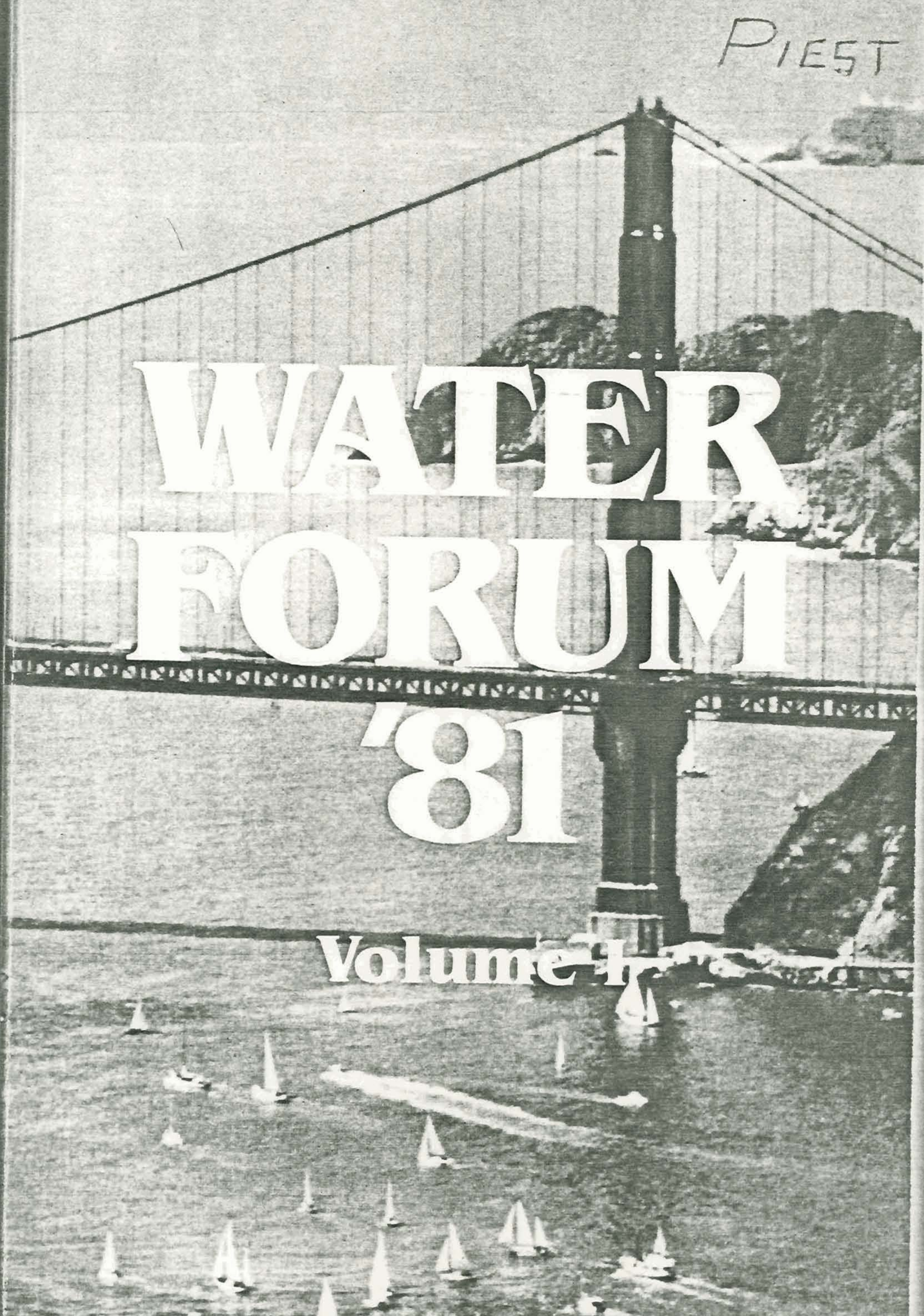
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Improved Techniques for Control of Gullying

Robert F. Piest, M. ASCE[1/], Charles T. Crosby[2/]
and Ralph G. Spomer[3/]

ABSTRACT

Gullying has often been cyclic through geologic time, but the present accelerated activity is symptomatic of environmental changes wrought by man. Gullying rates for several problem areas of the mid-Missouri River Basin have been monitored and are cited. Four characteristic types of gullies are identified and some site-specific treatments are recommended.

INTRODUCTION

Regions with deep soils and unconsolidated substrata, including much of the Midwest, have been periodically dissected throughout geologic time. Brice (3) has traced these episodes of valley incisement and subsequent channel filling during the past 12,000 years in the loess-mantled terrain of Medicine Creek Basin, southwestern Nebraska. Daniels and Jordan (5) have similarly reviewed the fluvial morphology of several western Iowa drainage basins. Studies such as these have contributed to the sum of academic knowledge of geomorphic processes. But they take on added import because of the accelerated downcutting (gullying) of upland drainageways during the past century.

No single feature distinguishes a gully from another drainage channel. Some definitions prescribe limits to gully size and contributing drainage area. For our purpose, the essential feature of a gully is an incision in the drainageway of a small valley or along the perimeter of an adjacent upland field. Four types of gullying problems that we are addressing are illustrated in Figures 1-4. Aside from the differences apparent from an inspection of the figures, the stability of the Iowa gullies is usually aggravated by perennial seepage from the banks.

The authors wish to briefly examine some of the causes of recent gully formation and channel downcutting, to quantify the problem for representative drainage areas, and to propose techniques that may better fit the pressing need for more cost-effective erosion controls.

1/ Hydraulic Engineer, U.S. Dept. Agric., Science and Education Administration, Columbia, Missouri.
2/ Deputy Director, Div. of Agric. Eng., Pretoria, South Africa.
3/ Agricultural Engineer, U.S. Dept. Agric., Science and Education Administration, Council Bluffs, Iowa.

Figure 1.-

Figure 2.-

Figure 1.--Valley-bottom gully draining 80-acre cornfield, Pottawattamie County, Iowa

Figure 2.--Active erosion scarp causing channel degradation and enlargement, Keg Creek, Iowa

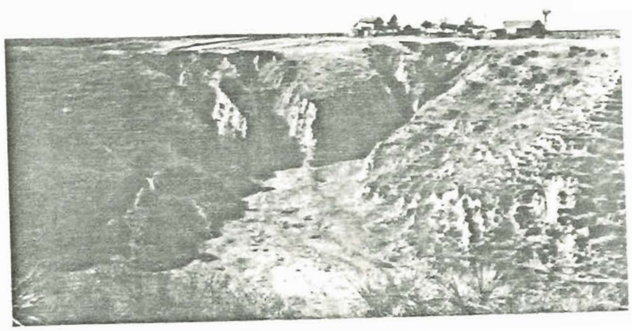

Figure 3.--Gully headcutting, Dry Creek, NE, where the valley-head gullies encroach onto nearly-flat upland field

Figure 4.--Valley-bottom gully and headcut, Dry Creek, NE (draining 6 sq. mi.)

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CAUSES OF MODERN DOWNCUTTING

Runoff is a necessary, but not always sufficient, cause for the massive scouring of upland channels. In fact, gully erosion is essentially a supply-dependent process (10). Shearing forces of flowing water act to scour a channel at some base rate that depends upon erodibility characteristics at the flow boundary. In localities with the most serious gullying problems, however, the rate of incisement is often influenced as much by downstream base levels as by the water conveyed.

In the process of thalweg adjustment to lower base levels, a much higher erosion rate can be triggered by random vegetative or soil instability, change in flow gradient, moisture-induced change in soil stress-strength relationships, tunnel erosion in dispersive soils, or other weathering forces. Whatever the combination of these forces, the effect is to create a discontinuity in the longitudinal profile. This results in a channel erosion scarp that progresses upstream (see Figures); the banks of the channel then weaken and fall (or slump) and the slough materials are flushed through the drainage system even with minimal runoff.

Most of these enumerated factors were in existence in pre-settlement times, but Piest et al. (11) cited additional factors which have tended to greatly accelerate channel deterioration. These include such overt anthropic activities as channel dredging and straightening, which tended to cause steepened and non-uniform channel gradients that spawned scarp formation and growth. More subtle and far-reaching effects were also cited, such as increased surface runoff induced by conversion of virgin lands to clean-till agriculture in the last century, which caused the equivalent of a significant climatic shift. The quantity of surface runoff from rowcrop land in the Midwest is 2 to 3 times the pre-agricultural level, and peak runoff rates from rowcrop fields are increased as much as 50 fold or more for some storm events. Much of this surcharge of high-energy runoff is now contained in the channel, rather than dissipated overbank. In other regions, increased runoff from irrigation wastewaters routed to previously stable channels has also been observed to cause severe channel degradation (8). Combined with added man-induced stresses in drainageways, large runoff surcharges can in time effectively cut off meander bends and cause channels to degrade--even without straightening and dredging activities.

CHARACTERISTIC GULLIES AND SOME RECOMMENDED TREATMENTS

Pottawattamie County, Iowa

SEA Watersheds 0.30-0.61 km^2 (0.12-0.23 mi^2)--Runoff from clean-tilled fields in the loess hills region of western Iowa is often outletted to grass waterways which quickly degenerate into gullies of typical size--about 18 m (60 ft.) wide and 6.1 m (20 ft.) deep--as shown in Figure 1. The most erodible of the four SEA watersheds is a 0.30 km^2 (0.12 mi.^{2}) cornfield with average 9 percent landslope. It is representative of fields that are continuously rowcropped, with no conservation treatments except contour planting and some grass waterways. Runoff and erosion from both the cornfield and the upstream-advancing headscarp have been continuously monitored since 1964 (2). Gully erosion in the short length of channel near the headscarp has averaged 363 metric tons (400 tons) per year, 1964-79, with 23 percent of the total occurring in June 1967. Sediment entered the gullied channel from the cornfield (sheet-rill erosion) at nearly 4 times the gullying rate; the sediment concentration of runoff averaged 50,000 ppm, with peak concentrations exceeding 200,000 ppm.

In contrast to this unterraced cornfield, runoff and sediment movement from nearby conservation watersheds were at manageable levels, Spomer et al. (12). The conservation treatments included: till-planted corn without terraces; till-planted corn with double-spaced level terraces; corn with conventional level terraces; and grass pasture.

In summary, the sixteen-year record shows that treatment options which can increase infiltration and thereby decrease surface runoff rates will restrict gully growth or halt it completely. Pastures and hay crops can easily meet this criterion, but economic realities usually mandate rowcropping of these fields. Although conservation tillage methods show some potential for reducing surface runoff to acceptable levels, the most viable present option is to terrace the fields, and install underground drains to carry excess impounded runoff. This system has demonstrably increased infiltration into the soil profile, and the accretion to groundwater and resultant seepage along the stream-banks has not aggravated channel stability whenever surface runoff is sufficiently reduced to allow vegetation to stabilize the channel.

Keg Creek, Pottawattamie County, Iowa 230 km^2 (90 mi^2)--The migration of a single low scarp within the entrenched (7.6 m or 25 ft. deep) channel of Keg Creek (Figure 2) has been observed since 1945. By best account from the landowner and from inspection of aerial photos, the scarp at no time in the 35-year period exceeded 1.8 m (6 ft.) in height, and it was often reduced to a series of smaller scarps or rapids that occasionally coalesced. Total movement during the period was more than 1.6 km (one mile). Based upon representative cross section measurements that show an average 40 percent areal increase with scarp passage, the channel voiding rate was 50,000 metric tons per kilometer (92,000 tons/mile), or 1.4 metric tons/yr/m (0.5 ton/yr ft.) of channel. Principal hazards resulting from incisement of these valley-bottom gullies include further channel voiding and destruction of bridges due to the widening that is commensurate with the deepening process--and the lowering of tributary base levels and increasing dissection of the cropped bottomland fields. Evidence of the channel widening problem is cited by a recent survey that showed 18 percent of the more than 5000 bridges in 13 southwestern Iowa counties have approach spans; this is usually considered to be evidence of recent degradation-widening processes (7).

Many schemes to halt gully incisement and stabilize channel gradients have been attempted in this region--with varying degrees of success. Structural controls were installed in problem areas of the midwest in the 1930's, notably the driftless region of southwestern Wisconsin and the Little Sioux Basin of western Iowa. Nearly every facet of structure performance was evaluated, including sediment trap efficiency,

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deposition gradients, reliability of outflow works, and maintenance needs for long-term satisfactory performance (9). These structures, if properly maintained, are effective but expensive, a fact emphasized by the many types of experimental structures still evolving. In southwestern Iowa, for example, about 250 flume bridges of varying designs have been built in the past 40 years in an effort to more economically solve the grade control problem (7).

The objective of grade control on Keg Creek would be to maintain the channel at reasonable depth, and especially to halt the deterioration caused by movement of the scarp shown in Figure 2. Wooden piling, driven to some depth below maximum scour and stabilized by cable ties into anchors located in each bank, is proposed as one inexpensive control method with a reasonable chance for success. A grid of reinforcing mesh is attached to the piling in any vertical increment desired and debris (including sediment) is trapped behind the structure. The longitudinal spacing of pile bents along the channel depends on channel gradient, height of reinforcing mesh, and quantity of sediment in transport. Pile bent designs on Keg Creek would be especially attractive because they could be installed with minimum disturbance to the adjacent cultivated flood plain. Trenching to place anchors and cable ties could easily be accomplished with their placement several feet below ground level.

Another scheme having relevance involves the use of fly ash in soil cement or concrete to produce more economical structures. Fly ash is a material having pozzolanic properties that is produced in prodigious quantities at several coal-fired power plants recently built along the Missouri River. Although the fly ash produced in the region has a recognized value for roadbase stabilization and for substitution in concrete mixes, much of it is presently wasted. At the five dollar per ton present cost for fly ash, rich mixes with regular aggregates or with on-site soils must be considered an outstanding alternative material for more economical grade controls.

Dry Creek Basin, Frontier and Lincoln Counties, Nebraska

Valley-Head Gullies, Dry Creek Basin--The erosion scarps in Figure 3 are typical of those identified as valley-head gullies by Brice (3). Valley-head gullies are most prevalent along the bluff line of streams with valleys incised into thick deposits of unconsolidated material. Perhaps the greatest erosion hazard exists where land adjacent to the bluff line is relatively flat and tillable; the excessive runoff generated by rowcropping cannot be safely conveyed by conventional waterways because bluff line relief is too great. In the 52 km^2 (20 mi^2) drainage area of Dry Creek, Brice determined that valley-head and associated valley-side erosion in the 15-year period, 1937-52, was about 76,000 m^3 (100,000 cu yds.) or 1.3 t/ha/yr (0.6 t/a/y). Much of this eroded soil is deposited in the valley because most valley-head gullies are of the discontinuous type shown. The senior author has also witnessed such severe gullying problems from valley-head erosion in Illinois, Iowa, and Alabama. Control options for gullies of this type are extremely limited because the potential for non-structural treatment is low; e.g., waterways alone cannot effect control. The scarps must be dewatered, either by normally-dry detention structures which collect the field runoff and convey it safely to the gully bottom--or by storing runoff in terrace systems. In more humid regions where runoff potentials are higher, underground pipe drains are necessary to remove terrace-impounded waters, and emergency grass waterways are needed to minimize damages from terrace overtopping. The first method involves a relatively low storage capacity with high discharge capability. With the second method, terraces can store and infiltrate appreciable quantities of runoff and, where necessary, release it at lower discharge rates through underground drains. Specific site conditions will usually dictate the most economic alternative.

Valley-Bottom Gullies, Dry Creek Basin 52 km^2 (20 mi^2)--The relatively level cultivated uplands which generate much of the runoff in Dry Creek Basin are sharply differentiated from the drainage system and comprise about a third of the total area. The remaining area is an incised valley that begins with gully knickpoints at lower field edges, Figure 3, and proceeds through flat-bottomed (though occasionally incised) tributaries to the main drainage system, Figure 4, which lies about 30 m (100 ft.) below the upland.

Gully erosion rates in the basin were measured by Brice (3) from aerial photographs, 1938-52. They have also been quantified on the basis of monumented surveys and by sampling streamflow (6). A series of active erosion scarps exist in the drainage system of Dry Creek, including a 5.2 m (17-ft.) high headscarp in the main channel, Figure 4, that advanced upstream 232 m (760 ft.) in 28 years, 1951-1979, removing more than 27,000 metric tons (30,000 tons) of soil. A tributary headscarp moved upstream 344 m (1130 ft.) in this same period. Highest erosion rates were in 1951, when measured sediment yield at the gaging station was 308,000 metric tons (340,000 tons), or 58.3 metric tons per hectare (26 tons per acre) of drainage area (6). Further channel degradation can be expected to occur unless the channel grade can be stabilized. The channel gradient is steep and secondary channel scarps can develop and move upstream in the main channel and tributaries. Also, the high rate of sediment movement downstream is decreasing the storage capacity of an irrigation reservoir.

The entire valley is grass that would not suffer from occasional flooding, so the optimum conservation goal would be to completely fill the existing gully. This can be accomplished by conventional grade control structures, but these are usually unaffordable even with favorable benefit/cost ratios. The authors know of no such structures in the entire Medicine Creek Basin 1700 km^2 (650 sq. mi.), although several flood control dams have been built at a unit cost of nearly one-half million dollars. There is some merit, therefore, in considering an entirely new concept in conservation design, where channel grade controls can be effected, along with a measure of flood control and improved stockwater supply. It would also be desirable to accomplish this conservation design by alternative materials and methodology synthesized from other locations, as proposed herein.

Reinforced earth technology (1), a patented technique less than 20 years old, requires properly graded soil, mostly noncohesive, with

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