Erosion for All Capability Classes

Land Use	Average Annual Erosion Rate *(Tons Per Acre)*	Acres *(Millions)*	Total Erosion *(Millions of Tons)*
Cropland	4.7	413	1,926
Rangeland	2.8	408	1,154
Forestland	1.2	367	445
Pastureland*	2.6	133	346
Totals		1,321	3,871

*Includes native pasture.

Source: USDA, RCA Appraisal 1980, Part II.

shown in Table 2.

Land use significantly affects erosion rates. Table 2 shows that nearly half of the total sheet and rill erosion occurs on cropland. The 1977 erosion rates were about ten t/a/y on thirty-two percent of the lands used for row crops in the South; nine perent in the Northeast; and nineteen percent in the Corn Belt. Erosion in excess of five tons per acre per year on cropland is shown in Table 3. About fifty-three percent of the sheet and rill erosion is occuring on lands with an average annual erosion rate greater than five tons, but these lands comprise only 23.5 percent of the cropland base.[27]

To get a more complete picture of the soil erosion problem, we can add the wind erosion estimates collected in the 1977 National Resource Inventories for the ten Great Plains states, along with the erosion estimates on pasture, range and forest land. This information is shown in Table 4. Figure 1 indicates the distribution of the soil erosion problem as revealed by the NRI.

Effects of Soil Erosion on Productivity

To assess the implications of soil erosion on future agricultural productivity, we must first address the concept of a "tolerable" soil loss.

Soil formation is a slow, continuous process, with new soil material gradually being formed as minerals break down during chemical and biological processes. Soil scientists estimate that one inch of new topsoil is formed every 100 to 1,000 years.[28] This is equivalent to a maximum rate of about 1.5 tons per acre per year. The rate varies widely, influenced by land use, climate, vegetation, soil disturbances, and the nature of the soil.[29]

Table 4.
Sheet, rill and wind erosion on nonfederal agricultural land, 1977, in acres of rural land, by erosion rate, in tons per acre per year.

	(1,000 acres) Less than 5	5-13.9	14+
Cropland	272,224	93,053	48,100
Pastureland	119,021	9,485	5,062
Forestland	353,047	11,721	4,895
	Less than 2	2-4.9	5+
Rangeland	283,478	55,501	68,882

Source: USDA, RCA, Draft Summary of Appraisal and Program Report

Table 3.
National summary of sheet and rill erosion on cropland and the amount of sheet and rill erosion in excess of five tons per acre per year, by erosion interval.

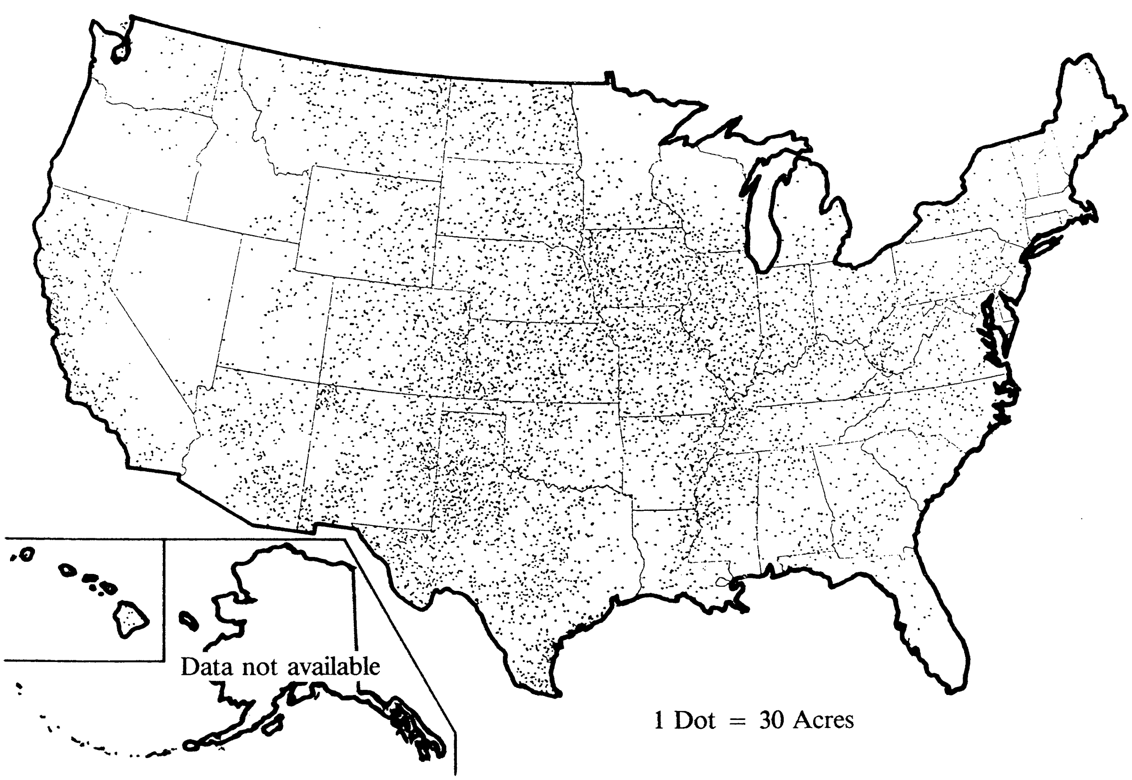
Erosion Interval	Acres	Cumulative Percentage of Acres	Total Erosion in Excess of Five Tons Per Acre Per Year	Cumulative Percentage of Erosion in Excess of Five Tons Per Acre Per Year
Tons Per Acre Per Year	*(1,000)*		*(1,000 tons)*	
0–1	128,186	31.0	0	0.0
1–2	72,596	48.6	0	0.0
2–3	51,619	61.1	0	0.0
3–4	37,060	70.1	0	0.0
4–5	26,693	76.5	0	0.0
5–6	18,661	81.0	7,464	0.7
6–7	13,659	84.3	19,123	2.6
7–8	9,794	86.7	23,506	5.0
8–9	7,667	88.6	26,068	7.5
9–10	6,143	90.0	27,029	10.2
10–11	4,985	91.3	26,919	12.9
11–12	3,754	92.2	24,026	15.2
12–13	3,027	92.9	22,400	17.5
13–14	2,770	93.6	23,268	19.8
14–15	2,403	94.1	22,588	22.0
15–20	7,714	96.0	95,654	31.4
20–25	4,382	97.1	76,247	39.0
25–30	2,891	97.8	64,758	45.4
30–50	5,469	99.1	191,415	64.3
50–75	2,240	99.6	128,800	77.0
75–100	777	99.8	64,103	83.4
+100	712	100.0	168,032	100.0
TOTAL	413,202		1,011,398	

Source: USDA, RCA Appraisal 1980, Part II.

Soil loss tolerance is defined as the maximum rate of annual soil erosion that will allow a high level of crop productivity to be sustained economically and indefinitely. If there is to be no loss of the soil's long-term productive capacity, the thickness of the A horizon (topsoil) and a sufficiently favorable rooting depth must be maintained, along with favorable physical, chemical, and biological conditions for plant growth.

No single tolerance rate is applicable to all types of soil. Ranging from a low of around one t/a/y to a high of five t/a/y on some soils, the judgment of soil scientists, agronomists, and geologists is that five t/a/y is the maximum rate of loss with which indefinite and economical productivity can be maintained. Generally, the national average is lower, probably near four

Figure 1.
Acreage where wind and water erosion are greater than five tons per acre per year, 1977. (USDA, 1978b)



t/a/y. But here especially, one must be careful when using national averages.

The estimates of tolerable levels of erosion noted above relate to the physical detachment and transport of soil particles by wind and water.

Critics of the concept of a soil loss note that nearly seventy-five percent of the "eroded" (detached and trasported) soil is eventually deposited on another site, and thus has not been truly "lost," as it goes from one part of a field to another. However, it is nutrient-rich organic and clay particles that tend to be the soil particles dislodged and carried away by erosion. This loss of organic matter, nutrients, and water holding capacity results in lower productivity.[30]

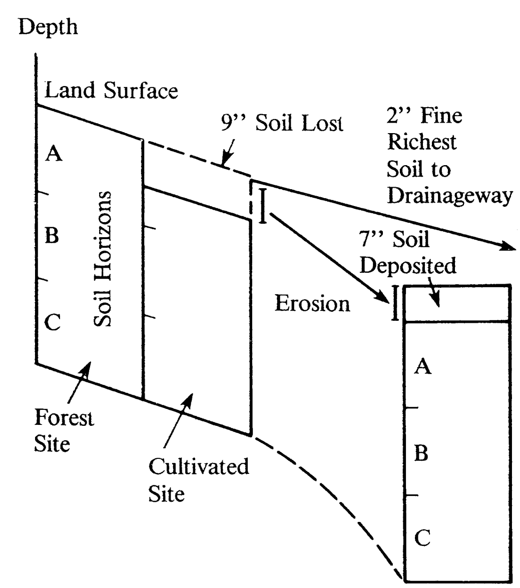
What we do know is that erosion causes significant qualitative changes in soils. A field experiment conducted in Wisconsin clearly illustrates the qualitative change that may take place. It was done in the drumlin area (ridge lands) of Dodge County, Wisconsin.[31]

Soil profiles were studied on a hillslope both in a forest and in an adjacent field, and on the footslope at the bottom of the same field. A schematic representation of this study's result is given in Figure 2. The "A" horizon, which is a mixture of mineral and organic matter, was fourteen inches deep in the woodland, but nine inches had been eroded away at the cultivated site.

On the footslope, seven inches of somewhat sandy portions of the eroded soil had been deposited. About two inches of nutrient-rich organic and clay material had been eroded away beyond the field to the natural drainage-ways. As a result of this erosion, the downhill (colluvial) soils generally required more fertilizer and lime than the eroded soils.

An explanation of this fertility degradation lies in the available stock of nutrients held in the lower soil horizons. In the downhill soils, this fertility bank was covered with seven inches of eroded material. Many of the nutrients associated

Figure 2.
An Example of the Impact of Erosion on a Hill Slope and a Footslope in Dodge County, Wisconsin.



with the organic fraction were carried away by the surface runoff. Thus, top soil deposited by erosion may be of high quality, but it can be inferior to the soil which it covers up.

In the past, many adverse effects of soil erosion on land productivity have been masked by other factors. Periods of good weather can result in larger crop yields, despite loss of productivity due to erosion. There is evidence that weather patterns from 1900 to 1970 also were unusually favorable for agriculture.[32]

Agricultural productivity in the United States was increasing most rapidly between 1930 and 1970. The most rapid increase took place during and after World War II. These probably were the most abnormally mild years in the last 11,000 years. A cooling trend started in the 1950's.[33] Some climatologists believe that the yield increases experienced during the 1950's and 1960's owed as much to unusually favorable weather conditions as to the widespread application of agricultural technology.[34]

In recent years, yields of major crops have not risen as fast as they did in the fifties and sixties.[35] In some cases, wheat for example, the yields leveled off. In others, yields have actually decreased.[36]

Some analysts are concerned that the climate may be entering a period of less favorable, although, in fact more "normal," weather patterns which could adversely affect agricultural production. While the climatological trend is not certain, "bad" weather — certainly a major cause behind the plummeting yields in 1973 and 1974 — has caused a reexamination of traditional views about crop productivity gains. This reexamination will become essential if erratic weather continues to be the "norm" in the future.[37]

New and more productive crop varieties, coupled with the use of fertilizers, pesticides, and other capital inputs, have increased yields. Better control of pests and crop diseases, together with improved tillage and planting methods, also have assisted in maintaining high production levels.

When erosion reduces cropland yields to unprofitable levels, shifts in land use frequently occur. From 1967 to 1975, fifty-three million acres were changed from cropland to pastureland and rangeland, and eight million to forestland. A portion of these shifts is attributable to erosion.

Low commodity prices, the economic advantage of larger operating units, and resulting production costs have contributed to this acreage shift.

The deterioration of cropland by erosion also has played a role. Thirty-two million acres of pastureland and rangeland and eleven million acres of forestland were brought into cultivation to partially offset cropland losses. As a result, the quality of the nation's cropland rose slightly.

More Class I to II land was used as cropland, while some Class IV to VIII land was retired.[38] Total cropland acreage was not dramatically altered, and productivity increased, even though the potential product and the total productive base for agriculture was lowered.

Two methods are proposed to help quantify the adverse effect that soil erosion losses will have on productivity. Neither provide entirely satisfactory estimates. One was used by USDA as part of its assessment of national soil and water resources.[39] Data from over 1,100 published county soil surveys and other sources were used to create a data base of soil characteristics by soil mapping unit. These soil surveys include crop yields. But because these yields were obtained over a period of nineteen years when the technology and farm practices were rapidly changing, it was necessary to "normalize" these yields to a common year. This was accomplished by a statistical analysis of county crop yield data over the period 1969 to 1977. From technology-trend lines, the estimated "normalized" yields were calculated, representing 1974 technology.

Using these values and the soil mapping unit acreage as weights, the estimated soil survey yields were adjusted to represent an average yield for each crop (at the 1974 technology level).

These "normalized" crop yields were used as the dependent variable in a multiple regression analysis of the relationship between yield and basic soil properties. The equations estimated by USDA were then utilized to develop the Yield-Soil Loss (Y/SL) Simulator.

A Y/SL equation was formulated for each of the ten basic crops used in the Iowa State University Linear Programming Model (ISU-LP) model: corn, soybeans, cotton, wheat, oats, barley, sorghum, legume and non-legume hay, and pasture.

Multiple regression estimates were calculated for each crop in each of the twenty-one Water Resource Regions (WRR) where the crop is grown. Three of the eighteen WRR's were divided into two sub-regions because of geographical size and diversity of soil types.

A primary objective of this research effort was to estimate the relationship between depth of soil and crop yields. This mathematical relationship subsequently became a part of the linear-programming model that was utilized in making the USDA Resource Conservation Act projections of future demands on the resource base.

The Y/SL simulator was specifically developed for use in the RCA projections. The purpose was to correct future estimated yields for productivity lost because of erosion-induced decreases in soil depth. The results of this research project can be drawn upon to develop estimates of the yield reduction anticipated from a one-inch reduction in topsoil depth. Using this method, USDA estimated that if the current level of erosion were allowed to continue for the next 50 years on the 290 million acres contained in the USDA-RCA statistical model, erosion would cause a reduction of productive capacity equivalent to the loss of twenty-three million acres of cropland, or eight percent of the total base considered.

The estimated erosion-induced yield reduction for a given crop in a given region depends on the coefficients in the relevant Y/SL equation and the severity of the erosion rate on the acres growing the crops as projected by the model.

The impact of yield reduction from the Y/SL Simulator is insignificant where

Table 5.
Expected change in yields of corn (in subarea 43) and soybeans (in subarea 41) by 2030 at 1977 erosion rates.

Crop & producing area	Soil group[1]	1977 annual rate of erosion	Cumulative soil loss over 50 years	Present yield	Maximum potential yield in 2030[2]	Yield in 2030 if present erosion rate continues	Percentage of maximum yield in 2030[3]
		(Tons per acre)	(Inches)	(Units)[4]	(Units)[4]	(Units)[4]	(Percent)
Soybeans	1	3.2	1.0	34	51	51	100
41	2	4.9	1.6	29	44	43	98
(Iowa)	3	16.6	5.6	26	39	33	85
Corn	1	4.0	1.3	91	137	137	100
43	2	5.1	1.7	74	111	110	99
(Illinois	3	18.5	6.2	71	107	90	84
& Missouri)	4	14.7	4.9	62	93	76	82
	5	31.5	10.5	50	75	53	71

[1]Soil groups are made up of aggregations of land capability classes and subclasses in the following manner:

Soil group	Land capability class and subclass
1	I
2	II, IIIs, IIIc, IIIw, IVs, IVc, IVw, V
3	IIIe
4	IVe
5	VI, VII, VIII

[2]Based on 1 percent annual increase in yields resulting from technology.

[3]Percentages were calculated from unrounded data and therefore may not represent the ratio between the numbers shown for maximum potential yield and eroded yield.

[4]Units are in bushels for all crops but cotton, which is shown in pounds.

Source: Analysis of data from 1100 published soil surveys. RCA analysis and Evaluation Work Group 1979.

erosion is less than five tons per acre; is occasionally significant when erosion is between five and fourteen tons per acre; and is usually significant when erosion is in excess of fourteen tons. These general conclusions are supported by Table 5 which presents representative simulator results.

A basic conclusion advanced by RCA analysts is that the loss of an inch of topsoil will reduce future corn yields three to four bushels per acre when management practices remain constant. Other research indicates that a yield reduction of this magnitude may be incurred even when farmers intensify fertilizer and other mangement practices in an attempt to replace lost fertility. (Shrader/Langdale).

Two examples of the yield-reduction estimated by the Y/SL Simulator are presented for crops grown in the Corn Belt, one of the most productive farming areas in the world.

Concern about lost productivity in the fertile Midwest is heightened when it is recognized that about forty-three percent of the land used for row crops in the Corn Belt is composed of highly erodible soils. *If erosion in this area is allowed to continue at the 1977 rate, USDA estimates that potential corn and soybean yields would probably be reduced by fifteen to thirty percent on some soils by the year 2030.* Table 5 shows how present erosion could reduce potential productivity in two Corn Belt regions over the next fifty years.[40]

Predictive modeling efforts like the yield-soil loss-simulator sacrifice a degree of accuracy in order to produce results covering the vast diversity of soils in the United States. Other field level estimates of yield soil loss relationship have been made by soil scientists using carefully controlled studies. These estimates are far more reliable than yield-soil-loss projections, but are specific to a particular crop, soil, set of management practices, and region. Based on many field level studies, the loss of six inches of topsoil will severely compromise the productivity of most cropland, if not make it uneconomic to farm.[41]

For example, in the Southern Piedmont, a six-inch reduction in topsoil has been found to reduce average crop yield forty-one percent.[42] In western Tennessee, similar soil erosion reduced corn yields forty-two percent.[43]

Adams,[44] Buntley, and Bell[45] found this degree of erosion reduced the yield of vetch and fescue forage twenty-five percent and that of wheat/oat grain by nearly thirty percent. Even though nonirrigated corn yields in the Southern Piedmont region have more than doubled in the past thirty years, the loss of six inches of soil has continued to reduce the yield forty percent.[46]

Additional information on field-level studies can be found in an excellent review article entitled "Effect of Soil Erosion on Soil Productivity," written recently by Shrader and Langdale.[47] This article summarizes four decades of research on the effects of soil erosion. Based on their review and experience as research scientists, the authors state:

> "Unless liberal amounts of plant nutrients are added, especially nitrogen (N) and phosphorus (P), soil erosion sharply reduced yields of grain crops such as corn, soybeans, and wheat...
>
> If no fertilizers are used, yields of crops other than legumes are uniformly lower than normal in eroded areas...
>
> An evaluation of the effect of soil erosion on crop production must be specific for a particular crop on a given soil under a defined level of technology. Erosion always increases cost of production. On some soils the damage results largely from loss of fertility and thus fertility can be restored at a cost. On other soils the loss in productivity results because of decreases in rooting depth or soil water-holding capacity. On some soils even this decrease can be compensated for, but only at great expense."[48]

Another rough estimate of lost productivity caused by erosion is to examine the loss in terms of "acre-equivalents" of cropland. Based on 1.01 billion tons of erosion in excess of five tons per acre per year, the nation may be losing an equivalent of 1.01 million acres of cropland annually to erosion. This is based on the assumption that six inches of topsoil weighs about 1,000 tons, and that the loss of this amount of topsoil is equivalent to an irreversible conversion of an acre of cropland.

Of course, soil depth and erosion rates vary tremendously in different regions and even within a given field. Some land could become unproductive long before six inches are lost. Other land would hardly be affected because of deep topsoil resources. These "acre-equivalents" represent the gradual loss of productivity that may be occurring over millions of acres of American farmland.[49]

To cover the entire country, losses by wind erosion also must be considered. Following similar reasoning, wind erosion in the ten Great Plains States would add 0.24 million acre-equivalents to the 1.01 million that appear to be lost from sheet and rill erosion. Over the next fifty years up to sixty-two million acre equivalents could be lost, assuming the 1977 rate of erosion persists. Using the Y/SL simulator and a different set of assumptions (outlined in Appendix D), USDA analyses calculated that up to thirty-two million acre-equivalents could be lost by the year 2030 from sheet and rill erosion.

The various estimates give a range of twenty-five to sixty-two million acre-equivalents that could be lost due to soil erosion on cropland. All of those estimates could be low. Data collected by the National Resource Inventories on the extent of gully erosion were not available for inclusion. Wind erosion data outside the Great Plains were not obtained. No erosion calculation was made for the effects of applied water on irrigated land, and the

Universal Soil Loss Equation may understate erosion west of the 100th meridian.

Near-term damage to crops from wind erosion also can be significant, though national data are lacking except in the ten Great Plains States.[50] For example, between November 1977 and June 1978, 2.2 million acres of crops were destroyed on land that itself was not damaged. During that same period, 7.9 million acres of land were damaged. This damage occurs primarily as the result of the abrasive action of wind-driven soil particles, the uncovering of plant seed, and changes in plant metabolism processes. Crop damage may occur even though soil tolerance is not exceeded.

Estimated crop tolerances to wind erosion range from nearly zero (e.g., onion, cucumbers, lettuce) to above the soil tolerance limit (e.g., buckwheat, barley), with most crops showing some damage at a level of one ton per acre per year or less. Wind erosion thus has significant adverse effects on productivity, both in the short and long terms.

Finally, little consideration is usually given to the effect of erosion on rooting depth. The weathering of parent rock into a favorable root zone is a distinctly different phenomenon from the formation of

Table 6.
Acre-equivalent of soil productivity lost annually from soil erosion on agricultural lands in the United States.

Agricultural Land Use	(Thousands of Acres) Types of Soil Erosion: Sheet & Rill	Gully	Streambank	Wind	Total Loss
Cropland	1,010	?	?	240	1,250
Pasture	53a	?	?	b	53
Rangeland	94c	?	?	c	94
Forest land	308d	?	?	b	308
Total Acre-Equivalents					1,705

[a]Source: USDA, 1980, RCA Appraisal, Part I, Table 3B-1.
[b]Probably negligible
[c]Source: USDA, 1980, RCA Appraisal, Part I, Table 3C-2. This includes sheet, rill and wind erosion. Excess erosion over 2 t/a/y (felt by USDA to be the tolerance limit for rangeland) in tons, divided by 500 = acre-equivalents of loss. Rangeland, because of arid climates and thin topsoils, is more rapidly damaged by soil erosion, thus the use of only a 3-inch topsoil loss to approximate loss of productivity.
[d]Source: USDA, 1980 RCA Appraisal, Part I, Table 3D-5. Erosion over 5 t/a/y was found in the NRI only on grazed forest lands in Capability Classes IVs, VII and VIII.

topsoil.[51] In most soils it proceeds more slowly; thus, while limiting erosion to five t/a/y might maintain the topsoil, the total root zone would become thinner.

Data on the rate of development of a favorable root zone is not conclusive. However, a renewal rate of 0.5 t/a/y (equivalent to 0.003 inches) may be about average for unconsolidated materials. For consolidated (rock) material, the rates are much lower.[52] Keying the permissible loss of favorable rooting depth to the rate of soil renewal will ensure that soil thickness is maintained.

These unquantified factors add to the total loss of productive capacity from sheet, rill, and wind erosion on cropland alone. A summary of these losses is illustrated in Table 6, along with several other types of loss that should be added but about which there is not adequate quantitative data at this time.

It should not be inferred that the long-term productivity losses from pasture, range, and forest lands are equal to the loss of cropland. Cropland produces much more usable food or fiber per acre than pasture or forestland. The loss of an acre-equivalent of pasture, range, or forest, is however, a permanent loss to the nation.

As the pressure rises for more cropland output, pasture, range, and forest lands will be converted to cropland use. The full importance of past erosion losses on land devoted to these other agricultural uses will become apparent.

Three: SOIL COMPACTION AND OTHER PHYSICAL DETERIORATION

Soil Compaction

In recent years, most agricultural areas have experienced a trend toward larger and more capital-intensive farming. Farm equipment has become larger and heavier. Row cropping has increased by twenty-seven percent, and rotation hay and pasture has dropped forty percent.[53] For example, the total acreage of corn and soybeans in Iowa, Wisconsin, and Minnesota has risen sharply since 1965, and hay acreage has dropped accordingly.[54]

This increased use of heavy farm equipment causes soil compaction, now considered a serious problem in many cultivated areas.[55]

It is common for field operations to compact soil to depths of at least twelve inches. It should be noted, though, that compaction varies with the kind of soil, amount of organic matter, and surface texture. Wet soils and soils lacking significant levels of organic matter are especially susceptible to compaction.

Compaction reduces water infiltration, resulting in more surface runoff and attendant erosion.[56]

Additionally, compaction vastly reduces root growth in the upper soil layer. Since most fertilizer is incorporated in this surface soil, plant uptake of immobile fertilizer elements—sulfur, and phosphorous—may be greatly reduced.

It has been proposed that freezing and thawing alone would sufficiently alleviate compaction. But not all cropland freezes. The most pronounced effect of freezing is in the upper two to three inches, where up to ninety percent of the compaction is released. Recovery is less at greater depths.

Fall plowing, especially with a moldboard, helps alleviate surface compaction but may lead to what is called a "plow sole." A plow sole is a compacted subsurface soil layer, developed after several years of plowing at the same depth. Fall plowing also may increase the susceptibility of the field to sheet and rill erosion from snowmelt and rains, and to wind erosion.

Estimates of yield reductions due to compaction are at best localized in nature. Data do not exist that would permit estimates on a regional or national basis. While rotation and tillage techniques can be employed to minimize the adverse effects of compaction in the surface layers, it may be quite difficult to offset the effects of compaction which occur below normal tillage depths.

Loss of Organic Matter

If there is any single indicator of qualitative change within the soil itself, it is probably best expressed by the soil's organic matter content. The selective removal of organic matter is seen as a primary reason for the lower productivity of eroded soils.[57]

Organic matter increases soil structural stability which, to a large degree, determines its resistance to erosive forces. Improved soil structure also enhances water infiltration. Moreover, organic matter supports most of the soil microbial populations that are so vital in recyling plant nutrients. The soil's water-holding capacity is enhanced, and crops are more capable of withstanding periods of drought.

The continuing reduction of organic matter is highly significant since most cropland soils already have lost at least forty percent of their original organic matter and nitrogen.[58] It should be noted that the excessive removal of plant material from fields for energy production may *further exacerbate* this loss of organic matter.[59]

Calculating the impact of these soil degradation trends separately from those caused by soil erosion is difficult. We know these trends are occuring, and that they have a negative impact on productivity. Deep compaction of internal soil layers can retard root growth and limit the free movement of water, particularly in irrigated soils of the West. For most cultivated soils, soil organic matter levels are known to be lower than they were in the native state. But the extent of these problems is not yet known, nor do we know their ultimate impact on agricultural productivity.

Two studies, however, deserve brief attention: one by Lucas, Holtman, and Connor[60] on corn in the Midwest, the other by Burt[61] on wheat in the Pacific Northwest. These researchers stress the impact of soil erosion on the organic matter level within the soil, and develop empirical models that explicitly include the contribution of organic matter (as a proxy for tilth and other beneficial soil characteristics) to crop production. The models are solved for equilibrium or steady-state organic matter levels, assuming various initial soil types, slopes, and mangement routines. Burt concludes that: "These fairly high marginal values (of organic matter based on contribution to net returns to wheat production) illustrate the value of organic matter in a farming system even though quite large amounts of inorganic fertilizer, particularly nitrogen, is used" (6, p. 15).[62]

The corn study stresses the importance of incorporating the residue of high-yielding corn crops into the soil. It concludes that if residues are turned under, "soil organic matter should not be difficult to maintain or improve."[63] The authors also state that increasing organic matter from 1.7 percent to 3.6 percent would raise "the yield potential about twenty-five percent for corn", with significant implications for fertilization requirements and energy costs. The authors estimate that about ten tons of manure per acre annually would nearly achieve this increase in potential yield, assuming soil erosion was under control.

Taken together, these studies indicate that the long-run indirect agronomic benefits to soil preservation may result in significant reductions in future costs of production, especially as energy-based inputs rise in value.

Four: SOIL AND WATER PROBLEMS AFFECTING AGRICULTURAL PRODUCTIVITY

Water Supplies for Irrigation

The United States has a great deal of water, but it is not always located where needed for agricultural production. Water supply shortages have been identified in sixty percent of the nation's hydrologic subregions. Competition for scarce supplies is the greatest in arid and semi-arid regions.

An estimated eighty-one percent of all water consumed in the United States is for irrigation. In arid and semi-arid areas, water consumed for irrigation often exceeds ninety percent, and streamflows often are inadequate to maintain such "instream values" as water quality, fish propogation, recreation, etc. Regional average annual data often mask local periodic water shortages.[64]

Ground water resources have been estimated to have a volume far greater than all the surface waters, and more than the total capacity of all the nation's lakes and reservoirs (including the Great Lakes). The volume is equivalent to about thirty-five years of surface runoff (100 to 180 billion acre-feet.)[65] Yet, increasingly, local demands for irrigation cause mounting stress on the resource. (See Figure 3.)

Diminishing artesian pressure, declining spring and streamflow, land subsidence, and salt water intrusion problems are strong evidence of the excessive use or "mining" of ground waters.

One of the more dramatic instances of ground water depletion is found in the Trans-Pecos area of Texas. Continuous declines of the ground water table in this area are the result of decades of irrigation pumping and more recently, withdrawals of water for homes and industries. Large acreages of irrigated cropland have been abandoned and thus have reverted to rangeland when pumping costs rose because of fuel cost increases. Increased depth of water, and pumping costs rendered irrigation uneconomic in much of this region. Other areas are likely to follow suit.

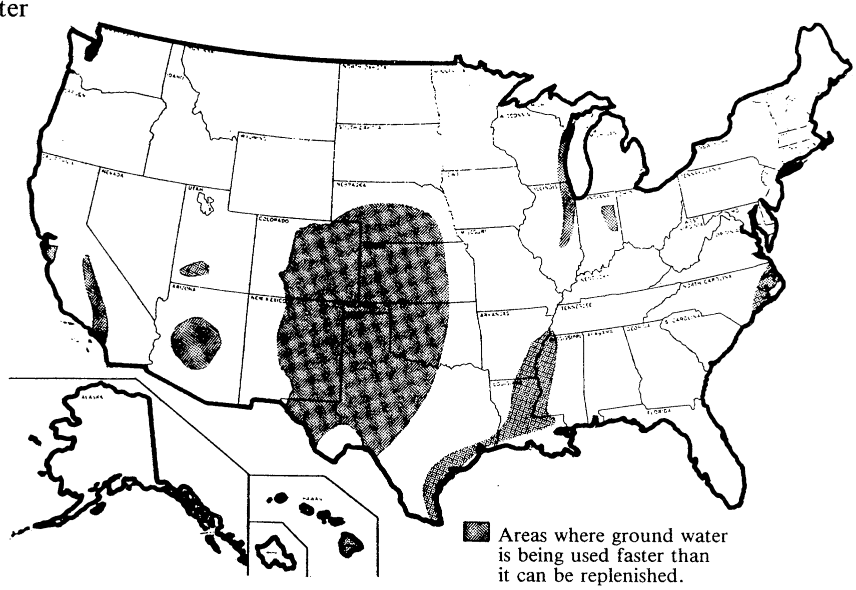
The High Plains area of West Texas and Eastern New Mexico is the largest irrigable land mass in the world—fifty-two million acres. *Nearly ten million of these presently irrigated acres, supplied by the Ogallala aquifer, are threatened by continuous removal of ground water greatly in excess of recharge.*

The conversion of irrigated lands to dryland production, of course, will yield less food and fiber. However, the potential loss has not been estimated.

The pumping of ground water at rates exceeding natural recharge (i.e., mining) requires that: (1) alternative sources (e.g., interbasin transfers) or less demanding crops be employed, or (2) the land must eventually be phased out of irrigated agriculture. In some areas, because of rapidly rising pumping costs, declining water tables will cause abandonment of activities before the water is totally consumed.

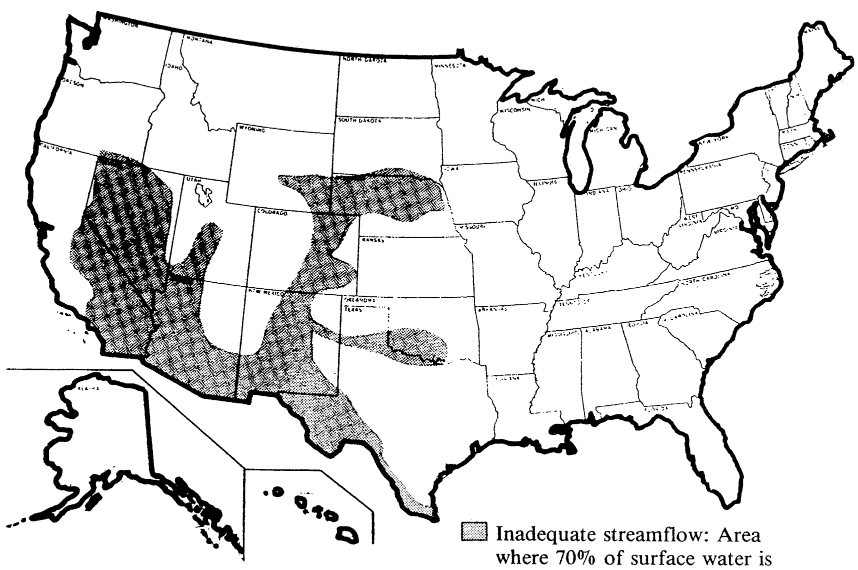
Figure 3. Water Resource Problems

Overdraft of Ground Water



Areas where ground water is being used faster than it can be replenished.

Surface Water Supply



Inadequate streamflow: Area where 70% of surface water is depleted in an average year.

Salinity and Alkalinity

A major problem of irrigated agriculture the world over is the build-up of soluble salts in the surface soil. The principal dissolved salts, whose accumulation in soil is commonly referred to as "salinity," are the cations of calcium, magnesium, and sodium, and the anions sulfate, chloride, and biocarbonate.[66] When these dissolved salts form soda, or highly alkaline compounds, particularly difficult soil problems are created.[67]

Increased salinity in soils restricts the kinds of plants that can be grown, sometimes severely. In alkali soils, organic matter and salts may be dissolved and recemented on the surface to produce an impermeable, sterile soil upon which nothing can grow.

Critical diffuse salt source areas occur in much of the arid and semi-arid portions of the eleven western states. Over twenty percent of the western soils have significant salinity in their soil profile. Such regions frequently are associated with outcrop areas or soils derived from soft shales, siltstones, claystones, and lake bed deposits in valley alluvium. Such soils frequently were formed in the bed of ancient salt-water seas.[68]

Saline seeps have developed recently in many cropland areas of Montana and North Dakota due to natural geologic conditions aggravated by agricultural practices. Salts also have built up over time in the Yakima Valley of Washington; the Imperial, Sacramento, and Tulare Basins of California; and the Closed Basin of the Rio Grande in Colorado because of inadequate leaching or leaching with "low quality" water under arid climatic conditions.

Dry cropland areas in these western states, where production either has been eliminated or significantly reduced due to increased salinity, are estimated to comprise 150 to 200 thousand acres. *The number of these acres is increasing annually at a rate of about ten percent.*[69]

Evaporation losses from reservoirs and other water bodies, consumption losses associated with municipal and industrial water uses, evapotranspiration losses from native vegetation on noncropped land, irrigation use and return flows, and out-of-basin diversions of water are all factors that increase the concentration of salinity.

Irrigated crops are large consumers of water—living plants extract water from the soil and leave salts behind, resulting in a further concentration of dissolved mineral salts.

Salinity rarely causes soils or plants to exhibit overt symptoms. Therefore, it is difficult to assess exact losses in productivity due to the increasing saline content of soils and irrigation waters. The most common effects are seedling kill and a general stunting of plant growth.

Not all plant parts, however, are affected equally. Top growth is often suppressed more than root growth. Grain yields for rice and corn may be reduced appreciably without affecting straw yield. With some crops (e.g., barley, wheat, cotton) seed or fiber production decreases much less than vegetative growth. Furthermore, varieties of the same crop may react differently. Nor are the effects caused by a common mechanism. Some plants are susceptible to specific ion toxicities; in others, salinity induces nutritional imbalances or deficiencies.[70]

The Environmental Protection Agency has attempted to estimate the total costs for the Lower Colorado Basin and Southern California, where salinity concentrations are now approaching critical levels because of the sensitivity of the crops normally grown in these regions. The economic penalty that agriculture must pay for salinization (marginal costs of increases in salinity concentrations above 1960 conditions) is estimated to reach 21 million 1974 dollars annually by the year 2010.[71]

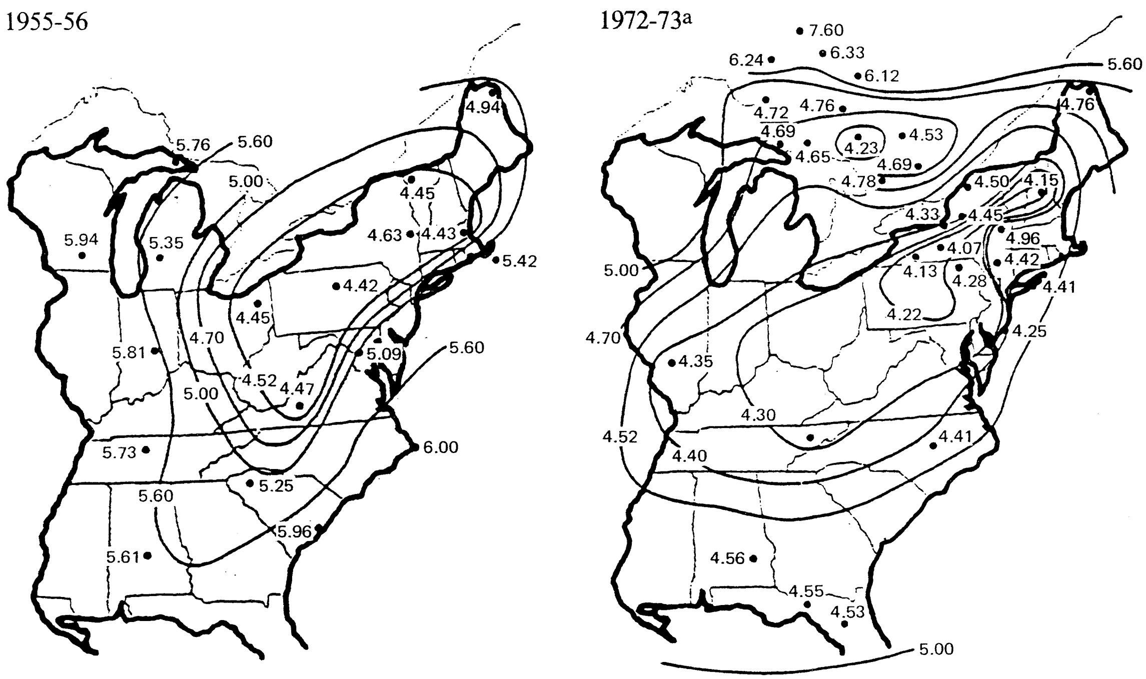
Increasing salinity will definitely play a major role in impairing future productivity of cropland in the western states. It appears that management techniques could be employed successfully to minimize this loss, but those techniques will increase crop production costs and may result in much irrigated land becoming less economically competitive, particularly for lower-value crops.[72]

*F*ive: *AIR POLLUTION—ACID RAIN*

The United States annually discharges approximately 150 million metric tons of sulfur oxides and nitrogen oxides into the atmosphere as a result of the combustion of tremendous quantities of fossil fuels such as coal and oil. Through a series of complex chemical reactions, these pollutants can be converted into photochemical smog and acids, and the latter may return to earth as components of rain or snow. This "acid rain" may have severe impacts on widespread areas of the environment. Figure 4 shows that the acidity of rain has increased in the eastern U.S.

Figure 4. Acidity of precipitation has increased markedly in the eastern U.S. . . .[1]

Average pH of annual precipitation



Source: C. V. Cogbill and G. E. Likens

[a]Data From Oak Ridge, Tenn., for 1873-74; data from Tallahassee, Fla., for 1974-75' and from Gainesville, Fla., for 1976. Source: Various, including C. V. Cogbill, Thomas Burton, Patrick Brezonik, and Gray Henderson.

[1]Source: Galloway, James et. al., National Atmospheric Deposition Program. "A National Program for Assessing the Problem of Atmospheric Deposition (acid rain)", prepared for the Council on Environmental Quality, Washington, D.C. 1978, p. 1.

Hundreds of lakes in North America and Scandanavia have become so acidic that they can no longer support fish life. More than ninety lakes in the Adirondack Mountains in New York State are fishless because acidic conditions have inhibited reproduction.

Recent data indicate that other areas of the United States, such as northern Minnesota and Wisconsin, may be vulnerable to similar adverse impacts.

While many of the aquatic effects of acid precipitation have been well documented, data related to possible terrestrial impacts are just beginning to be developed. Preliminary research indicates that the yield from agricultural crops can be reduced as a result of both the direct effects of acids on foliage, and the indirect effects resulting from increased leaching of minerals from soils. The productivity of forests may be affected in a similar manner.[73]

Additionally, the components of smog—oxides of nitrogen, ozone, ketones, aldehydes, and dozens of other chemicals, many created in the atmosphere from the compounds formed by the burning of coal and oil—may adversely affect vegetation through direct toxic action or by interfering with important plant biological processes. In 1975, the National Academy of Sciences noted that air pollution is "an unwitting constraint on agricultural production efficiency."[74]

Crops are affected by pollution in many parts of the nation. A classic example is the abandonment of the Zinfandel grape in parts of California because of damage from air pollutants. Similarly, air pollution has forced the abandonment of varieties of cigar tobacco in the Connecticut Valley. Spinach is disappearing from vegetable farms near cities for the same reason.

Yields of potatoes per acre in the Connecticut Valley, where pollution is high, have been decreasing slowly since 1960 due in part to air pollution. Legumes are particularly vulnerable to injury from pollutants, especially sulfur dioxide.[75]

Smog in the Los Angeles basin contributed to the slow decline of citrus groves south of the city, and damages trees in the San Bernadino National Forest fifty miles away. Flouride and sulfur oxides, released into the air by phosphate fertilizer processing in Florida, have blighted numerous pines and citrus orchards. In New Jersey, pollution injury to vegetation has been observed in every county, and damage has been reported to at least 36 commercial crops.[76]

Studies in southern California found sizable reductions when measuring yields of crops grown in ambient polluted air versus yields of crops grown in filtered clean air. Alfalfa yields declined thirty-eight percent; blackeyed peas, thirty-two percent; lettuce, forty-two percent; sweet corn, seventy-two percent; and radishes, thirty-eight percent. In Massachusetts, similar experiments showed yield reductions from ambient air pollution of fifteen percent for beans and thirty-three percent for tomatoes.[78]

Data assembled in 1974 showed that acid raid covered part or all of the land in the United States east of the 100th meridian and showed up in large areas of the West, particularly around Los Angeles, Oregon's Willamette Valley, Tucson, and Grand Forks, Nebraska.[79] The damage potential, especially in humid areas, is substantial.[80]

The Clean Air Act Amendments of 1970 require the Environmental Protection Agency to establish primary air quality standards, which, in addition to protecting human health and secondary standards, will protect the public "welfare." This includes the effects of air pollution upon agriculture. While the nation has made significant progress toward formulating "primary" standards to accomplish the former objective, in many Air Quality Control Regions pollution continues to jeopardize agricultural crops.[81]

Thus, without compliance to "secondary" air quality standards, a continued decline in agricultural productivity can be expected if current trends continue.[82]

The effects of acid rain, resulting in a gradual decrease in soil pH, may eliminate particular growing regions from production.

An intensive research effort on this problem is being undertaken in the United States and Canada, but there is yet little evidence that could be used to convert productivity losses from acid rain into "acre" equivalents of lost productivity as was done for soil erosion. In some respects, these losses may be fundamentally unlike those due to soil erosion, salinity, water mining, etc. If air pollution were to cease, further damage would slow dramatically, and natural recycling or man's intervention through soil amendments (such as lime) might bring back at least a portion of the lost productivity. Thus, it could be argued that, at least to some degree, soil damage by acid rain is fairly reversible.

Six: SOIL PROBLEMS IN URBANIZING AREAS

Conversion of farm land to urban and built-up or other uses not only sacrifices productivity of the land converted, but may adversely affect surrounding agricultural enterprises.

As farms give way to development and residential concerns, agricultural uses sometimes cease or change in character as acres await development. Even before land use conversions actually occur, soil conversion incentives are destroyed. There may be little incentive to maintain soils, soil conservation practices and structures, barns, drainage, and fencing if a farm operator believes that a land speculator or developer will acquire the land in the near future. One New York study has shown that farmers tend to exploit or mine land they do not own or control with long-term leases.[83]

The potential impact of diminished productivity due to a lower level of soil care in urbanizing regions is disturbing, and is a major policy concern from both a farm land preservation and soil conservation perspective.

An attempt to quantify the relationship between ''buckshot'' or scattered urbanization and agricultural productivity found a measurable effect, however, only in relation to dairying.[84] This study revealed that farm land idled, or rendered less productive as the result of these indirect effects, is probably slight and diverse. Currently, these effects appear as little more than ''noise'' in the data being collected. It remains difficult to estimate the total nation's lost productivity on agricultural lands resulting from population spread into rural areas.

Seven: *SUMMARY AND CONCLUSION*

Future need of agricultural commodities for domestic consumption and foreign trade will grow. Though the amount and timing of increase cannot be fixed precisely, growth of population and income, and more diverse uses of agricultural commodities here and abroad will require progressively larger harvests to meet domestic and foreign demands for food and fiber.[85] With rising demand, the country's cropland will be placed under increased pressure for more intensive production practices. Should there be conversion to crop production of significant amounts of land from other uses—including such extensive agricultural uses as grazing and forest land—*more of the country's agricultural land will be vulnerable to accelerated degradation from a variety of physical processes.*

Erosion is the most significant and widespread threat to the continued productivity of the nation's soils resource base. In addition, yields may be diminished by air pollution and growing soil salinity, soil compaction, depletion of ground water supply, acid rain, or unfavorable climate change. Soils that are water-logged, compacted, or have lost significant amounts of organic matter produce lower crop yields with the same inputs. These destructive effects are compounded by the abandonment of existing conservation practices and the disruption of land near urban areas of housing developments or other conflicting nonagricultural land uses.

Land degradation can become a vicious cycle, leading to the eventual permanent loss of cropland.

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APPENDICES

Appendix A. The Land-Capability Classification

The capability classification[1] is one of a number of interpretive groupings made primarily for agricultural purposes. The capability classification begins with the individual soil-mapping units. In this classification the arable soils are grouped according to their potentialities and their limitations for sustained production of the common cultivated crops without specialized site conditioning or site treatment. Nonarable soils (soils unsuitable for long-time sustained use for cultivated crops) are grouped according to their potentialities and their limitations for producing permanent vegetation and according to the risks of damage if mismanaged.

The capability classification provides three major categories: capability unit, capability subclass, and capability class. A capability unit is a grouping of soils that are suited to the same kinds of common cultivated crops and pasture plants and have about the same responses to systems of management.

The second category, the subclass, is a grouping of capability units having similar kinds of limitations or hazards. Four kinds of limitations or hazards are recognized: Erosion, wetness, root zone limitation, and climate.

In the third and broadest category of the capability classification all the soils are grouped in eight capability classes. The risks of soil damage or the limitations in use become progressively greater from class I to class VIII. Under good management soils in the first four classes are capable of producing adapted plants, such as forest trees, range plants, and the common cultivated field crops and pasture plants. Soils in classes V, VI, and VII are capable of producing adapted native plants. Some soils in classes V and VI are also capable of producing specialized crops, such as certain fruits and ornamentals and even field and vegetable crops under highly intensive management that includes elaborate practices for soil and water conservation. Soils in class VIII do not return onsite benefits for inputs of management for crops, grasses, or trees without major reclamation.

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Capability Classes

Land suited for cultivation and other uses.

Class I. Soils in class I have few limitations that restrict their use. They are suited to a wide range of plants and may be used safely for cultivated crops, pasture, range, forest, and wildlife. The soils are nearly level, and the erosion hazard (wind and water) is low. They are deep, generally well drained, and easily worked. They hold water well and are either fairly well supplied with plant nutrients or highly responsive to fertilizers.

These soils are not subject to damaging overflow. They are productive and can be cropped intensively. The local climate is favorable for growing many of the common field crops. The soils that are used for crops need only ordinary management practices to maintain productivity.

In irrigated areas, soils may be placed in class I if the limitation of the arid climate has been removed by rèlatively permanent irrigation systems. Such soils are nearly level, have deep rooting zones, have favorable permeability and water-holding capacity, and are easily kept in good tilth. Some of the soils may require initial conditioning, including leveling to the desired grade, leaching of a slight accumulation of soluble salts, or lowering of a seasonal high water table. If the limitations of salt accumulation, high water table, overflow, or erosion are likely to recur, the soils are regarded as subject to permanent natural limitations and are not included in class I.

Class II. Soils in class II have some limitations that reduce the choice of plants or require moderate conservation practices. They require careful soil management, including conservation practices, to prevent deterioration or to improve air and water relations when the soils are cultivated. The limitations are few and the practices are easy to apply. The soils can be used for cultivated crops, pasture, range, forest, or wildlife habitat.

Limitations of soils in class II may include singly or in combination (1) gentle slopes, (2) moderate susceptibility to wind or water erosion or moderately adverse past erosion, (3) less-than-ideal soil depth, (4) somewhat unfavorable soil structure and workability, (5) slight to moderate salinity or alkalinity easily corrected but likely to recur, (6) occasional damaging overflow, (7) wetness that can be corrected by drainage but is a permanent moderate limitation, and (8) slight climatic limitations on soil use and management.

Soils in this class give the farm operator less latitude in the choice of either crops or management practices than soils in class I. They may also require special soil-conserving cropping systems, soil conservation practices, water-control devices, or tillage methods when used for cultivated crops.

Class III. Soils in class III have severe limitations that reduce the choice of plants or require special conservation practices, or both. These soils have more restrictions in use than those in class II. When they are used for cultivated crops, the conservation practices are usually more difficult to apply and to maintain. They can be used for cultivated crops, pasture, forest, range, or wildlife habitat.

These soils have limitations that restrict the amount of clean cultivation; timing of planting, tillage, and harvesting; choice of crops; or a combination of these items. The limitations may result from one or more of the following: (1) Moderately steep slopes, (2) high susceptibility to water or wind erosion or severe past erosion, (3) frequent overflows causing some crop damage, (4) very slow permeability of the subsoil, (5) wetness or some continuing waterlogging after drainage, (6) shallow depth to bedrock, hardpan, fragipan, or claypan that limits the rooting zone and water storage, (7) low moisture-holding capacity, (8) low fertility not easily corrected, (9) moderate salinity or alkalinity, or (10) a moderate climatic limitation.

Class IV. Soils in class IV have very severe limitations that restrict the choice of plants or require very careful management, or both. The restrictions in use for these soils are greater than for those in class III, and the choice of plants is more limited. If these soils are cultivated, more careful management is required and the needed conservation practices are more difficult to apply and maintain. They can be used for crops, pasture, forest, range, or wildlife habitat.

Soils in class IV may be well suited to only two or three of the common crops or the yields may be low in relation to the inputs over a long period. Their use for cultivated crops is limited because of one or more permanent features such as (1) steep slopes, (2) high susceptibility to water or wind erosion, (3) severe past erosion, (4) shallowness, (5) low moisture-holding capapcity, (6) frequent overflows causing severe crop damage, (7) excessive wetness with a continuing hazard of waterlogging after drainage, (8) severe salinity or alkalinity, or (9) moderately adverse climate.

In humid regions, many sloping soils in class IV are suited to occasional but not regular cultivation. Some of the poorly drained, nearly level soils in class IV are not subject to erosion but are poorly suited to intertilled crops because of the time required for the soil to dry out in the spring and because of their low productivity for cultivated crops.

In subhumid and semiarid regions soils in class IV may produce good yields of adapted cultivated crops during years of above-average rainfall, low yield during years of average rainfall, and failures during years of below-average rainfall. During low-rainfall years the soils must be protected even though there is little probability of producing a marketable crop.

Land limited in use, generally not suited for cultivation

Class V. Soils in class V have little or no erosion hazard but have other limitations that are impractical to remove and that limit their use largely to pasture, range, forest, or wildlife habitat. They have limitations that restrict the kind of plants that can be grown and that prevent normal tillage of cultivated crops. They are nearly level, but some are wet, are frequently overflowed, are stony, have a climatic limitation, or have some combination of these limitations. Examples of soils in class V are (1) soils of the bottom lands subject to frequent overflow that prevents the normal production of cultivated crops, (2) nearly level soils in an area in which the growing season prevents the normal production of cultivated crops, (3) level or nearly level stony or rocky soils, and (4) ponded areas where drainage for cultivated crops is not feasible but the soils are suitable for grasses or trees. Cultivation of the common crops is not feasible, but pastures can be improved and benefits from proper management can be expected.

Class VI. Soils in class VI have severe limitations that make them generally unsuited to cultivation and that limit their use largely to pasture, range, forest, or wildlife habitat. The physical conditions of these soils are such that it is practical to apply range or pasture improvements if needed, such as seeding, liming, fertilizing, and water control by contour furrows, drainage ditches, diversions, or water spreaders. These soils have continuing limitations that cannot be corrected , such as (1) steep slope, (2) hazard of severe erosion, (3) past erosion, (4) stoniness, 5) shallow rooting zone, (6) excessive wetness or overflow, (7) low moisture-holding capacity, (8) salinity or alkalinity, or (9) severe climate. Because of one or more of these limitations, these soils are not generally suited to growing cultivated crops but they can be used for pasture, range, forest, and wildlife habitat or some combination of these.

Some soils in class VI can be safely used for the common crops if unusually intensive management is used. Some of the soils are also adapted to special crops, such as sodded orchards, blueberries, and similar crops. Depending on their characteristics and the local climate, the soils may be well or poorly suited to growing trees.

Class VII. Soils in class VII have very severe limitations that make them unsuited to cultivation and that restrict their use largely to grazing, forest, or wildlife habitat. The physical condition of these soils is such that it is impractical to apply pasture or range improvements, such as seeding, liming, fertilizing, and water control by contour furrows, ditches, diversions, or water spreaders. The restrictions are more severe than those for soils in class VI because of one or more continuing limitations that cannot be corrected, such as very steep slopes, erosion, shallowness, stoniness, wetness, presence of salts or alkali, unfavorable climate, or other limitations that make them unsuited to common cultivated crops. Under proper management, these can be used safely for grazing, forest, wildlife habitat, or some combination of these. Depending on their characteristics and the local climate, these soils may be well or poorly suited to growing trees.

Class VIII. Soils and landforms in class VIII have limitations that preclude their use for commercial crop production and that restrict their use to recreation, wildlife habitat, water supply, or aesthetic purposes. They cannot be expected to return significant benefits from management for crops, grasses, or trees, although benefits from their use for wildlife habitat, watershed protection or recreation may be possible.

Limitations that cannot be corrected may be one or more of the following: (1) Past erosion or erosion hazard, (2) severe climate, (3) wetness, (4) stoniness, (5) low moisture-holding capacity, and (6) salinity or alkalinity. Badlands, rock outcrops, sandy beaches, river wash, mine tailings, and other nearly barren lands are included in class VIII. It may be necessary to protect the soils and landforms and to manage them for plant growth to protect other more valuable soils, to control water, for wildlife habitat, or for aesthetic reasons.

Capability Subclasses

Subclasses are groups of capability units within classes that have the same kinds of dominant limitations to agricultural use as a result of soil and climate. Some soils are subject to erosion if they are not protected; others are naturally wet and must be drained if crops are to be grown. Some soils are shallow or droughty or have other deficiencies. Still other soils occur in areas in which climate limits their use. The four kinds of limitations recognized at the subclass level are: Risk of erosion, designated by the symbol, e; wetness, w; root-zone limitations, s; and climatic limitations, c. The class and subclass designations provide information about both the degree and the kind of limitation. Capability class I has no subclasses.

Subclass e (erosion hazard) consists of soils for which susceptibility to erosion or past erosion damage is the dominant problem or hazard in their use.

Subclass w (excess water) consists of soils in which excess water is the dominant hazard or limitation in their use. Poor soil drainage, wetness, high water table, and overflow are the criteria for determining which soils belong to this subclass.

Subclass s (other unfavorable soil conditions) consists of soils in which the soil characteristics of the root zone are the dominant limitations in their use. These limitations are such factors as shallowness, stoniness, low moisture-holding capacity, low fertility difficult to correct, and salinity or sodium.

Subclass c (climatic limitation) consists of soils for which the climate (temperature and lack of moisture) is the major hazard or limitation in their use.

Because limitations imposed by erosion, excess water, shallowness, stoniness, low moisture-holding capacity, salinity or alkalinity can be modified or partially overcome, they take precedence over climate in determining subclasses. The dominant kind of soil limitation or hazard determines the assignment of capability units to the e, w, and s subclasses. Capability units that have no limitation other than climate are assigned to the c subclass.

If two kinds of limitations that can be modified or corrected are nearly equal, assignments to subclasses have the following priority: e, w, and s. For example, in grouping soils of humid regions that have both an erosion hazard and an excess water hazard, the erosion hazard takes precedence over wetness; for soils having both an excess water limitation and a root-zone limitation, wetness takes precedence over the root-zone limitation. In grouping soils of subhumid and semiarid regions that have both an erosion hazard and a climatic limitation, the erosion hazard takes precedence over the climatic hazard; for soils that have both a root-zone limitation and a climatic limitation, the former takes precedence over the latter.

Appendix B. The Universal Soil Loss Equation

The universal soil loss equation (USLE) is a formula used to predict soil losses caused by water erosion. It was used to estimate sheet and rill erosion for the NRI.

The use of equations to calculate field soil loss began around 1940 in the Corn Belt. A national committee met in Ohio in 1946 to adapt the Corn Belt equation to cropland in other regions. This committee reappraised the Corn Belt factor values and added a rainfall factor. The resulting formula, generally known as the Musgrave Equation, has been widely used for estimating gross erosion from watersheds in flood abatement programs.

The USLE was developed at the National Runoff and Soil Loss Data Center, which was established in 1954 by the Agricultural Research Service (now Science and Education Administration (SEA)) in cooperation with Purdue University. Federal-state cooperative research projects at forty-nine locations contributed more than 10,000 plot-years of basic runoff and soil loss data to this center for summarization and statistical analyses. After 1960, rainfall simulators operating from Indiana, Georgia, Minnesota, and Nebraska were used on field plots in sixteen states to fill some of the gaps in the data needed for factor evaluation.

Analyses of this basic data provided several major improvements for the soil loss equation: (a) a rainfall erosion index evaluated from local rainfall characteristics, (b) a quantitative soil erodibility factor that is evaluated directly from soil properties and is independent of topography and rainfall differences, (c) a method of evaluating cropping and management effects in relation to local climatic conditions, and (d) a method of accounting for effects of interactions among cropping systems, productivity levels, tillage practices, and residue management.

Developments since 1965 have expanded the use of the universal soil loss equation by providing techniques for estimating site values of its factors for additional land uses, climatic conditions, and management practices.

The equation is: A = RKLSCP.

A is the average annual soil loss in tons per acre predicted for a given area.

R is the rainfall erosion factor. Soil is eroded from cultivated land in direct proportion to the product of kinetic energy multipled by the maximum thirty-minute intensity of a rainstorm. This product, called the erosion index, shows the erosion potential of the rainfall within a given period. Annual erosion indexes and monthly rainfall distribution curves have been computed for locations throughout the United States where sheet and rill erosion is a problem. These curves were developed using Weather Bureau and SEA data accumulated over more than twenty years.

K is the soil erodibility factor, which expresses soil loss in tons per acre per unit of rainfall erosion index (R) for a slope of specified dimensions, steepness, and length. K factors vary with soil type, series, and degree of erosion. K values have been determined for all soils on the basis of the soil characteristics that determine erodibility.

L is the length of slope factor. This factor is the ratio of soil loss from a specific length of slope to that from the length specified for the K factor of the equation. Slope length is defined as the distance from the point of origin of overland flow to the point where the slope decreases and deposition begins, or to the point where runoff enters a well defined channel.

S is the steepness of slope factor. It is the ratio of soil loss from the field slope gradient to that from a standard slope under otherwise identical conditions.

C is the cover and management factor. This factor takes into account the combined effect of crops, crop sequence, and various management practices on soil erosion. It is the expected ratio of soil loss from land cropped under specified conditions to soil loss from continuously cultivated fallow land with identical soil, slope, and rainfall conditions. SCS has estimated C factors for rangeland and forest land as well as for cropland.

P is the erosion control practice factor. This factor is the ratio of soil loss under a specified conservation practice to that with uphill and downhill farming operations when other conditions, such as soil, slope, and rainfall, are equal.

Soil Loss Tolerance (T)—In addition to the USLE factors, SCS determined the kind of soil and the average annual soil loss tolerance (T) factor at each random point. This factor is the soil loss in tons per acre per year that can be tolerated indefinitely without interfering with a sustained high level of production. The amount lost through erosion can be no greater than that replaced through soil building processes. T values have been established for all soils. They range from two to five tons per acre per year.

Use of the USLE in the National Resource Inventories (NRI)—SCS gathered data from each NRI sample point to determine each factor in the USLE. The annual soil loss per acre was computed at each point classified as "all cropland," "cultivated cropland," "forest land," "rangeland," or "pastureland." Computations of sheet and rill erosion did not include points in water, snow and ice fields, farmsteads, other land in farms, quarries and pits, barren lands, or urban lands where C factors were not available and the USLE did not apply.

See Wischmeier, W. H. and Smith, D.D. 1978. "Predicting rainfall erosion losses—a guide to conservation planning." Science and Education Administration, U.S. Department of Agriculture, Agricultural Handbook No. 537. This handbook gives the details on the use of the Universal Soil Loss Equation.

Appendix C: The National Resource Inventories

The National Resource Inventories (NRI) provided much of the data used in preparing the 1980 RCA Appraisal. For the NRI, the Statistical Laboratory of Iowa State University selected random sample areas known as primary sample units (PSU's) for each county in each state. Most PSU's in midwestern, western, and southern states were 160 acres; most in eastern states were 100 acres. Some were as small as forty acres and some as large as 640 acres.

Three points were selected at random within each PSU (only two points were used in PSU's of forty acres). The Soil Conservation Service (SCS) examined about 200,000 sample points in the field and compiled data for the NRI. SCS field specialists and technicians collected the data. State SCS staffs and the Iowa State University Statistical Laboratory made quality control checks. SCS reexamined more than 6,000 sample points in the field for correctness, and the Statistical Laboratory made other special computer checks for consistency.

County Base Data—Basic data about the gross area of each county and the net area of land and water in each county were obtained from the U.S. Department of Commerce, Bureau of the Census. Estimates from the 1970 Census were provided to SCS field offices. Field personnel reported any changes in land and water areas between 1970 and 1977. Such changes might have been caused by county boundary changes, construction of large reservoirs, or other activities.

The Forest Service reported land it administered as National Forest System or National Grasslands, and the Bureau of Indian Affairs reported the acreage of land it administered. Field personnel determined from state and local sources the acreage of land administered by other federal agencies.

SCS used existing data to measure roads and railroads that connect rural and urban areas to determine the amount of land used for major rural transportation systems. Transportation categories included:

1. Interstate highways
2. Paved primary federal and state highways
3. Other paved roads
4. Gravel roads
5. Dirt Roads
6. Railroads

The number of miles of roadway in each transportation category, the average width of the corridor, and the total acreage occupied were recorded.

PSU Data—Maps were submitted to the Statistical Laboratory showing the location and extent of urban and built-up land of more than forty acres and the location and extent of irrigated land. The Statistical Laboratory used these maps in selecting the size and location of PSU's and then notified the SCS field offices that were to gather the field data. SCS obtained the following information for each PSU:

• Size—The actual size of each PSU in acres was recorded. For irregularly shaped PSU's the acreage was determined by dot grid or by planimetering the area on a map or photograph.

• Urban and Built-up Land—The acreage of urban and built-up land in each PSU was determined. This acreage included contiguous areas of more than ten acres used for residences, industrial and commercial sites, institutional sites, railroad yards, small parks, cemeteries, airports, and similar urban facilities.

• Small Built-up Land—The acreage of small built-up areas was also determined in each PSU. These areas are like "Urban and Built-Up Land" except that they are smaller than ten acres but larger than 0.25 acre.

• Farmsteads—The acreage of farmsteads in each PSU was determined. This acreage included land used for dwellings, buildings, barns, pens, corrals, windbreaks, family gardens, and other purposes connected with operating farms or ranches.

• Water Bodies Less Than forty Acres—All permanent water bodies of less than forty acres were identified and their use was recorded. This information was recorded for all water bodies even if only part of their total area was within the PSU. SCS field personnel recorded at least one but no more than three of the following uses for each water body:

1. Irrigation
2. Livestock water
3. Water supply (municipal, industrial, household, firefighting)
4. Recreation, fish and wildlife
5. Erosion and sediment control
6. Flood prevention and flood control
7. Water quality control (livestock waste lagoons and sewage lagoons)
8. Other (power, navigation, cooling, etc.)

• Perennial Streams Less Than One-Eighth Mile Wide—SCS also collected data on the width, length, and acreage of the parts of perennial streams less than one-eighth mile wide that were within each PSU. The field personnel determined that the water in each perennial stream was used for at least one but no more than two of the following purposes:

1. Irrigation
2. Livestock water
3. Water supply (municipal, industrial, household, firefighting)
4. Recreation, fish, and wildlife
5. Other (power, navigation, cooling, drainage, etc.

The most important use was recorded first.

• Perennial Streams More Than One-Eighth Mile Wide—Field personnel recorded whether the PSU contained part of a perennial stream wider than one-eighth mile.

• Construction—Data were recorded about any construction activities within the PSU involving an area of more than one acre. Construction areas were defined as land areas where man has modified the land surface, that were bare of vegetation at the time of observation, and that were expected to remain without plant cover for more than thirty days.

• Roads—SCS also recorded any rural road within the PSU. For the purpose of this inventory, roads included farm lanes, logging roads, woods roads, and other private roads as well as paved or gravel public roads. (Roads included in "Urban and Built-Up Land" were not in this category.)

• Active Gullies—Field personnel recorded the number of active gullies in each PSU. An active gully was defined as an eroding channel through which water flows only during and immediately after heavy rains or during the melting of snow. For the purpose of this inventory, a gully was further defined as a channel one foot or more deep.

Data on construction sites, roads, and gullies were recorded as preliminary information for use in a subsequent phase of the NRI concerning roadside, streambank, construction site, and gully erosion.

Sample Point Data—The PSU data were the main source of information about the total acreage of farmsteads and small urban, built-up, and water areas. SCS obtained more specific information from the point data in the NRI. An SCS representative visited each PSU and made observations at random points in the PSU selected by the Statistical Laboratory. Some information had to be obtained from the owner or operator of a farm. For data points on land that had been in crop production at some time during the previous four years, the kinds of crops and residues were determined for each year. This information was used in the wind erosion and universal soil loss equations.

Other information was gathered at each point. For all land areas, this included the soil name and symbol, the land capability class and subclass and the soil loss tolerance. A determination was made as to whether the point was on prime farmland. For urban areas, SCS gathered information on the density of urban development. For rural lands, the information obtained included the type of irrigation, the kinds of conservation practices being applied, the treatment needs, the type of ownership, and data for the universal soil loss and wind erosion equations. For rural noncropland, SCS gathered data on potential cropland, and for water, on the size of the stream or water body.

In addition to the soil and water data, other information was collected at each sample point. This information included the land use and whether or not the point was in a flood prone area or in an area that met the definitions of type Three to Twenty wetlands (Shaw and Fredine, 1956). For urban lands, SCS estimated the amount of impervious cover. For points on irrigated land, the type of irrigation was recorded. Field personnel recorded the type of ownership, the existing conservation practices, and the type of treatment needs. For undeveloped land not in cropland, the potential for conversion to cropland was determined, the major soil and water problems or other problems that might hinder conversion to cropland were noted, and the type of effort necessary for conversion was determined.

Use of Soil Surveys

For the NRI, states had the option of mapping the entire primary sample unit (PSU) in accordance with the standards and procedures of the National Cooperative Soil Survey or of determining the specific soil map unit at individual sample points. This means that uniform soil survey interpretations were made for each sample point. These interpretations provided such information as the K and T values for the universal soil loss equation, the I factor and the wind erosion equation and the land capability class and subclass. The subclasses define the limitations of the soil, including wetness, erodibility, and such climatic and inherent soil problems as stoniness, droughtiness, and salinity.

Appendix D. USDA RCA "Acre Equivalent" Approach

Nationwide, about 100 million acres (of the 413 million in cropland use in 1977) are eroding at a rate that exceeds five tons per acre per year. The total excess erosion is 1.01 billion tons from sheet and rill.

The entire 1.01 billion tons of excess sheet and rill erosion (in excess of five tons per acre per year) is occuring on one-fourth of the nation's cropland. If a uniform rate of erosion is assumed, the division of 1.01 billion tons by 100 million acres shows that the *average* rate on these acres would be about ten tons per acre per year. At this rate, these soils would lose an inch of soil to erosion every fifteen to seventeen years and over a fifty year period would lose about three to 3.2 inches of soil. This would in most cases reduce the productive capacity by about twenty to thirty percent. A twenty to thirty percent reduction in productive capacity on twenty-five percent (100 million acres) of U.S. cropland (413 million acres) would mean an overall production loss of about seven to eight percent nationally. This would be a loss of about twenty-eight to thirty-two million "acre equivalents" from sheet and rill erosion alone. Additional losses would also occur from wind and other forms of erosion.

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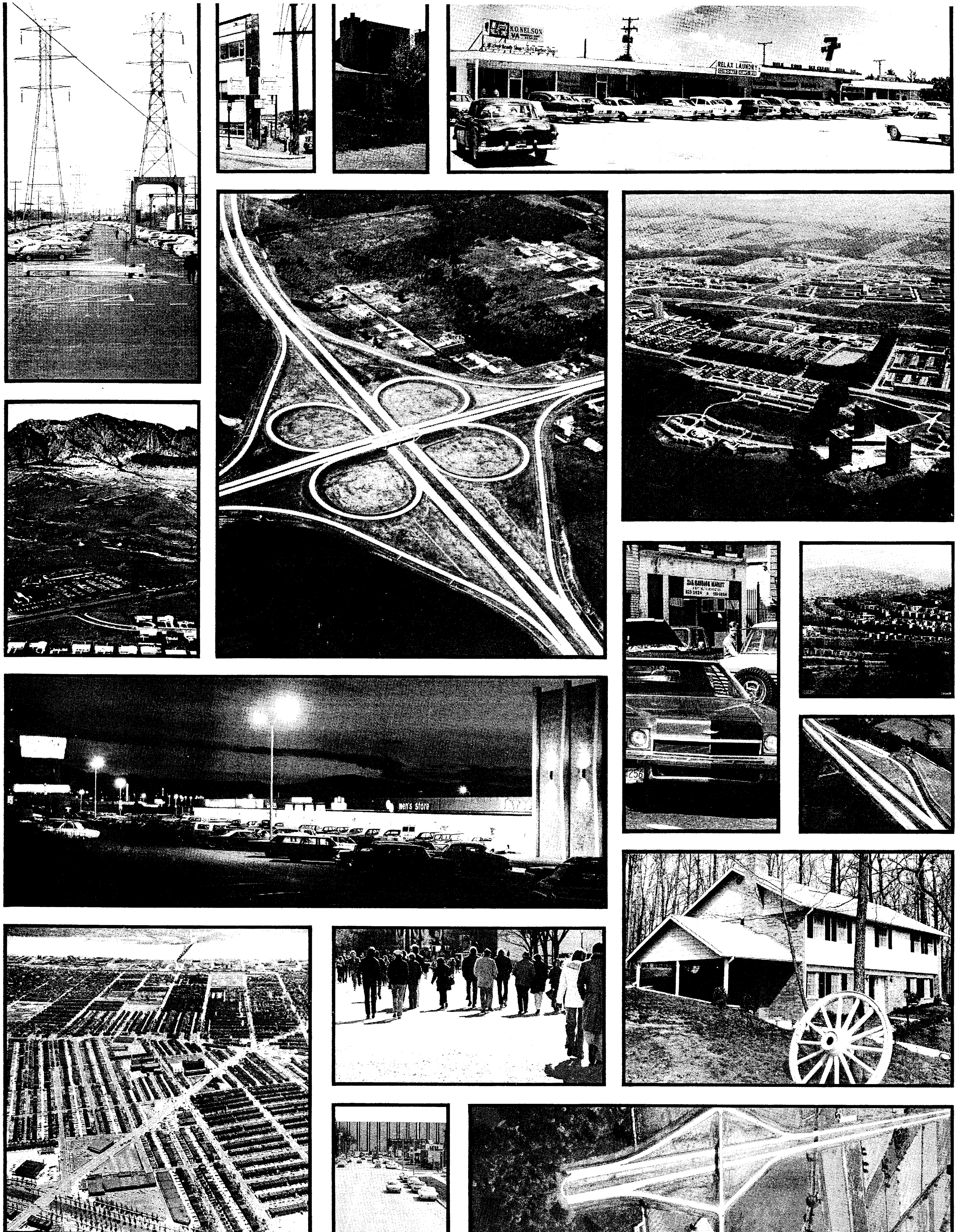

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