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Evolution of Vegetated Waterways Design

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Abstract. *In 1990, the USDA-ARS Hydraulic Engineering Research Unit (HERU) was recognized as a National Historic Landmark by ASABE for its groundbreaking work and development of vegetated waterways design procedures. In 2000, ASABE acknowledged the vegetated waterway design criteria as an Outstanding Achievement of Agricultural Engineering in the 20th Century. Current design procedures have evolved, but its roots are in the early conservation programs of the 1930s when former ASABE Fellow and one of the pioneering researchers of the vegetated waterways design criteria, William O. Ree, began studies on the subject in South Carolina while working for the Soil Conservation Service (now NRCS). He completed this work at HERU near Stillwater, OK in the 1940s. During this time, permissible velocities for vegetated channels and n-VR curves were developed as valuable design tools. The design criteria developed by Ree have been used worldwide for more than 60 years. In 1987, the design method evolved to a stress-based procedure. Today, NRCS is leading an effort to update current design procedures in their Engineering Field Handbook and developing computer aided design software for vegetated waterways with the assistance of the USDA-ARS HERU. Researchers at HERU have continued to study vegetation in high stress flow environments that have played an important part in the development of the computational models, SITES and WINDAM, for evaluating vegetated auxiliary spillways and earthen embankments. SITES is used by NRCS and engineers worldwide for the design and analysis of watershed flood control dams. The evolution of the design procedures for grass-lined channels has had a tremendous impact on agricultural engineering.*

Keywords. Vegetated waterways, grass-lined channels, erosion control, erosion, headcut, spillways, earth embankments

Introduction

The Dust Bowl of the 1930s brought national focus to soil erosion and the havoc it was creating on U.S. farmland. Congress recognized the quandary farmers were faced with and created the United States Department of Agriculture (USDA) Soil Conservation Service (SCS), now known as the Natural Resources Conservation Service (NRCS), in 1935. Hugh H. Bennett, the first chief of the SCS, believed that soil conservation should be based on a combination of management and vegetative measures including strip cropping, crop rotation, contouring and terracing, wildlife enhancement, pasture improvement, and returning unsuited cropland back to its native forest (Helms, 2007). Bennett suggested that a multidisciplinary group of specialists including engineers, economists, agronomists, soil scientists, wildlife biologists, and others work together to achieve and develop mutually supporting soil and water conservation practices and measures (Helms, 2007).

Engineers worked on new innovative ways to control soil erosion.   Terracing farmland across the nation became a common conservation practice to control soil erosion by water. Terracing is accomplished by constructing ridges and channels across the slope of the land so that runoff can be directed away from the field. In the early days, conservationists realized that the probability for gully erosion to develop at the terrace outlet was great. In the beginning, structural measures were used to control the erosion at the terrace outlet (Figure 1); however, engineers discovered scour development at the toe of the drop created instability in the structure. Additionally, these measures were costly and not aesthetically pleasing. Engineers preferred the use of a more economical and natural material like grassed channels to give the protection and the stability needed at the terrace outlet. Yet, research was required to prove whether this erosion control measure would work. The research interest on grass-lined channels led to the establishment of the USDA-SCS Outdoor Hydraulics Laboratory in Spartanburg, South Carolina in 1936. The laboratory was later transferred to its current location seven miles west of Stillwater, Oklahoma near Lake Carl Blackwell in 1940 (Figure 2), and became known as the Hydraulic Engineering Research Unit (HERU) of the USDA-Agricultural Research Service (ARS) in 1953. The historic research on grassed waterways at the Hydraulic Laboratory laid the foundation for the pioneering research on vegetated spillway erosion technology and embankment overtopping protection. Much of the research that continues today at the laboratory ties back to its “grass” roots in which it was founded.

Figure 1. Structural drop used to convey runoff from terraced agricultural lands to stream channels.

Figure 2. Aerial view of the USDA-ARS Hydraulic Engineering Research Unit.

In the beginning…

In the beginning, the Hydraulic Laboratory mission was to study the hydraulic performance of grass-lined channels. This work was later expanded into farm reservoir emergency spillways, diversions, meadow strips, and embankment overtopping protection. The laboratory was under the direction of ASAE (now ASABE) Fellow and one of the pioneering researchers and engineers in vegetated waterway design, William O. Ree (Figure 3). It was Ree's intent to keep the experiments on grass-lined channels simple and straight forward so that the results could be directly applicable to the field problem. Ree accomplished just that. Research on vegetated channels provided permissible velocity criteria and n-VR curves, both of which are valuable tools for the design of vegetated waterways (Cox and Palmer, 1948; Ree, 1949). The information obtained from this research effort resulted in the publication of SCS-TP-61, the *Handbook of Channel Design for Soil and Water Conservation* (USDA-SCS, 1954). This document has been used worldwide for the design of vegetated channels for more than 60 years. After the release of this publication, research on vegetated channels continued with investigations into cultural practices including testing different species of vegetation, freeze and thaw cycles of the vegetation, dormant versus active vegetation (Ree, 1958 and Ree, 1976). In 1990, ASAE recognized the laboratory as a Historic Landmark for the design concepts for vegetated waterways. At that time, an estimated a half million miles of vegetated waterways had been constructed, and if laid end to end, these channels would wrap around the earth approximately 3 times. In addition to its historic landmark status, ASAE recognized the design procedures for vegetated channels as one of the Outstanding Achievements of Agricultural Engineering in the 20th Century (Cuello and Huggins, 2000). Today, NRCS is leading an effort to update current design procedures in their Engineering Field Handbook and developing computer-aided design software for vegetated waterways with the assistance of the USDA-ARS HERU.

Figure 3. Early-day ARS research on vegetated channels.

The legacy continues…

The research legacy of Ree continues today with advancements in the design of vegetated waterways and with the development of vegetated auxiliary spillway erosion prediction technology and research of embankment overtopping protection. In the 1980s, Temple et al. (1987) focused on the development of a stress-based vegetated channel design method as described in *Agricultural Handbook 667* rather than the velocity-based vegetated channel design method. The performance of vegetated earth channels used as auxiliary spillways for flood control dams and other hydraulic structures were evaluated during this time (Figure 4). Spillway erosion is considered permissible if the spillway does not breach during a freeboard or maximum flood event. To have a better understanding of vegetated spillway erosion, the ARS teamed with the NRCS to form the Emergency Spillway Flow Study Task Group. The NRCS was responsible for observing and gathering field data on spillways that had experienced greater that 0.9 m of head or those that had sustained major damage from flood flows. HERU engineers were responsible for conducting research on erosion related processes of spillways including further study on the failure of grass channel linings and surface and headcut erosion processes related to spillway performance (Temple et al., 1987; Hanson, 1991; and Robinson, 1992). By 1991, the partnership between the ARS and the NRCS evolved into the Design and Analysis of Earth Spillways team. This team was responsible for developing and documenting new technology for the design of vegetated earth spillways. Research and field data acquisition efforts continued on vegetated channels. The compiled data was used for the development of a computational algorithm for use in design and analysis of earth spillways (USDA-NRCS, 1997). This computational algorithm was incorporated into the Water Resources Site Analysis computer program, SITES, used by NRCS for design and analysis of watershed flood control dams. This software provides procedures for routing flow through the reservoir and for determining vegetal failure timing and headcut advancement location based on the vegetal cover, geologic materials underlying the spillway, and the spillway flow. HERU, the NRCS, and Kansas State University continue to maintain and upgrade the software as needed.

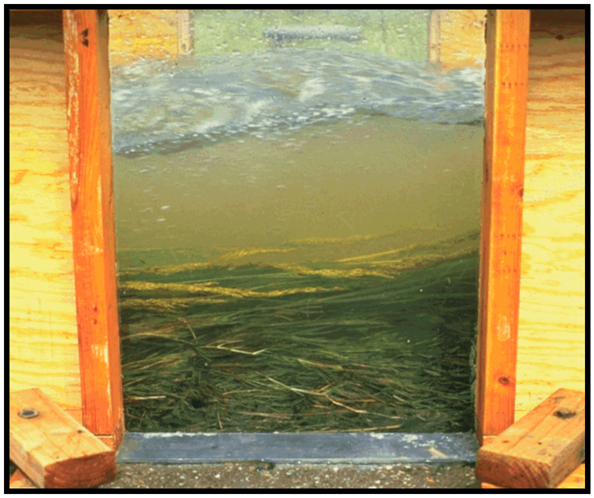

Figure 4. Vegetative spillway research.

An important key in predicting spillway erosion with the SITES program is the headcut erosion calculations within the software. As part of the testing regime, headcut erosion processes, particularly as they relate to gully headcut advancement, were examined closely (Robinson and Hanson, 1996; Hanson et. al, 1997; Hanson et. al, 2001; Robinson and Hanson, 2001). Figure 5 illustrates one of these tests conducted on earthen spillway headcut advancement. The development and movement of gullies in earthen auxiliary spillways is a dominant form of earthen spillway damage. ARS conducted numerous tests on headcut development examining such things as variations in the pre-formed overfall height and flow rate provided for the experiment as well as variations in soil properties like compaction and moisture content. Based on the accumulated data, Hanson, et. al (2001) developed a simplified, deterministic equation to predict headcut advance in vegetated earth spillways.

Figure 5. Research on headcut advance in a flume.

The continued research on vegetated earth spillways led to other technological advancements in the examination of soil erosion. In the early 1990s, Hanson (1991) developed a laboratory instrument known as a submerged-jet testing device for the evaluation of soil erodibility (Figure 6a). The testing device and subsequent methods and procedures for characterizing the erosion resistance of soils have become valuable tools for examining the effects of soil properties including compaction and moisture content on erosion resistance of soil materials. Several patents have been awarded for the developed apparatus and procedure (Hanson, 1993a; Hanson, 1993b; and Hanson, 1994), and the procedure for determining soil erodibility appears as ASTM standard D5852-95 in the 2000 *Annual Book of ASTM Standards*. This testing device has evolved, making it possible to characterize the soil erodibility of streambeds and stream bank materials (Figures 6b and 6c) (Hanson et al., 2002).

Figures 6. a). Original laboratory submerged jet-test device, b). Modified submerged jet test device examining streambeds, and c). Modified submerged jet-test device examining stream banks.

The procedure for evaluating the time of vegetal failure in earth spillways is ever evolving. In more recent years, Temple and Hanson (1998, 2002) show that the procedures developed within the SITES software is applicable for steeper slopes associated with vegetated embankments when subjected to hydraulic stress, and experience in the field has concurred with these results in that some embankments can handle a limited amount of overtopping with little or no damage. The concept of allowable overtopping of earthen embankments was proposed by Temple and Irwin (2006) with the introduction of WINDAM, Windows Dam Analysis Modules. As in the SITES software for vegetated spillways, WINDAM evaluates the vegetal protection on three levels of surface or cover discontinuities and focuses on the hydraulic attack required to fail the vegetal protection (Temple and Irwin, 2006). WINDAM does not include any provision for evaluating concentrated hydraulic attack at the toe of the dam or at the berm, so examination of these areas would need to be conducted independent of WINDAM. Additionally, WINDAM in its current version does not give an indication on the timing of breach of the embankment or even if a breach will occur following the initial failure of the vegetal protection on the dam face. The next stage in WINDAM development is envisioned to include breach prediction technology, which evaluates the beginning of the breach erosion processes upon failure of the vegetal cover (Temple and Irwin, 2006). Breach prediction technology is currently part of a research tool known as SIMBA (SIMplified Breach Analysis) that HERU engineers are evaluating.

Summary

In 1990, the USDA-ARS Hydraulic Engineering Research Unit (HERU) was recognized as a National Historic Landmark by ASAE for its groundbreaking work and development of vegetated waterways design procedures. In 2000, ASAE recognized the waterways work as an Outstanding Achievement of Agricultural Engineering in the 20th Century (Cuello and Huggins, 2000). Current design procedures have evolved, but its roots are in the early conservation programs of the 1930s when William O. Ree began studies on the subject in South Carolina while working for the SCS. He completed this work at HERU near Lake Carl Blackwell outside of Stillwater, OK in the 1940s. During this time, permissible velocities for vegetated channels and n-VR curves were developed as valuable design tools and led to the publication of SCS-TP-61, the *Handbook of Channel Design for Soil and Water Conservation*. In 1987, the design method evolved to a stress-based procedure as described in *Agricultural Handbook Number 667*. Today, NRCS is leading an effort to update current design procedures in their Engineering Field Handbook and developing computer aided design software for vegetated waterways with the assistance of the USDA-ARS HERU.

Researchers at HERU have continued to study vegetation in high stress flow environments that have played an important part in the development of the computational models SITES and WINDAM for evaluating vegetated auxiliary spillways and earthen embankments. The SITES software is used by NRCS and engineers worldwide for the design and analysis of watershed flood control dams. Additionally, complementary research on headcut advancement and soil erodibility has provided a better understanding of vegetated earth spillway erosion. Research and experience have shown the relationships developed within the SITES software are applicable for steeper slopes associated with vegetated embankments. These relationships and procedures have been incorporated into WINDAM application software used to evaluate vegetal protection and allowable overtopping of earthen embankments. The evolution of the design procedures for grass-lined channels has had a tremendous impact on agricultural engineering.

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