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Erosion and sedimentation research in agricultural watersheds in the USA: from past to present and beyond

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Abstract In ancient times, sediment and sedimentation were a blessing that brought fertility to the land and made it possible for people to live and prosper. This is the story of the Egyptians in the Nile Delta where they lived this way for thousands of years in harmony with annual floods that brought soil and nutrients to the land. In other places, sediment and sedimentation proved to be valuable for gaining new land (the Netherlands). But then in other places, and in recent times, sediment was seen as a nuisance that caused flooding, destroyed or damaged human habitat, and adversely impacted productive land because of excessive sedimentation. This article briefly discusses how erosion and sedimentation research in agriculture came to be what it is today in the USA. That experience has in many ways guided today's erosion and sedimentation research programmes and conservation efforts around the world. Secondly, and again in a limited way, the current focus of erosion and sedimentation research in the USA will be described as well as the problems the USA faces today and how they are addressed.

Keywords erosion; sedimentation; sediment; TMDL; CEAP; dam removal; watershed models

HISTORICAL PERSPECTIVE

Where there is sediment, there are nearby sources where soil eroded. Geologic erosion has existed for millennia and new landscapes have formed as a result of deposited sediment. Productive soil profiles that were suitable for a productive agriculture developed from these deposits. Those areas are the places where man settled, whether along the sea or in the valleys of streams in the interior. Erosion and sediment deposition that has taken place over eons during geological time scales is the reason why to-day the low lying areas in the world are teeming with life, where great and highly populated cities arose in spite of the occasional disaster of floods and storms. Because of its inherent proximity to open water, commerce engendered, trade developed, and civilizations arose, especially when the adjoining hinterlands offered opportunities for the development of agriculture, industries, and mining activities. It is with some irony when one looks at the problem of "sediment" over different time scales that views differ. On one hand, some one might see the benefit of sedimentation because of the development of new land, while others might view sediment mostly as a problem, as something to get rid of, as a pollutant, etc.

Sediment is, by volume, the largest pollutant but its adsorptive and reactive surfaces may be far more consequential for human health and habitat and the ecology than a simple volume measure. Soil erosion and sedimentation are, by definition, related to each other. Sediment transport is the connecting process. Large parts of the world have been severely damaged by soil erosion due to negligence by man and man's poor land management practices. Civilizations have disappeared and conflicts have arisen when land resources became scarce or were unable to sustain productivity. One does not need to go far into recorded history to see that during the last 5000 years the legacy of mankind's neglect of its precious resource, soil, has led to deserts and less habitable land areas. Examples are abundant. One may simply look at the coastal areas of the Mediterranean basin: Turkey, Lebanon, North Africa and Spain, East Africa, the Loess Plateau in China, ancient Mesopotamia, etc., where most of the better known civilizations existed, and where large scale land degradation has taken place, and forests have disappeared. Most of the damage occurred in the last 2000 years as populations increased. In the western world of North and South America the experience is not too different. What in Europe and Asia happened in several millennia, the settlers in the USA were able to bring about in less than 100 years: degraded land, severely eroded areas, and reduced soil productivity. That was especially true in the highly erosive climate of the humid southeastern part of the USA, with its rolling topography, highly erodible soils, and cropping system of cotton that afforded poor soil and land protection. One may ponder the question what current large scale uncontrolled deforestations in the interior of Brazil and the tropical land areas of Indonesia and Malaysia may be doing in due time to those landscapes, and what the impact of land degradation may be on local climate change.

THE USA EXPERIENCE

In the brief time span of about 100 years from 1830 to 1930 that the Europeans settled the eastern and southern parts of the USA, soil erosion of the upland areas and sedimentation in the valleys of the stream system had taken on calamitous proportions. There was no coordinated or systematic effort by citizens or government to address this issue. The catastrophe that had been unfolding in the State of Mississippi reached its climax with the major 1927 flood in the Lower Mississippi River Basin. While the basic reason was extreme and prolonged rainfall over a wide area in the 4.76 million km^2 Mississippi River Basin, the problem in Mississippi was aggravated by runoff and soil erosion in the severely eroded Bluff Line watersheds in the Lower Mississippi River Basin that drained into the Mississippi Delta and the Mississippi River tributaries.

Flooding and levee failure were frequent and widespread. Up until this time, but less consequential, other parts of the southeastern USA that were not part of the Mississippi River Basin had their own history of severe erosion and sedimentation problems, most notably the Piedmont region in the states of North and South Carolina and Georgia. While the southeast and south central part of the USA were devastated by water erosion and sedimentation, the southern plain states of Texas, Oklahoma, Kansas, and Colorado were devastated by wind erosion following settlement and the advance of the railroad system in those areas, with the concomitant break-up of the prairie sod by the newly arrived settlers. The result of the large scale break-up of prairie grounds in this windy part of the USA was the development of huge dust storms which culminated in 1933 with the well-known Dust Bowl. It was then that the political climate, dominated by the more densely populated and industrial areas along the eastern seaboard of the USA, changed, and those in charge were ready to address the erosion and sedimentation problems in the interior of the USA. During this time and leading up to this decision, were the tremendous efforts, speeches, writings, photographs, and congressional testimonies by those who had seen and experienced first hand the landscape devastation, siltation, and sedimentation that had taken place. Among those, the most notable was Hugh Hammond Bennett, generally known in the USA as the father of soil conservation. This experience of land degradation and the subsequent actions of soil conservation is in some way testimony of the typical characteristic of the American political system that nothing will change unless there is a crisis. The impetus of the Dust Bowl was the establishment of the Soil Erosion Service, later more appropriately renamed the Soil Conservation Service (SCS). This Service, initially modestly funded, established natural runoff plots and small size agricultural research watersheds across the nation to measure and evaluate the scale of soil erosion, improve management practices, and advise the farming community on what could be done. Nowhere in modern times has there been made such a committed and concentrated effort than by the US government to address this issue. Even today, few nations, which in one form or another suffered the same problems, have followed the scale of government involvement as happened in the USA. In Europe and elsewhere, most erosion studies emanated from academia with much less involvement of the public sector, even though the erosion problem existed in many of these nations too, except that the scale of this problem in those nations was less, had a lesser intensity, and changes in land quality were not as visible or apparent in one’s lifetime.

RECLAMATION AND CONSERVATION

With the establishment of the Soil Conservation Service (SCS) farmers had the opportunity to seek advice and assistance to implement programmes and practices that would control or reduce erosion on the upland production areas. Often financial assistance was provided on a cost share basis. The recommended measures were mostly concentrated on the upland agricultural production area and could be of an agronomic nature or involve structural practices like terracing, contouring, impoundments, strip-cropping, etc. Also, larger scale measures were taken at the county or state level, such as stream channelization projects, stream hydraulic control structures, sediment trapping impoundments, or the building of flood control reservoirs. Often, streams were channelized to enhance better drainage. In the process of doing so, the seeds of channel instability through headcut development and stream bank failure were sown, which was counter to the intended purpose of stream stabilization: rapid drainage of excessive water in STABLE streams. For the most part though, efforts focused on providing direct assistance to the farming communities through cost share programmes. Besides the need for these programmes, their implementation during the early phases was aided by the economic depression of the 1930s, when labour was in ample supply and work programmes were instituted to offer employment opportunities.

On the research front, natural research plots and experimental watersheds were established in many parts of the country to collect an erosion and sedimentation database representative of the prevailing conditions in the region. For many years data sets were collected and compiled without much thought on how to generalize and integrate the acquired information and how to develop usable management tools from this data base. The multitude, complexity, and variability of erosion and sedimentation contributing factors were too complex to arrive quickly at simple and effective management tools and useful predictive solutions. In 1954 the Agricultural Research Service (ARS) was established and was assigned the role of conducting most federal agricultural research including soil and water research. Personnel that worked for the SCS on runoff plots, watersheds, and stream systems in the SCS became part of the Soil and Water Conservation Research Division within ARS. Close cooperation remained between researchers of the ARS and those that implemented conservation practices based on experimental findings by the SCS. It was this close cooperation that eventually led to the first slope practices relationship with general applicability for predicting soil erosion. This relationship was gradually expanded to include many more soil erosion related factors and became what is now known as the Universal Soil Loss Equation (USLE) (Wischmeier & Smith, 1964). This relationship was upgraded in 1978 (Wischmeier & Smith, 1978). In spite of its many shortcomings, this relationship, its updated versions, and improved successors (i.e. RUSLE of 1997, Renard *et al.*, 1997, and RUSLE2 of 2005, USDA-ARS, 2005) have been extensively used as the main management tool for conservation practices in the USA. Because of its simplicity and general applicability it has been adopted and adapted to local conditions in many other countries. The RUSLE relationship has been integrated in a larger watershed scale model (AGNPS) to make it useful for predicting sediment movement from agricultural land into the stream system of watersheds.

The USLE relationship in its initial concept was a factor relationship, consisting of factors that represent the effect of the major factors that affect soil loss from agricultural fields. This relationship was a statistical tool that indicated what the average annual soil loss was from a unit land area for a given situation relative to the erosivity of the rainstorm regime, soil type, topography, cropping and soil management practices, and soil erosion control practices. Over time, the underlying physical factors have become far more deterministic or scientifically based, so that today RUSLE2, the most recent updated version of the USLE, represents one of the most versatile management tools for soil loss predictions from agricultural fields and for soil conservation recommendations. It should be noted that a number of process based soil erosion models have been developed such as WEPP and others. Those developments were inspired by the notion that a greater applicability to a wider range of situations could be better served by physically based models. While this might be true, it also would require many more parameters that have to be determined, evaluated, and calibrated. Countless interactions need to be studied. A large lead-time will be required for getting this information. The process of improved development is still ongoing. The biggest hurdle will be, as experience has shown, training an educated work force capable of applying this model for a variety of conditions and collecting an appropriate database.

MODEL DEVELOPMENT

Since the 1990s and with the rapid development of computer technology, modelling erosion and sedimentation processes became a favourite pass time for many scientists and engineers in the subject area. It was perceived as the solution to addressing highly complex problems, involving many factors and their interactions. Perhaps the first and simplest erosion model was that by Meyer & Wischmeier (1969). This model basically described the interaction between soil detachment and sediment transport limiting processes. These concepts, together with the concepts of rill and interrill erosion (Foster & Meyer, 1975) that describe sheet erosion, have dominated the analytical thinking of many erosion specialists in the USA for the last 35 years. During these years substantial progress has been made in modelling, data collection, process description, and analysis. However, new demands of an environmental or economic nature were placed on the erosion and sedimentation research community in which water quality issues often became of dominant concern, but in which erosion and sediment played an integral part. The impetus for this work was Section 208 of Public Law 92-500, the amendment of the Clean Water Act. The response to this mandate was the development of the CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems) model (Knisel, 1980), which is a field scale mathematical model that evaluates non-point source pollution from field-sized areas. A closely related development was the GLEAMS (Groundwater Loading Effects of Agricultural Managements Systems) model (Leonard *et al.*, 1987) that simulates processes affecting water quality events on an agricultural field. Particular emphasis is placed on the subsurface hydrology component concerning agri-chemical movement. One of the more prominently known erosion and water quality prediction models that was developed and that also has received wide acceptance in Europe and elsewhere is SWAT (Soil and Water Assessment Tool) (Gassman *et al.*, 2007). The current (2007) version is the culmination of 30 years of ARS modelling experience. It has as precursors CREAMS, GLEAMS, EPIC (Erosion Productivity Impact Calculator; Williams, 1990), SWRRB (Simulator for Water Resources in Rural Basins; Arnold & Williams, 1987). The SWAT model is a basin-scale, continuous-time model that operates on a daily time step and is designed to predict the impact of management on water, sediment, and agricultural chemical yield in ungauged watersheds.

Another watershed water quality model that has found wide acceptance is AGNPS (Agricultural Non-Point Source model; Young *et al.*, 1989) and its derivative the AnnAGNPS (Annualized Agricultural Non-Point Source model; Cronshey & Theurer, 1998). The former is a distributed, cellular event-based watershed model that simulates surface runoff, sediment, and nutrient transport from agricultural watersheds, while the latter is a distributed parameter, continuous simulation, daily time step, cellular pollutant loading model to predict long-term runoff, sediment, and chemical transport from agricultural watersheds. Both models were designed to serve as prediction models for agri-chemical and sediment transport from upland areas in watersheds. They include erosion and sediment transport components as predicted by RUSLE. The AnnGNPS model has the capability of predicting the impact of sources of chemical and sediment sources anywhere in the watershed on the output at the outlet and therefore has the potential to evaluate the impact of source loadings and corrective actions on water quality at the watershed outlet. Both the SWAT and AnnAGNPS model require broadly based data sets that pertain to field scale type data sets such as those for the USLE and RUSLE models.

The usefulness of the AGNPS and SWAT models for watershed applications was enhanced with the development and integration of CONCEPTS (Conservation Channel Evolution Pollutant Transport System) (Langendoen, 2000; Langendoen *et al.*, 2009). This model enables a stream-corridor scale analysis of in-stream morphologic processes to evaluate the effectiveness of stream and riparian zone management. The model has the capability to simulate the complete, long-term adjustment dynamics of streams due to natural and anthropogenic disturbances using physically- and process-based methods rather than simple applications of empirical relationships. It can simulate fractional transport of cohesive and non-cohesive sediments, toe erosion, and mass wasting of cohesive banks, and link the dynamics of flow and sediment transport to in-stream structures.

A different class of scientifically-based advanced engineering models that were developed through the assistance of the USDA-ARS are the CCHE1D, CCHE2D, and CCHE3D stream system models developed by the National Center for Computational Hydroscience and Engineering (NCCHE) at the University of Mississippi. These highly sophisticated numerical computational models, that use detailed and variable grid systems, are capable of simulating three-dimensional, unsteady, free surface turbulent flows and transport phenomena in streams and open water bodies. These models will be extremely useful in applications related to levee and dam failures in assessing potential flooding and security hazards of stream systems and reservoirs. In short, a large array of watershed computer models were developed during the last 20 years that were often motivated by water quality considerations, but that also include, in part or in full, sediment transport routines.

CURRENT RESEARCH FOCI

During the last 5–8 years, new problem areas have come into focus that need to be addressed with increasing emphasis and urgency, and for which the models that have been developed may provide the necessary tools. These problems have economic, environmental, or security concerns. The first one concerns the development of TMDLs (Total Maximum Daily Loads). This problem area is primarily motivated by environmental considerations of addressing water quality problems at the watershed scale. The second problem area arose because of economic considerations and concerns about the economic benefits, efficacy, and efficiency of many costly conservation measures. This problem area is being addressed by the CEAP (Conservation Effect Assessment Project) project. The third problem area is largely security based and concerns the stability and safety of dams, levees, and structures that were built for water storage, flood control, sediment retention in reservoirs, or power generation. This problem area must address the issue of what to do with these structures once they become unsafe and decisions have to be made to decommission or to rehabilitate these structures, and what to do with the impounded sediment that has built up over many years and that may be contaminated with chemical pollutants.

TMDLs

The pervasive and widespread nature of water quality problems and the difficulty (economic and political) of addressing this issue, were ultimately the reasons why it took more than 30 years after the passage of the Clean Water Act of 1972 by the US Congress, to put stringent regulations in place for the enforcement of the provisions of this Act. Initially, the emphasis was on addressing point source problems such as discharge of industrial wastes at outlets of manufacturing plants and at other locations where wastes of different origin were discharged at a specific location into the stream system. These sources were readily identifiable and more amenable for control and treatment. Non-point sources, such as runoff from agricultural land contaminated by sediment, agri-chemicals, fertilizers, pathogens from animal wastes, heavy metals, etc. are more difficult to control. Since these sources are often diffused and rarely concentrated at specific locations, they are best controlled or reduced in quantity by on-site best management practices (BMPs). In this case, tested and proven techniques can be employed, such as better agronomic and structural practices as far as agriculture is concerned. They may consist of a single measure or a combination of measures, such as no- or reduced tillage, cover crops, stiff grass hedges, grassed waterways, impoundments, de-watering ditches, wetlands, terraces, etc. Management tools and models such as RUSLE2 and AGNPS can be very helpful to predict the expected sediment load for different cropping systems, rainfall regime, topography, into the drainage system and at the outlet of a watershed. The responsibility of defining TMDLs for enforcement and compliance lies with the individual states. Should they fail or otherwise be unable to meet these goals, then the USEPA could step in. State agencies were required to identify which open waters, lakes, streams, rivers were impaired and what the nature of the impairment was so that water quality standards (TMDL) relative to the impairment or contaminant could be formulated. Details on how TMDLs can be established and calculated have been described by USEPA (2007) http://www.epa.gov/owow/tmdl/techsupp.html.

TMDLs are based on two considerations: (1) flow duration curves which are representations of the cumulative frequency of historic flow data over a given period; (2) load duration curves that are obtained from stream flow multiplications with concentration data for a given water quality parameter, say sediment. The flow duration curves for a given location in the stream system relates the flow rate to the percent of time that a given flow rate has been exceeded. Figure 1 shows the flow duration curve for Salt Creek near Greenview, Illinois (USGS Flow data; EPA 841-B-07-006). The flow duration data represent daily average discharge rates. In the USA, the USGS has for reasons of diagnostics and analytical use, grouped or characterized the flow regime into five intervals or zones: high flows (0–10%); moist condition (10–40%); mid-range (40–60%), dry conditions (60–90%); and low flows (90–100%). This classification facilitates descriptions of general hydrological conditions. The water quality parameter, usually a concentration quantity of a particular pollutant or sediment, is the critical value for calculating the loadings. In practice these loadings are determined by the local conditions. Its value may be constant or near constant, as is often the case with chemicals, or it may be variable, as with sediment, which may be flow rate dependent.

Once formulated and accepted, the water quality standard or TMDL are used as a criterion for determining compliance. Figure 2 represents a typical loading duration curve for a sediment TMDL of Willow Creek near Turkey Gap.

TMDLs are defined as the greatest amount of loading that a water body can receive on a daily basis without violating water quality standards. The standards are set in relation to the nature of the water impairment, which may be the use of water as drinking water, for recreational use, etc. TMDLs are defined as:

TMDL = SWLAs + SLAs + MOS

where SWLA represents the sum of the point source load allocations to the stream system, SLA is the sum of the non-point source allocation to the stream system, and MOS is the allowed margin of safety.

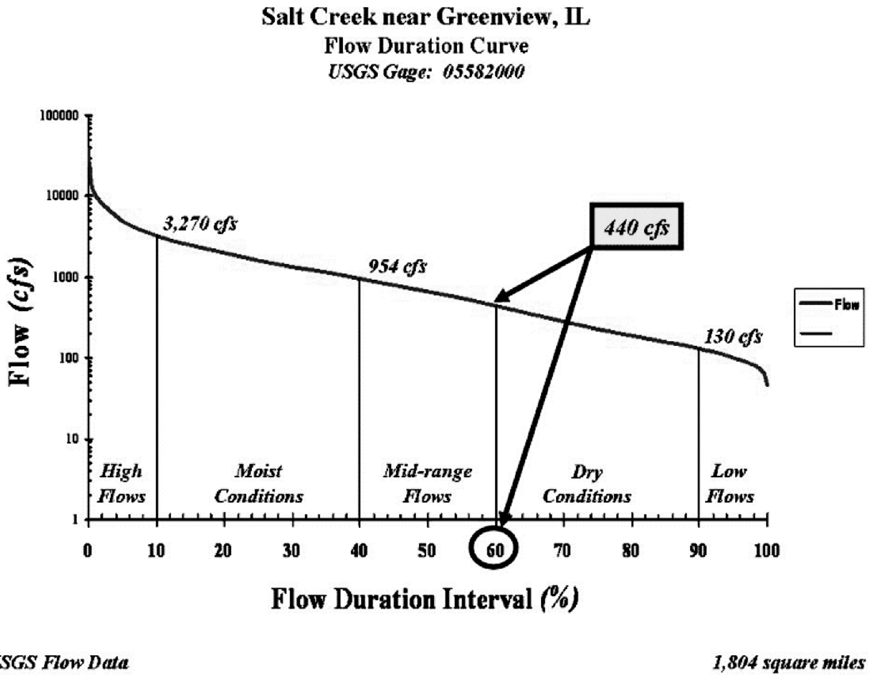

Fig. 1 The flow duration curve for Salt Creek.

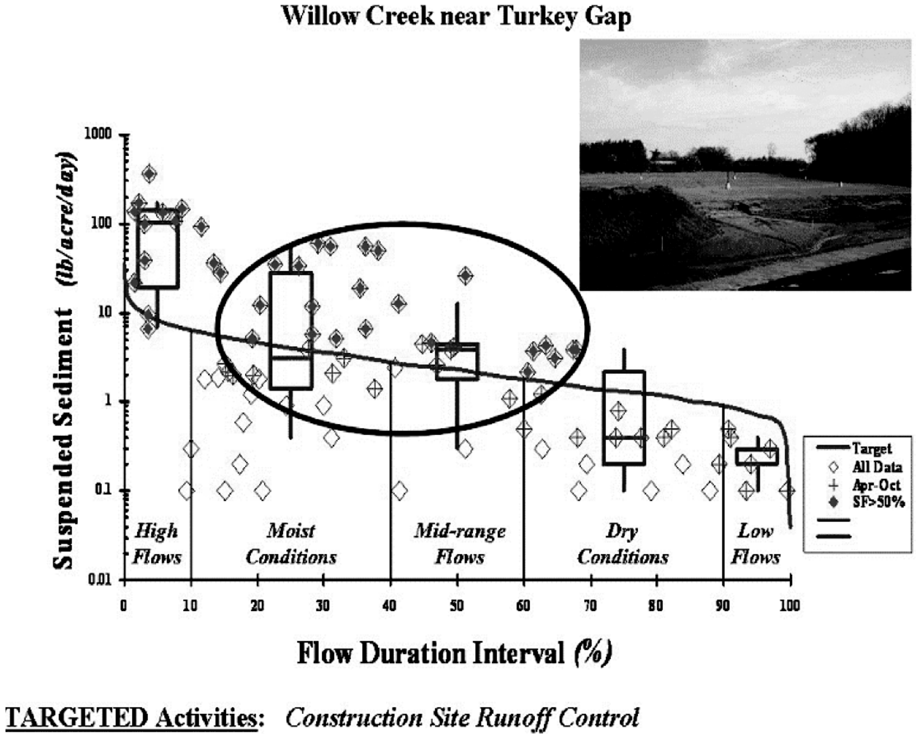

Fig. 2 The loading duration curve for Willow Creek.

The conservation effect assessment project (CEAP)

For many years the Natural Resources Conservation Service (NRCS) of the US Government has administered programmes to control soil erosion and promote conservation. These programmes have cost billions of US dollars and involve millions of acres of land (1 ha = 2.5 acres). Assistance was usually given on a cost share basis. Landowners had to be in compliance with US Government conservation policies in order to qualify for these programmes. Farm subsidy programmes were often tied to the adherence by landholders to certain conservation policies. While the NRCS administered these programme based on well defined guidelines, which are usually developed by the NRCS State Technical Committees, their success in terms of economic benefits was never evaluated. As a result, the US Congress mandated the NRCS in the 2002 Farm Bill to assess the effectiveness and efficiency of these programmes. That programme was named CEAP. Several conservation programmes were developed. They include: the Environmental Quality Incentive Programme (EQIP), the Conservation Reserve Programme (CRP); the Conservation Security Programme (CSP); the Wetland Reserve Programme (WRP); the Wildlife Habitat Incentives Programme (WHIP); NRCS-Conservation Technical Assistance Programme; and the Grassland Reserve Programme (GRP). Each one of these programmes targeted a certain area of environmental or ecological concern with specific objectives and constraints. The conservation practices that are assessed in these programmes are: conservation buffers, erosion control, wetland conservation and restoration, establishment of wildlife habitat, and management of grazing land, tillage, irrigation water, nutrients, and pests. CEAP is to develop scientific databases to produce scientifically credible estimates of the environmental benefits of these programmes. The initial focus was water quality, soil quality and water conservation on cropland to be followed by similar concerns for grazing land, and wetlands. CEAP will also be concerned with developing appropriate and affordable analytical approaches for other land uses and natural resource concerns. The CEAP programme has two components: (1) A National Assessment with two goals: (i) obtain quantitative estimates of the benefit of conservation practices for national and regional reporting, and (ii) assess the potential for existing conservation programmes and future alternatives to meet the Nation's environmental and conservation goals.

(2) Watershed Assessment Studies (WAS) that should complement the national assessment with in-depth assessments of water quality improvements and other benefits. There are three CEAP watershed categories: (i) 12 Agricultural Research Service Benchmark Watersheds, (ii) 9 Special Emphasis Watersheds concerned with specific resources (manure management of feedlots; water use and irrigation on irrigated cropland, (iii) 8 Competitive Grants Watersheds with the purpose of better scheduling conservation efforts within a watershed. Details of the CEAP programme can be obtained on the CEAP home page http://www.nrcs.usda.gov/technical/NRI/ceap.

The underlying approach to the project is to acquire, analyse, and interpret data from the 12 benchmark watersheds and to test and evaluate models that can be used for the national assessment. Conservation practices have been or will be applied on the 12 watersheds. When the project was initiated, the benchmark watersheds were at different stages of research implementation, ranging from little or no existing data to fully implemented experiments with water quality measurements and ongoing discharge monitoring activities at several scales. The project has five highly integrated objectives. The field component research involves six multi-location teams that will analyse and interpret the data and provide the development, validation, and application of models. Each team has assumed a certain responsibility concerning: (1) data management, (2) watershed design for determining environmental effects, (3) model evaluation, evaluation, and uncertainty analysis, (4) economic analysis, (5) model development and regionalization, and (6) data quality and assurance, and the development of standard procedures for data collection and analysis. The current project version has been in progress for about 4 years and as many as 50 people may be involved. Progress is slow but steady. ARS projects have a lifetime of 5 years. This work will surely last 10–15 years. There are annual meetings to report on progress made and to make operational adjustments as needed.

Dam removal or decommissioning

In recent years, there is increasing concern about the stability and safety of dams that were built many years ago. The oldest dams were built more than 200 hundred years ago and were usually small structures built in the industrial northeast of the USA to power sawmills for lumber production or grain mills. A certain amount of water was diverted from a stream and channelled to a place downstream where sufficient drop height allowed the waterwheel to be driven with sufficient power to do the job required. Depending on the local situation, several mills could be found along a stream reach and were usually built from stone or concrete. Sediment movement in this part of the USA was usually of limited concern and did not impose limitation on the operations of these mills. Today many of these structures are being proposed for elimination as they are outdated and considered to be environment and ecology (aquatic habitat) unfriendly. In some cases, debris rather than sediment are the obstructions found in the streams.

In the early part of the 20th century and with the development of the western part of the USA a large number of dams were built for electric power generation and for storing water for irrigation of a developing agriculture and for domestic and industrial water use. The dam structures are usually much larger and block the entire stream cross-section. In recent years some of these structures have been removed or are being proposed for removal. Where the sediment that has built up behind these dams is coarse or gravelly, the stepwise change in the streambed will rapidly dissipate over a relative short distance and time period as was clearly indicated during the Marmot Dam (Oregon) removal. Where the sediment has a fine texture, dam removal may be felt throughout the stream and can have a disastrous ecological impact. The removal plan may have to include sediment disposal by mechanical means before a systematic or stepwise removal of the dam in phases is initiated. It is evident that carefully developed and calibrated reliable sediment transport models will be imperative to satisfactorily perform these tasks.

In the southeast and south central part of the USA some 12 000 dams were built, starting in the late 1930s, to serve as flood control reservoirs, as sediment traps, or as storage reservoirs for irrigation water and to meet domestic and industrial needs. The projected lifetime of these reservoirs and related structure at the time of construction was 50 years and thus the issue of what to do with the sediment associated with these structures and basins is becoming of major concern. The structures are usually earthen dams. Over time, many have deteriorated because of surface erosion, seepage, growth (trees), or due to lack of maintenance. High sedimentation rates, especially in the smaller reservoirs, over the intervening years have reduced the storage capacity, increasing the hazard of overtopping during severe and prolonged rainstorms. Fortunately, conservation measures on the upland source areas contributing to these dams has reduced the sedimentation rates and in effect prolonged the life of these reservoirs. Nevertheless, at some point decisions need to be made whether to decommission or to rehabilitate these structures and reservoirs. Sediment may have to be removed or gradually released, in which case sediment transport models of the type discussed will be useful tools in guiding this process. Secondly, models of the 2-D CCHE type can be used to assess and predict the degree and extent of flooding hazards downstream from these structures or levees, in case of sudden or gradual failures under various scenarios and to prepare for contingency measures should such an event come to pass. Developing technology of a chemical engineering nature might be employed to remove or neutralize toxic sediment contaminants such as PCPs (pentachlorophenol).

It is clear that the measures described will benefit from chemical and computer technology that were developed in recent years and are still being improved. Also, the Federal Interagency Subcommittee on Sedimentation (SOS) is working on dam removal analysis guidelines, which are expected to be completed by the end of 2010.

CONCLUDING REMARKS

Erosion and sediment related research in the USA has made tremendous progress during the last 70 years from the perspective of identifying, understanding, and addressing these problems. In many ways the USA has led on these fronts. It must be recognized, however, that most of this era (post-World War II) was one of significant economic growth and affluence, when resources were adequate to finance these endeavours. In recent years, significant changes have taken place in the economic position and scientific capabilities of the USA. There are huge budget deficits, huge trade deficits, a financial system that almost collapsed, a developing educational deficit in the difficult but essential, supportive subject matters of engineering and physical sciences, and a developing inward rather than outward looking view of the world. Sixty to 70% of the students in these subjects across all universities in the US are foreign nationals, mostly from China and India. With the rapid improvement in the standard of living in their home countries, many are returning home, leaving a potential gap in the ability of the USA to fill the needs for an advanced, scientifically trained workforce. These issues will, without question, also impact the dynamics and level of commitment in addressing erosion and sediment research in the USA in the longer term.

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