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A Perspective of the USDA Watershed Erosion and Sedimentation Research

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ABSTRACT: Ever since Europeans immigrated to and opened up the interior of the USA, soil erosion and sedimentation problems were part of the early American agricultural legacy, which ultimately led to the devastating "Dustbowl" in the 1930s. This article provides a brief overview of the research that was initiated, the practices that were used, and the models that were developed at the field and watershed scale in response to this calamity. This paper presents in a chronological sequence the research that resulted and its accomplishments. It indicates collateral developments of addressing agriculturally related water quality and ecological research, watershed modeling, and the broadening scope of the mission of the USDA-ARS natural resources research at the National Sedimentation Laboratory (NSL). The article also identifies areas of research deficiency and needs to provide a more holistic research approach of addressing erosion and sedimentation problems at the watershed scale. Finally, it expresses deep concern for the systemic financial problems that this research faces in today's budget climate and the planned elimination of vital research by administrative fiat.

Keywords: Soil conservation, Erosion prediction, Sedimentation, Soil erosion

1 HISTORY

1.1 *The early years*

Erosion and sedimentation related watershed research is for the most part traceable to the calamitous events during the “Dustbowl” of the 1930s. At that time, large areas in the Plain States of the USA (Oklahoma, Kansas, Western New Mexico, eastern Colorado, and western Texas) experienced serious wind storms which removed large amounts of surface soil from plowed-up and dried-out unprotected land. While this part of the USA suffered serious agronomic and ecological damage by wind and threatened and impoverished to a catastrophic degree the livelihood of the rural population, the south-eastern part of the USA suffered severe erosion problems by water from rainfall and runoff especially during severe rainstorms on cultivated unprotected sloping land. In response to these conditions, the U.S. Congress, encouraged by President Roosevelt, set in motion the legal and technical framework to address these problems (Bennett, 1939; Römkens, 2010; Burns, 2012).

Wind erosion brought public attention to these problems in rural America far away from the denser populated eastern seaboard where most of the political cloud was concentrated. Water erosion, an equally severe problem and closer to home for most of America, received relatively more financial support to address this problem. In this article, we will follow the development that took place in the water erosion research area. The Soil Conservation Service (SCS) was established to perform research and to recommend and assist landowners and farmers with measures to control soil loss. Initially, the primary focus was on on-site monitoring and quantifying soil loss at different locations from natural runoff plots having different soil types and different agricultural practices with sloping topography. Erosion control on agricultural land consisted mainly of mechanical practices such as contouring, strip cropping, and terracing, and of large scale reforestation on degraded gullied land. In the channel system of watersheds sediment movement was monitored at suitable locations. Remedial measures to lessen flooding were channelization, thereby often planting the seeds of stream instabilities due to changes in the gradients. The main purpose of the SCS was to conserve the soil on upland areas, stabilize streams, and prevent flooding.

1.2 *The intervening years (1940s-1990s)*

In the 1940s and 1950s SCS' erosion and conservation research was expanded to include to a limited degree process oriented research and to arrive at predictive relationships for the effect of hydrology, topography (Zingg, 1940), soil type (Olson and Wischmeier, 1963), and agronomic and mechanical practices (Wischmeier, 1960). During this period the well-known Universal Soil Loss Equation (USLE), a regression equation based factor relationship, was developed that had a major impact on soil conservation practices and recommendations. The updated versions of this relationship are today the main tools for conservation management programs on upland areas. Since 1954, the Agricultural Research Service (ARS) has been assigned the soil erosion and conservation research program, while the SCS maintained its role of implementing conservation practices at the farm and watershed level. The early research consisted of collecting data at a multitude of locations without much national coordination.

In the 1960s the USLE underlying factor relationships were developed and improved. The physics of erosion processes became the subject of many research projects. The use of rainfall simulators (Meyer and McCune, 1958; Swanson, 1965) became an important part in the erosion research program, which shortcut many of the otherwise long-term soil erosion studies and could evaluate in a relatively brief period the effectiveness of soil conservation practices. Also, the study of erodibility in relation to soil properties took center stage (Olson and Wischmeier, 1963; Barnett et al., 1965; Wischmeier and Mannering, 1969). It climaxed in the development of the soil erodibility nomograph (Wischmeier et al., 1971).

In the 1970s soil erosion mechanics on upland areas, signifying the beginnings of process and analytical approaches in soil erosion research, became of major interest. Of particular significance were the introduction of new concepts on upland areas such as rill and interrill erosion (Foster and Meyer, 1975) and the concepts of detachment and transport limiting processes, first introduced by Ellison (1947), and mathematically further developed by Meyer and Wischmeier (1969) and Foster and Meyer (1972, 1975). The advent of computer technologies for both statistical and deterministic analyses and calculations, facilitated model development of complex processes and provided better insight and interpretation of soil erosion and sedimentation processes. At the same time, the USLE was improved and has remained the primary tool for guiding and managing upland conservation practices in water erosion prone agricultural watersheds. The usefulness of the USLE was strengthened by its large database that was collected since the 1930s and involved hundred thousands of data points representing many spatial and temporal conditions, details of hydrologic events, soil types, topographic conditions, cropping systems, etc. The 1970s was also a period in which water quality issues became of concern and in which sediment, because of its voluminous nature was a large component (Stewart et al., 1975).

In the 1980s process erosion models such as WEPP (Water Erosion Prediction Project) were developed within USDA-ARS (USDA, 1995). The premise was that a better scientific basis for predicting and controlling soil erosion would be obtained for predicting soil erosion on upland areas and for conditions not or inadequately covered by the USLE. So, there was this parallel effort of improving the USLE as a land management tool while at the same time efforts were under way to develop processed based research models. The USLE and WEPP were primarily hill-slope models. The USLE was updated twice in 1965 (Wischmeier and Smth, 1965) and in 1978 (Wischmeier and Smith, 1978) and became in 1997 the Revised Universal Soil Loss Equation (RUSLE) with the publication of Agricultural Handbook 703 (Renard et al., 1997). Since that time, the more recent and scientifically improved and technically superior 2008 version, known as RUSLE2 can be accessed on the Home page of the NSL. RUSLE2 has added capabilities. The USLE can only be used in cases where erosion takes place and is not applicable to situations when sediment deposition occurs. RUSLE2 can be applied on upland areas with both erosion and sediment deposition problems. RUSLE does not address ephemeral or permanent gully erosion. The huge advantage of the RUSLE2 model is the large database that was used to developed this model, the scientific thoughts behind this model, and the simplicity of the model with look-up tables that readily can be used by field technicians trained in the use of this model.

The 1980s was a period with great interest in developing agricultural watershed scale models for upland areas. That interest came to fruition through models such as AGNPS (Agricultural Non-Point Source Pollution Model) and AnnAGNPS (Annualized AGNPS). Also, the basin scale model SWAT (Soil Water Assessment Tool) was developed. These models were actually developed as water quality models but do contain erosion and sedimentation components. AGNPS (Young et al., 1985) is a continuous simulation surface runoff model designed to predict non-point source pollutant loadings within agricultural watersheds. AnnAGNPS is a distributed parameter, continuous simulation, watershed scale, pollutant loading computer model developed jointly by USDA-ARS and USDA-NRCS and written in standard ANSI Fortran 95. SWAT was developed by USDA-ARS and Texas A&M University to quantify the impact of land management practices on water, sediment, nutrient and pesticide yields in large, complex watersheds (Neitsch et al., 2011). It is a direct outgrowth of the SWRRB (Simulator for Water Resources in Rural Basins) model developed by Williams et al. (1985) and Arnold et al. (1990) and contains features from several ARS models such as CREAMS (Chemical, Runoff, and Erosion from Agricultural Management Systems (Knisel et al, 1980), GLEAMS (Groundwater Loading Effects on Agricultural Management Systems (Leonard et al., 1987)), and EPIC (Erosion-Productivity Impact Calculator (Williams et al., 1995)). These models are widely used.

Another first of its kind research at the NSL was agro-ecological research in agricultural watersheds. This work was conducted in the drainage channels of the major flood control reservoirs in northern Mississippi and the Oxbow Lakes or cut-off arms of the Mississippi River and its tributaries in the lower Mississippi River Delta. This research related water quality to runoff, sediment, and associated agri-chemicals and nutrients on ecology of plankton and benthic macro-vertebrate in the stream system of the Mississippi Delta agricultural watersheds. The Mississippi Delta agricultural watersheds are known to have received for many years large amounts of pesticides and herbicides during the cotton production era (Cooper, 1984). Many of the streams draining Bluff line watersheds along the Mississippi Delta were unstable and had severely eroded ever since these watershed were put into production during the 19^{th} and first half of the 20^{th} century. These channels were in many places silted up and created serious flooding and sedimentation problems in the Mississippi Delta. The remedies consisted of large scale reforestation of the slopes and degraded upland areas, channelization of the bottomland streams, and conservation measures on agricultural land. However, more vigorous measures had to be taken to stabilize the streams. The solutions consisted of hydraulic flow control structures, check dams, drop structures under the provisions of the DEC (Demonstration Erosion Control) Project. This project created an opportunity to stabilize the stream banks and utilize the pools constructed near the control structures to improve the habitat for fish and wildlife (Cooper and Knight, 1987; Knight and Cullum, 2014). Thus, what was designed to prevent flooding through stream stabilization, also had a beneficial effect of improving the ecology of the stream and channel system as a whole.

Channel erosion research has not received the highly integrated, systematic, and sustained approach per se seen in erosion research on upland areas. Much of the SCS data of earlier years have not been summarized, published, or collectively analyzed as was done with the data from natural runoff plots on upland areas that were deposited in 1954 at the Runoff and Soil Loss Center at Purdue University. Substantial research efforts were made in sediment transport in laboratory flumes at the NSL. That work was mostly designed to obtain a better understanding of sediment movement in relation to flow regimes and sediment characteristics. Some research was done on stream bank stability and protection, control structures, and sediment deposition in lakes and the stream system. Most of this work was of an experimental nature and was designed to monitor sediment movement under various flow regimes and to arrive at improved measurement techniques. Few readily useable transport relationships were obtained.

1.3 *The recent years (2000-present)*

In the 1990s and 2000s a number of erosion and transport research models were developed and improved that were aimed at special needs and involved different erosion and sedimentation issues. In the upland area, RUSLE2 received considerable interest when the utility and effectiveness of the erosivity factor was improved by introducing the concept of erosivity density. In this case, a huge variability that would be obtained if erosivity for locations were computed based on extreme precipitation events at a given point in a measuring location. With the erosivity density concept, a more uniform value for an area could be obtained (USDA, 2008).

The soil erodibility evaluation for certain soils did not change very much. The soil erodibility nomograph (Wischmeier et al., 1972) still is considered to be the best tool, although the bell-shaped erodibility relationship (Römkens et al., 1986; Römkens et al., 1997) expressed as a function of the geometric particle diameter may be preferred when dealing with global soils for which no direct or measured values are available. Its strength is related to the fact that the geometric particle of the soil diameter reflects a transportability characteristic. Also, broadening RUSLE2 from a 1-dim. to a 2-dim. erosion equation (Dabney, 2012) will give RUSLE2 a greater degree of accuracy and relevancy.

Other models and projects developed since the mid 1990s were mostly for applications at the watershed scale and emphasized water quality issues. These were MDMESA (Management Systems Evaluation Area, CEAP (Conservation Effect Assesment Project), TMDL (Total Maximum Daily Load), MRB (Mississippi River Basin), and LTAR (Long Term Agro-ecological Research).

The MSEA projects, established in 1989, were applied to 8 important but diverse agricultural areas in response to a National Presidential Initiative on Water Quality to improve and conserve America's water resources with as objectives: (1) to protect groundwater resources, and (2) to develop and seek water quality programs and alternative practices to address runoff contamination (USDA, 1994). The Mississippi Delta was chosen because it represents an special physiographic area that is an open system in the winter time and a closed system during the crop producing period, with a nearly level topography, high water tables, high rainfall (135 cm/annum) fertile medium to heavy soils, non-existent subsurface drainage, intensively cropped with row crops, and high usage of agri-chemicals for pest and weed control. This project was concluded in 1996.

CEAP is a multi-agency U.S. Government project that was initiated in 2003 to quantify in a scientific manner the environmental benefits of conservation practices by landowners participating in USDA's conservation programs (SWCS, 2006). After having spent hundred millionths of dollars on conservation program, no reliable database was available to quantify the effectiveness of these programs. The program consisted of two components: (1) a National Assessment, and (2) small watershed studies involving ARS benchmark, special emphasis, and competitive grants watersheds. The program is still on-going.

TMDL is a regulatory term defined in the U.S. Clean water Act of 1973, section 303(d) as the maximum amount of a pollutant that a water body may receive from all sources and still meets the water quality standards for its intended use. There may be TMDLs for pathogens, chemicals heavy metals, etc. including sediment. A water body is said to be impaired if a TMDL is exceeded and remedial measures must be taken to address the situation.

MRB is a 4-yr $ 320 million initiative by the U.S. Secretary of Agriculture to address water quality, wildlife, and natural resource conservation concerns in the 1.2 million mi^2 Mississippi River Basin. Farm runoff is the most significant contributor to the 1.57 million metric tons of nitrogen flowing into the Gulf of Mexico annually. Nitrogen is the principal cause of the hypoxic zone (dead zone) development.

LTAR represents a long-term agro-eco system research network of watersheds that will provide knowledge for sustaining agricultural productivity and eco-system services to society. This network will require and demand a productive and economically viable agriculture that is safe, environmentally sound, and socially responsible (Walbridge and Shafer, 2011). It is composed of watersheds that have research productivity, infra-structure capability, data availability and accessibility, geographic coverage, research partnerships, and institutional commitments.

The above projects and programs involve to different degrees erosion, sedimentation, and conservation models, calculations, and practices. They are integrated with water quality and ecological objectives and goals. Some of them overlap, but together they express a dynamic agriculture sensitive to the sustainability of food, feed, fiber, and fuel production in harmony with an ecological environment.

With the onset of improved digital computer technology, sophisticated computational numerical solutions and models have been developed that can approximate to a very reasonable degree the accuracy of sediment and water movement in a complex stream system and geomorphic conditions. Of particular significance are the basic 1D-, 2D-, and 3D-NCCHE numerical computational models developed by the National Center for Computational Hydroscience and Engineering (NCCHE) at the University of Mississippi which was established in 1982, continually supported since 1989 with Congressionally mandated funding, and administered under the auspices of the Agricultural Research Service by the NSL (Wang and Hu, 1992; Jia and Wang, 2001). With this mandate, the scope of the research mission of the USDA-ARS expanded greatly and entered into a new era heretofore unknown in the annals of ARS. These basic models and their problem-specific application derivative models are capable of predicting flow and sediment movement in stable and unstable stream systems with open boundaries and have the potential capability of predicting complex flow regimes and dynamic boundaries. Of immediate interest is their application to stream system of watersheds with a variety of flow and streambed conditions, including the simulation of flood waves and the concomitant movement of eroded and suspended sediment in cases of dam failure of both catastrophic (sudden collapse) or gradual failure in nature or in planned dam removals. Likewise, these models can be used to project and predetermine sediment movement in the upstream and downstream sections of the stream system during and following the removal of functionally outdated dams. Of particular value in this era of climate change are the ability of these models to predict the flow regime in real time, the capability to predict the progression of flow waves in terms of height, distance, and velocity, and thus the capability of offering under certain circumstances the possibility of developing an early warning system in case of dam or levee failure. The possibility of this capability is enhanced by the parallel development of geo-technical methods by the National Center for Physical Acoustics of the University of Mississippi (NCPA), also funded by a Congressional mandate through the ARS NSL, to determine, among other things, the stability conditions of earthen dams, and ultimately to assess the potential for failure (Hickey et al., 2014). The NCCHE-models also offer great potential in water quality research by following the movement of point and non-point pollutants through the watershed stream system, and estimating their abatement if combined with time dependent and natural decay rate processes. They are also very useful for Action Agency in devising policies regarding permissible discharges, evaluation of chemical hazardous conditions and spreading of pollutants in surface waters.

Other models that have been developed in-house in recent years and that address the stability and erosion of the stream channels per se within watersheds, are CONCEPTS and BSTEM. CONCEPTS (CONservational Channel Evolution and Pollutant Transport System) is a computer model that simulates the evolution of incised streams and evaluates the long-term impact of rehabilitation measures of stream systems of reducing sediment yield (Langendoen, 2000). It simulates unsteady, one-dimensional flow, graded sediment transport, and bank erosion processes in stream channels.

BSTEM (Bank Stability and Toe Erosion Model) can calculate critical conditions for stream bank stability and involves knowledge of the soil shear strength, effective cohesion, pore water pressures, and the effective internal angle of friction (Simon et al., 2011; Simon et al., 2000).

2 SELECTED AREAS OF KNOWLEDGE GAPS AND RESEARCH NEEDS

Tremendous progress has been made in soil conservation at both the field and watershed scale since the "Dustbowl" days of the 1930s. This is especially true, if one reflects at the magnitude and complexity of the problems that then existed and compare those with the current situation in the erosion prone areas where now fields are covered with crops and where streams are now incised stable systems. Nevertheless, continued vigilance is needed not to relapse into the situation ante the dust bowl. Now, water resources have become more scarce due to higher demand by a growing population, excessive harvesting of groundwater resources for domestic and industrial use, and for irrigation. Also, global climate change is affecting in many places the precipitation regime. Precipitation may change in intensity and become more irregular, causing longer and more periods of severe drought in some places and flooding in others. There are many other issues and impediments that affect the sustainability of agricultural production besides the efficiency in the application of conservation practices. Society should promote a holistic approach to our agricultural water resource problems at the watershed scale, such as the efficiency of water use in deficit areas, wider use of drip irrigation, groundwater recharge, plant breeding of water use efficient cultivars, use of water stored in reservoirs by improving controlled release and diversion to areas in need of water. In areas with surplus water, water should be stored in streams, reservoirs, lakes, or as groundwater, and only then to be discharged when a point of need or critical conditions are reached. Special areas of concern are:

2.1 *Improved water management*

Crop production and erosion control are interlinked. The most desirable situation is one where optimum conditions exist in water supply to the crops during the entire growing season. In that case, biomass production is at a optimum yielding the most cover through canopy development and potential residue for protecting the soil surface from the destructive impact of rainfall and runoff. Plant breeding research needs to be done to enhance biomass production of crops that would serve better erosion control. Proposals to use biomass as an alternate fuel source, a common practice in the developing world, could be very detrimental to erosion control if the needs for fuels are not carefully balanced against the residue needs for protecting the land surface from erosion.

2.2 *Improved knowledge of surface-subsurface water relationships at the 2-dim. watershed scale*

Water is the vector in erosion processes, whether as rainfall, surface flow, or as seepage. It is important to know what fraction of incident rain is available for plant growth, what fraction accrues to groundwater, and how much of it contributes to erosion and sedimentation processes by rainfall, runoff, or seepage, and at what location on the field and in the watershed.

2.3 *Seepage and seepage gradients*

Relatively little research has been done on seepage erosion. Yet, the effect of seepage on erosion processes can be very substantial through gradients at the soil-water-air interface where soil particles may be detached or in causing hydraulic pressures exerted on bulk soil (stream banks). Soil water pressures may especially be relevant in gully development and growth, a major mode of soil erosion on sloping land.

2.4 *Runoff on irregular surfaces*

Most erosion prediction models assume 1-dim. flow with uniform or segment-wise uniform slope gradients. The reality is quite different. The RUSLE2 prediction models is being modified to predict erosion on a 2-dim. surface using a spatial approach from cell-to-cell segments for runoff similar to the one used in the AnnAGNPS model in routing surface runoff .

2.5 *Gully erosion*

The most challenging aspect of upland erosion and sedimentation research is an inadequate understanding of the effect of surface and subsurface flow on ephemeral gully and gully development. EGEM (Ephemeral Gully Erosion Model (Merkel et al., 1988)) simulates a single ephemeral gully on a planar surface, which is not realistic in field applications. Surface discontinuities, concentration of surface flow, subsurface flow regimes, and tillage marks from implements makes it extremely difficult to come up with reliable and consistent values of soil loss from upland areas .The recent development of LIDAR technology and improved photogammetry (Wells et al., 2013; Gordon, 2012) capable of measuring accurately x-, y-, and z- dimensions even on deeply incised and gullied watersheds, should facilitate the development of an improved gully erosion predictive relationship.

2.6 *Process specific soil erodibility values*

These values and soil variability are complicated factors in determining soil loss from fields. Depending on the erosion agent, the soil response varies and different soils react differently to different agents. No universal soil property has yet been identified though the geometric particle diameter is probably the most important one as it represents to a better degree the transportability characteristic of sediment in runoff. Besides intrinsic soil properties, soil surface conditions due to antecedent soil water history and manipulation also affect the erodibility values.

2.7 *Freezing and thawing*

The effect of freezing and thawing on soil erosion has hardly been studied. Large portions of the northern hemisphere are covered by frozen soil for a substantive part of the season. While the underlying physico-chemical principles have been known for many years, their relevancy in erosion processes, have not been considered.

2.8 *Sedimentary fluid mechanics*

Sediment movement is usually related to the flow regime and particle size characteristics in channel flow. Little is known how the interaction of sediment particles affects their movement. Experimental and analytical research by Prasad et al. (2009) of movement of coarse size particles in steady uniform shallow overland flow has indicated that the transport capacity is appreciable affected by the concentration of the transported particles and that the initial uniform movement degenerates into a wave and meander form. How finer size soil material affects sediment movement in shallow or bulk flow is unknown.

2.9 *Intellectual Input*

Progress to improve our prediction capability will become more and more dependent on a workforce that is capable of handling the challenging and difficult fundamental subjects. While modeling is the manner in which knowledge is put together and may ultimately be the tool one is looking for in conservation management, the understanding of the system in detail is a must if one wants to be able to relate outcome to cause. With the budget cutbacks that have been sustained time and again in the USA, with past restrictions on foreign travel, and with less than the needed intellectual input in our research program, the U.S. is losing its eminence and leadership in erosion and sedimentation research.

3 CONCLUDING OBSERVATIONS

The complexity of erosion and sedimentation processes is self evident. Today, the focus in erosion and sedimentation research is for the most part on the development of predictive models that can be used for conservation practices, hazard prediction, environmental concerns, etc. at the watershed scale (AnnGNPS, SWAT, etc.) and ephemeral gully erosion and sediment transport in the stream system. Also, research emphasis is changing and is shifting from the 1-dim. situation for which most of the erosion and sedimentation existing relationships have been derived to the 2-dim. case in which a concomitant increase in the complexity of the models is experienced.

The professed policy and emphasis of USDA-ARS funding is to conduct research on problem solving in preference to fundamental aspects of erosion and sedimentation research. However, it would be illusory to think that one can conduct indefinitely problem solving research without studying the underlying fundamental aspects. In addressing the practical needs, two major impediments are encountered:

(1) Inadequate research funding has been encountered in recent years with the prospect that this will not improve much in the near term. Funding shortfall is currently being experienced across all research areas traditionally funded by the U.S. Government. Therefore, it is expected that research progress will be severely hampered.

(2) Inadequately trained scientists in the USA in the STEM (Science, Technology, Engineering and Mathematics) subjects that have the training and background to handle these complex research subjects in an increasingly complicated subject matter.

The research thrust in the natural resources area of USDA appears to be changing. There is increasing concern about the adequacy of the water supply in many parts of the country, especially in the southwestern U.S., but also elsewhere. Increases in population, increasing needs for water in agricultural, commercial, industrial, and public use, and changes in the availability of water due to global climate change, will invariably further stress access to the limited supply. Erosion and sedimentation research may have to take a back seat in the competing interests for the limited financial research resources. On the other hand, the experiences learned in pursuing erosion and sedimentation research, the models that were developed, and agricultural practices learned in times past can also be used to a considerable degree in addressing water management needs.

REFERENCES

Arnold, J.G., Williams, J.R., Nicks, A.D., Sammons, N.B. (1990). SWRRB: A basin scale simulation model for soil and water resources management. Texas A&M Univ. Press, College Station, TX.

Barnett, A.P., Rogers, J.S., Holladay, J.H., Dooley, A.E. (1965). Soil erodibility factors for selected soils in Georgia and South Carolina. Trans. ASAE 8(3): 393-395.

Bennett, H.H. (1939). Soil Conservation. McGraw-Hill Book Company, Inc. Pp. 993. New York and London.

Burns, K. (2012). The Dust Bowl. A PBS Film. Video.

Cooper, C.M. (1984). The freshwater bivalves of Lake Cicot, an oxbow of the Mississippi River in Arkansas. Nautilus 98:142 - 145.

Cooper, C.M., Knight, S.S. (1987). Fisheries in man-made pools below grade control structures and in naturally occurring scour holes of unstable streams. J. Soil and Water Conservation 42: 370-373.

Dabney, S.M., Yoder, D.C., Viera, D.A.N. (2012). The application of the Revised Universal Soil Loss Equation, Version 2, to evaluate the impacts of alternative climate change scenarios on runoff and sediment yield. J. Soil Conserv. 67(5): 343-353.

Ellison, W.D. (1947). Soil erosion-Part I and II. Agr. Engineering 28(4): 145-146, and 197-201.

Foster, G.R., Meyer, L.D. (1972). A closed Form erosion equation for upland areas. In: Shen, H.W. (Ed). Sedimentation (Einstein). Fort Collins. CO., Colorado State Univ. Ch. 12: 1-19.

Foster, G.R., Meyer, L.D. (1975). Mathematical simulation of upland erosion using fundamental erosion mechanics. In: Present and Prospective Technology for predicting sediment yields and sources. ARS-S-40. Agr. Res. Serv.., U. S. Dept. Agr., Washington, D.C. pp. 190-207.

Gordon, L.M., Bennett, S.J., Wells, R.R. (2012). Response of a self-mantled experimental landscape to exogenic forcing. Water Resources Res. 48, W10514, doi: 10.10029/2012/WR 012283.

Knight, S.S., Cullum, R.F. (2014). Effects of conservation practices on fisheries management . J. Of Agriculture and Biodiversity Res. ISSN 2277-0836 . www.onlineresearchjournals.org 3(1) 1-8.

Hickey, C.J., Römkens, M.J.M., Wells, R.R., Wodajo, L.. Gheophysical methods for the assessment of earthen dams. In: Advances in Water Resources Engineering. Eds: L.K. Wang and T. Yang. Chapter 8. (In Press).

Knisel, W.G. (1980). CREAMS, a field scale model for chemicals, runoff and erosion from agricultural management systems. USDA Conservation Research Report No. 26.

Langendoen, E.J. (2000). CONCEPTS - Conservational channel evolution and pollutant transport system. Research Report No. 16. USDA-ARS National Sedimentation Laboratory. Oxford, MS. 180 p.

Leonard, R.A., Knisel, W.G., Still, D.A.1(987). GLEAMS: Groundwater loading effects of agricultural management systems. Transactions of the ASAE 30: 1403-1418.
Merkel, W.H., Woodward, D.E., Clarke, C.D. (1988). Ephemeral gully erosion Model (EGEM). In: Modeling, Agricultural, Forest, and Rangeland Hydrology, 315+323. ASAE Publ. 07-88. St. Joseph, MI.
Meyer, L.D., McCune, D.L. (1958). Rainfall simulator for runoff plots. Agr. Engineering 39: 644-648.
Meyer, L.D., Wischmeier, W.H.. (1969). Mathematical simulation of the process of soil erosion by water. Transactions ASAE 12(6): 754-758.
Neitsch, S.L., Arnold, J.G., Kiniry, J.R., Williams, J.R. (2011). Soil and water assesent tool- Theoretical Documentation. Version 2009. USDA-ARS and Texas A&M Univ. Texas Water Resources Inst. Techn. Report No. 406. College Station, TX.
Olson, T.C., Wischmeier, W.H. (1963). Soil-erodibility evaluations for soils on the runoff and erosion stations. Soil Sci. Soc. Amer. Proc. 27: 590-592.
Prasad, S.N., Suryadevara, M.R., Römkens, M.J.M. (2009). Grain transport mechanics in shallow overland flow. Ecohydrology 2: 248-256.
Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., Yoder, D.K. (1997). Predicting soil erosion by water: A guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). Agricultural Handbook 703. Washington, D.C. U.S. Printing Office, 384 pp.
Römkens, M.J.M. (1985). The soil erodibility factor: A perspective. In: El-Swaify, S.A., W.C. Moldenhauer and A.L. Low (Eds): Soil Erosion and Conservation. Soil Conservation Society, Ankeny, IA. 445-461.
Römkens, M.J.M., Prasad, S.N., Poesen, J.W.A. (1986). Soil erodibility and properties. Transactions XIII Congress of the International Soc. of Soil Sci. 492-504. ISSS-AISS-IBG. Hamburg, Germany.
Römkens, M.J.M., Yong, R.A., Poesen, J.W.A., McCook, D.K., El-Swaify, S.A., Bradford, J.M. (1997). Soil erodibiity factor (K). In: Predicting soil erosion by water: A guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). Agricultural Handbook 703, Eds. K.G. Renard et al., U.S. Government Printing Office, Washington, DC.
Römkens, M.J.M. (2010). Erosion and Sedimentation Research in agricultural watersheds in the USA: from past to present and beyond. In: Sediment dynamics for a changing future. Proc. Of the ICCE Symposium pp. 17-26. Warshaw University. June 2010. IAHS Publ. 337.
Simon, A., Curini, A., Darby, S.E., Langendoen, E.J. (2000). Bank and near-bank processes in an incised channel. Geomorphology 35:183-217.
Simon, A., Pollen-Bankhead, N., Thomas, R.E. (2011). Development of a deterministic bank stability model for stream restoration. Geophysical Monograph Series 194. American Geophysical Union, Washington, DC. pp. 453-474.
Stewart, B.A., Woolhiser, D.A., Wischmeier, W.H., Caro, J.H., Frere, M.H. (1975). Control of water pollution from cropland. Vol. I and II. Report ARS-H-5-1 and ARS-H-5-2. U.S. Government Printing Office, Washington, DC.
Swanson, N.A. (1965). Rotating boom rainfall simulator. Transactions of the ASAE. Am. Soc. Of Agr. Engr. 8: 71-72.
Soil and Water Conservation Society. (2006). Conservation Effects Assessment Project. Final Report Blue Ribbon Panel External Review USDA. SWCS, Ankeny, IA. p. 24.
USDA. (1994). Water quality research plan for Management Systems Evaluation Areas (MSEA's): An ecosystems Management Program. Agricultural Research Service Bulletin, ARS-123, Washington, DC. 45 p.
USDA - Water erosion prediction project. (1995). Hillslope profile and watershed model documentation. Eds. D.C. Flanagan and M.A. Nearing. NSERL Report No. 10. USDA-ARS National Soil Erosion Research Laboratory. West Lafayette, IN. 131 p.
USDA-ARS-NSL. (2008). Revised Universal Soil Loss Equation 2. Reference User Guile (pp. 431) and Science Documentation (pp. 359) Http://www.ars.usda.gov/Research/docs.htm?docid=5971.
Walbridge, M.R., Shafer, S.R. (2011). A long-term agro-ecosystem reserch (LTAR) network for agriculture. Fourth Interag. Conf. On Research in the Watersheds. Sept. 26-30. Fairbanks. AK.
Wells, R, R., Momm, H.G., Rigby, J.R., Bennett, S.J., Bingner, R.L., Dabney, S.M. (2013). An empirical investigation of gully widening rates in upland concentrated flows. Catena 101:114-121.
Williams, J.R., Nicks, A.D., Arnold, J.G. (1985). Simulator for water resources in rural basins. J. Hydraulic Eng. 111(6): 970-986.
Williams, J.R. (1995). Chapter 25. The EPIC Model p. 909-1000. In: Computer Models of Watershed Hydrology. Water Resources Publications. Highlands Ranch. CO.
Wischmeier, W.H., Johnson, C.B., Cross, B.C. (1971). A soil erodibility nomograph for farmland and construction sites. J. Soil Water Cons. 26(5):189-193.
Wischmeier, W.H., Mannering, J.V. (1969). Relation of soil properties to its erodibility. Soil Sci. Soc. Amer. Proc. 33: 131-137.
Wischmeier, W.H., Smith, D.D. (1965). Predicting rainfall erosion soil losses from cropland east of the Rocky Mountains - Guide for selection of practices for soil and water conservation. Agr. Handbook 282 . Washington, D.C.
Wischmeier, W.H., Smith, D.D. (1978). Predicting rainfall erosion losses. A guide to conservation planning. U.S. Dept. Agric. Handbook 537. Washington, D.C.
Young, R.A., Onstad, C.A., Bosch, D.D., Anderson, W.P. (1985). Agricultural non-point surface pollutant model (AGNPS) I and II documentation. St. Paul, MN Pollution Control Agency and Washington, D.C.
Zingg, A.W. (1940). Degree and length of land slope as it affects soil loss in runoff. Agr. Engineering 21(2): 59-64.