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Proceedings of a Workshop on Suspended Sediments and Solids

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by

Joseph P. Schubauer-Berigan
Land Remediation and Pollution Control Division
National Risk Management Research Laboratory
Cincinnati, Ohio 45268

Scott Minamyer
Technology Transfer and Support Division
National Risk Management Research Laboratory
Cincinnati, Ohio 45268

Evelyn Hartzell
Science Applications International Corporation
11251 Roger Bacon Drive, Reston, VA 20190

National Risk Management Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
26 W. Martin Luther King Drive
Cincinnati, Ohio 45268

Notice

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[1] U.S. Environmental Protection Agency, National Risk Management Research Laboratory, 26 W. M. L. King Drive, Cincinnati, OH 45268.
[2] Science Applications International Corporation, 11251 Roger Bacon Drive, Reston, VA 20190.

Executive Summary

Introduction

This document contains a summary of the technical presentations and open discussions from a Workshop on Suspended Sediments and Solids held on July 11 – 12, 2002 at the United States Internal Revenue Service Training Center, Cincinnati, Ohio. The workshop was conducted by the US Environmental Protection Agency (USEPA) National Risk Management Research Laboratory (NRMRL). Representatives from NRMRL Divisions; other USEPA Offices, Regions, and Laboratories; the US Department of Agriculture (USDA); US Army Corps of Engineers (USACE); US Geological Service (USGS); US Fish and Wildlife Service (USFWS); states; academia; environmental organizations; and consulting firms attended.

Purpose and Objectives

The purpose of the workshop was to bring together interested USEPA scientists with leading researchers from academia, state and federal agencies, and others with expertise to provide information on the state-of-the-science in sediments management. It was also intended to foster working relationships and partnerships with others working on sediments issues. The workshop covered models, best management practices (BMPs), and biological indicators specific to sediments.

Six technical sessions were presented during the 2-day workshop. These sessions addressed the following topics:

$ Federal sediment research programs
$ Regional USEPA sediment issues and approaches
$ State sediment issues and approaches
$ Field measurements and field data availability
$ Sediment management models, tools, and analytical approaches
$ BMPs and models

The presentations were followed by open discussions at the end of each day and at the end of the sessions held on July 12, 2002. Participants were invited to comment on critical issues associated with the material presented during the open discussions.

Major Significance

This document summarizes the research findings and perspectives of some of the leading researchers from academia, state and federal agencies, and other experts in the field of suspended sediments and solids management. It contains a summary of the technical presentations and open discussions from the workshop. It also contains the final Agenda, List of Attendees, abstracts, and copies of the available speaker papers (Appendices A, B, C, and D, respectively). Appendix E contains a summary of the work group discussion that occurred in the evening of July 11, 2002. Appendix F contains the Risk Management Research Framework for Suspended Solids and Sediments produced by NRMRL. This document is intended to provide individuals with a resource for gaining insight into the state-of-the-science in the broad field of suspended sediments and solids management.

Foreword

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

Sally Gutierrez, Director
National Risk Management Research Laboratory

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A workshop focused on suspended sediments and solids and water quality was held on July 11–12, 2002 at the United States Internal Revenue Service Training Center, Cincinnati, Ohio. Dr. Joseph Schubauer-Berigan and Mr. Scott Minamyer of the USEPA, Office of Research and Development, National Risk Management Research Laboratory developed and conducted the workshop. They also were responsible for the editing of this summary report. Lisa Kulujian, Evelyn Hartzell, Kyle Cook, and Gregory Tracey of the Science Applications International Corporation (SAIC) provided support for the workshop and Evelyn Hartzell of SAIC prepared the initial draft of the summary report under Contract 68-C-02-067.

Acronyms

AGNPS	Agricultural NonPoint Source Model
ARS	Agricultural Research Service (USDA)
ASCE	American Society of Civil Engineers
BLM	Bureau of Land Management
BMP	Best Management Practice
CALM	Consolidated Assessment and Listing Methodology
CDF	Computational Fluid Dynamic
CO DPHE	Colorado Department of Public Health and Environment
CONCEPTS	Conservation Channel Evolution and Pollutant Transport System
CSI	Channel Sedimentation Index
CWA	Clean Water Act
DDD	Dichlorodiphenyldichloroethane (Rhothane)
DDE	Dichlorodiphenyldichloroethene
DDT	Dichlorodiphenyltrichloroethane
DEQ	Department of Environmental Quality
DGPS	Differential Global Positioning System
DNR	Department of Natural Resources
DO	Dissolved Oxygen
DOER	Dredging Operations and Environmental Research Project
DPT	Disrupt Pollutant Transport
EFDC	Environmental Fluid Dynamics Code Model
EMAP	Environmental Mapping and Assessment Program
EPT	Ephemeroptera, Plecoptera, Trichoptera
ERD	Ecosystems Research Division
ET	Evapotranspiration
ETV	Environmental Technology Verification Program
FEMA	Federal Emergency Management Agency
FISP	Federal Interagency Sedimentation Project
FTE	Full-Time Equivalent
GIS	Geographic Information System
GPRA	Government Performance and Results Act
GSTARS	Generalized Stream Tube model for Alluvial River Simulation
HCP	Habitat Conservation Plan
HQ	Headquarters (USEPA)
HSCTM2D	Hydrodynamic, Sediment and Contaminant Transport Model
HSPF	Hydrological Simulation Program B FORTRAN
HUC	Hydrologic Unit Code
IBI	Index of Biotic Integrity
INSE	Institute for Natural Systems Engineering (at Utah State University)
IO DNR	Iowa Department of Natural Resources
IOE	Institute of Ecology (University of Georgia)
M&E	Monitoring and Evaluation
MFD	Magnitude-Frequency-Duration

MMS	Minerals and Management Service
NCCHE	National Center for Computational Hydroscience and Engineering
NCEA	National Center for Environmental Assessment
NERL	National Exposure Research Laboratory
NHEERL	National Health and Environmental Effects Laboratory
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NPS	Nonpoint Source
NRCS	National Resources Conservation Service
NRMRL	National Risk Management Research Laboratory
NRP	National Research Program
NSIP	National Streamflow Information Program
NSLQA	National Sediment Laboratory Quality Assurance Program
NSSP	National StreamStats Program
NTU	Nephelometric Turbidity Units
OMB	Office of Management and Budget
OMS	Object Modeling System
ORD	Office of Research and Development
OSP	Office of Science and Policy
OST	Office of Science and Technology (USEPA OW)
OSW	Office of Surface Water (USGS)
OW	Office of Water (USEPA)
PAM	Polyacrylamide
PCB	Ploychlorinated Biphenyl
R&D	Research and Development
RCMAP	Reconfigured Channel Monitoring and Assessment Program
REMM	Riparian Ecosystem Management Model
RESIS	Reservoir Information System
RMS	Resource Management System
RSM	Regional Sediment Management Program (USACE)
RSMP	Regional Sediment Management Research Program
RUSLE	Revised Universal Soil Loss Equation
SDWA	Safe Drinking Water Act
SESD	Science and Ecosystem Support Division (USEPA Region 4)
SITE	Superfund Innovative Technology Evaluation Program
SMART	System-wide, Modeling, Assessment, and Restoration Technologies Program
SOP	Standard Operating Procedure
SPARROW	SPAtially-Referenced Regression On Watershed Attributes Model
SPO	Special Project Office
SRC	Source Reduction Control
SSC	Suspended Sediment Concentration
TAG	Technical Advisory Group
TGC	The Georgia Conservancy
TMDL	Total Maximum Daily Load
TSS	Total Suspended Solids
UGA	University of Georgia

USACE	US Army Corps of Engineers
USDA	US Department of Agriculture
USEPA	US Environmental Protection Agency
USFS	US Forest Service
USFWS	US Fish and Wildlife Service
USGS	US Geological Service
USL	Universal Soil Loss
USLE	Universal Soil Loss Equation
VFS	Vegetative Filter Strip
WCS	Watershed Characterization System
WEPP	Water Erosion Prediction Project
WQCC	Water Quality Control Commission
WQS	Water Quality Standard
WRD	Wildlife Resources Division (GA), or Water Restoration Division

1. Introduction

1.1 Overview

The Workshop on Suspended Sediments and Solids was held on July 11 – 12, 2002 in Cincinnati, Ohio. The workshop was conducted by the US Environmental Protection Agency (USEPA) National Risk Management Research Laboratory (NRMRL). Representatives from NRMRL Divisions; other USEPA Offices, Regions, and Laboratories; the US Department of Agriculture (USDA); US Army Corps of Engineers (USACE); US Geological Service (USGS); US Fish and Wildlife Service (USFWS); states; academia; environmental organizations; and consulting firms attended.

The purpose of the workshop was to bring together interested USEPA scientists with leading researchers from academia, state and federal agencies, and others with expertise to provide information on the state-of-the-science in sediments management. It was also intended to foster working relationships and partnerships with others working on sediments issues. The workshop covered models, best management practices (BMPs), and biological indicators specific to sediments.

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The presentations were followed by open discussions at the end of each day and at the end of the sessions held on July 12, 2002. Participants were invited to comment on critical issues associated with the material presented during the open discussions.

This document contains a summary of the technical presentations and open discussions. The final Agenda, List of Attendees, abstracts, and copies of the available speaker papers are presented in Appendices A, B, C, and D, respectively. Appendix E contains a summary of the work group discussion that occurred in the evening of July 11, 2002.

1.2 Welcome and Opening Remarks

Joe Schubauer-Berigan, Sally Gutierrez, and Laurel Staley, USEPA NRMRL

Joseph Schubauer-Berigan

Joseph Schubauer-Berigan welcomed the participants. Suspended sediments and solids have been identified as the most common causes of river and stream impairment in the US (rather than nutrients and metals). Suspended sediments and solids are also important sites for contaminant and nutrient adsorption/release and microbial transformations. As a consequence, USEPA NRMRL is performing research to examine structural and non-structural risk management alternatives for suspended sediments and solids and other non-point pollutants that have been identified as important Total Maximum Daily Load (TMDL) related stressors.

This workshop was developed to bring together researchers from NRMRL with other researchers working on suspended sediments and solids, including experts in academia and other state and federal agencies. The goal of the workshop is to define the state-of-the-science and to identify future directions for NRMRL research. In addition to defining the limitations of the approaches currently being used, the workshop is designed to encourage networking and collaborations between participants in order to use resources effectively and accelerate the development of risk management approaches to mitigate problems and prevent impacts.

A summary report will be developed summarizing workshop presentations and discussions.

Sally Gutierrez

As the Director of NRMRL's Water Supply/Water Resource Division, Ms. Gutierrez opened by noting that Cincinnati, Ohio has been a center for water research for a number of decades. A large amount of ground-breaking research has been performed in Cincinnati, including the development of the Streeter-Phelps equation and other monumental drinking water research.

After thanking Joseph Schubauer-Berigan for effectively communicating the workshop's goals, Ms. Gutierrez noted that the nation is currently faced with the formidable task of developing TMDLs to address water quality problems in impaired water bodies. Previously, efforts have focused on the actual development of the TMDLs (e.g., defining monitoring requirements, determining criteria, and assessing loadings). According to Ms. Gutierrez, identifying the actions needed to bring impaired water bodies into alignment with water quality goals is the biggest challenge associated with the suspended sediments and solids issue. Ideally, NRMRL will provide input that will be used to define these actions.

Although NRMRL began to evolve this research program 2 years ago, this is the first year that funding has been allocated to address these issues, specifically suspended sediments and solids. A preliminary analysis has been performed, including a thorough literature search, in order to identify the work that needs to be done. With the help of the workshop participants and others, NRMRL would like to start prioritizing and defining future research projects under this program.

Ms. Gutierrez closed by noting that NRMRL and the workshop participants need to define what is required for quantitative and effective watershed management of suspended sediments and solids. She then acknowledged the participation of Doug Norton, Bill Swietlik, and Chris Nietch.

Laurel Staley

After welcoming the participants, Ms. Staley reiterated that this is the first year that NRMRL has allocated resources in support of this research program. Although a couple of efforts have already started, the program is still in the early planning stages. As a result, input received during the workshop can have a significant impact on this program.

Currently most of the work associated with sediments is being performed by two of NRMRL's six divisions: 1) the Water Supply/Water Resource Division; and 2) Land Remediation Division. The Water Supply/Water Resource Division has overall responsibility for the Watershed Program (including all research activities); the Land Remediation Division controls the funding and is coordinating the program. Joseph Schubauer-Berigan is coordinating the overall effort and Chris Nietch has compiled a list of research questions requiring action. The Technology Transfer and Support Division is also supporting this effort, in particular Scott Minamyer. Related work is also being performed by the Subsurface Protection Remediation Division in Ada, Oklahoma. This division is responsible for the Ecosystem Restoration Program, which is very closely related to the Watershed Program and Sediments Program. There is also a group within NRMRL that may be responsible for studying the role that economics can play in addressing these sediment-related questions.

After noting that NRMRL will focus on the need to manage sediments in watersheds relative to potential community benefits and environmental impacts, Ms. Staley thanked the participants for taking the time to participate in the workshop.

2. Summary of the Technical Sessions

2.1 Federal Sediment Research Programs

2.1.1 USGS Support For "Clean" Sediment TMDLs

John Gray, USGS, Office of Surface Water (OSW), Water Restoration Division (WRD)

John Gray's presentation discussed USGS activities and capabilities in support of USEPA "clean" sediment TMDLs including different USGS offices, programs, and products.

USGS OSW
The USGS OSW (http://water.usgs.gov/osw) oversees the protocols used to collect surface water and fluvial sediment data and internally coordinates USGS national surface water programs, including the National Streamflow Information Program (NSIP). The USGS OSW also externally coordinates streamflow and sediment activities and provides quality control and training. This office also partially oversees the Federal Interagency Sedimentation Project (FISP) and fully oversees the Hydraulics Laboratory in Bay St. Louis, Mississippi.

USGS Hydrologic Data Collection Activities Related to Fluvial Sediment Assessment
The USGS has been mandated to coordinate the Nation's hydrologic data collection/storage/serving activities. Currently the USGS operates approximately 7,000 continuous streamflow stations, 3,000 water quality stations, and 140 sediment stations nationwide. The streamflow data collected by USGS are used to compute sediment discharges and are an important variable for suspended sediment assessments. Surface water data collected by the USGS, including historical suspended sediment data and daily, realtime, and historical streamflow data, can be accessed at http://water.usgs.gov/osw/data.html. Daily-value sediment data (through 1994) and instantaneous sediment USGS data are also available online and can be accessed at http://water.usgs.gov/osw/sediment/index.html and http://webserver.cr.usgs.gov/sediment, respectively.

Because the USGS sediment "program" peaked in 1979, the volume of sediment-related data collected annually has declined. Currently the number of continuous-record stations in operation in the US has decreased to 1948 levels. The number of daily sediment stations has also drastically decreased since the late 1970s and early 1980s. For example, although 37 stations collected at least 3 years of daily suspended sediment data between 1951 and 1999 in the Chesapeake Bay watershed, there are currently no daily load suspended sediment stations in operation in the Bay. Since these data are essential to assessing and responding to suspended sediment problems, Mr. Gray urged the attendees to support an increase in USGS sediment monitoring efforts.

Protocols for Data Assessment
The USGS has also developed protocols for data collection to aid in sediment assessments which are available online and in hard copy format. Protocols for flow, sediment, and water quality protocols include:

$ *Flow:* http://water.usgs.gov/pubs/wsp/wsp2175/ or USGS CD, WRI Report 00-4036, "Measurement of Stream Discharge by Wading"
$ *Sediment:* http://water.usgs.gov/osw/techniques/sedimentpubs.html or Sediment Data Collection CD in Development
$ *Water Quality:* http://water.usgs.gov/owq/FieldManual/

NSIP
NSIP is a nationwide base-funded system of gages for measuring streamflow and related environmental variables reliably and continuously in time. In addition to collecting data in response to major floods and droughts, this program periodically assesses regional and national streamflow characteristics, delivers streamflow information to customers, and researches and develops various streamflow techniques. Program success is partially attributable to stringent data processing, quality assurance, archival, and accessible procedures/requirements. Gaging stations feature the following:

$ Realtime stage-measurement capability
$ Rain gage
$ Two-way communications
$ Video capability
$ Surveyed cross-section
$ Realtime discharge and rating reporting
$ Ratings extended and flood hardened to 500-year level
$ Global Positioning System (GPS) located
$ Hourly temperature data

Although the number of long-term streamflow stations declined alarmingly after the 1970s, Mr. Gray encouraged participants to visit the NSIP web site at http://water.usgs.gov/nsip/index.html A national map containing NSIP streamflow data can also be accessed at http://water.usgs.gov/dwc/national_map.html.

StreamStats
StreamStats is a national web-based application for providing streamflow information to the public (see http://water.usgs.gov/osw/programs/streamstats.html). Streamflow statistics, such as the 100-year-flood data are used for: 1) water resources planning, management, and permitting; 2) instream flow determinations for pollution and habitat; 3) facility designs and permitting (e.g., wastewater treatment plants); and 4) infrastructure designs (e.g., roads, bridges, culverts, dams, locks, and levees).

StreamStats is currently operational for the Commonwealth of Massachusetts. The Massachusetts StreamStats web application provides published streamflow statistics, basin characteristics, and other information for data collection stations. It also provides estimates of streamflow statistics, basin characteristics, and other information for user selected points on ungaged streams.

StreamStats uses regression equations to estimate streamflow statistics for ungaged sites. The equations relate streamflow statistics to measured basin characteristics. These equations were developed by the 48 USGS districts on a state-by-state basis. Regression equations are not used very often, however, because of the level of effort needed to determine basin characteristics and because users often measure basin characteristics inaccurately.

StreamStats provides the following benefits to users:

$ Readily available published statistics.
$ The process for calculating streamflow characteristics for ungaged sites takes a fraction of the time required by manual methods (i.e., usually less than 15 minutes).
$ Large collections of maps, equipment, and software are not necessary.
$ The process is reproducible.
$ Little or no additional error is introduced in the accuracy of the low flow estimates.
$ Only a basic understanding of hydrology, computer science, and geographic analysis is needed.

SPAtially-Referenced Regression On Watershed Attributes (SPARROW) Model
SPARROW relates instream water quality measurements to spatially referenced characteristics of watersheds, including contaminant sources and factors influencing terrestrial and stream transport. The model, which was developed initially to determine nutrient transport, is currently being modified to address sediment transport. It can be accessed at http://www.rvares.er.usgs.gov/nawqa/sparrow. SPARROW accounts for land uses and sources, landscape features, and drainage and impoundments. SPARROW features include the following:

$ Nested monitoring sites
$ Spatially referenced source inputs and watershed attributes
$ Mass balance with non-conservative transport processes
$ Spatial nonlinear regression
$ Empirical estimates of flux to streams and watershed outlets from point and diffuse sources
$ Mean annual or seasonal flux
$ Contaminants: nutrients, atrazine, fecal strep. bacteria, sediment

Hydro 21
Hydro 21 is a committee that has been formed to identify new field technologies/procedures for collecting physical and chemical data, particularly for measuring streamflow. These technologies are intended to replace current procedures for making hydraulic field measurement that have been in place for over 50 years. In particular, non-contact measurements of river discharge using satellite telemetry are being investigated.

National Sediment Laboratory Quality Assurance (NSLQA) Program
The NSLQA Program provides quantitative information on sediment data quality to sediment laboratories and their customers. In addition to providing training in lab procedures and performing onsite lab evaluations, the NSLQA Program employs a single blind program and a double blind program. This national quality control data evaluation program also performs followup evaluations and provides documented quality control plans and procedures. Additional information is available about the NSLQA Program at http://sedserv.cr.usgs.gov/.

Reconfigured Channel Monitoring and Assessment Program (RCMAP)
RCMAP monitors and assesses the long-term geomorphic behavior of selected river and stream reaches that have previously undergone some physical modification. In addition to developing a uniform and versatile monitoring methodology for reconfigured channel reaches, RCMAP is responsible for creating and maintaining a database consisting of numerous monumented stream reaches. The program also revisits reaches periodically and assesses regional and temporal trends in the geomorphic response of the stream to the channel modifications. Although there is some question regarding whether the RCMAP format/structure/protocols will be useful to the "clean" sediment TMDL program, additional information on RCMAP is available at http://co.water.usgs.gov/projects/rcmap/rcmap.html.

Sediment TMDL Information
The USGS, with support from the USEPA Office of Water (OW), has developed a searchable archive system for sediment TMDL studies. Although this system is only available at the demonstration level, the archive contains selected information describing studies on TMDLs, including the methods used to estimate existing sediment loads and methods for monitoring data collection. Eventually interactive features will be developed for this application/website that will help the user investigate methods used in determining, estimating, and monitoring sediment TMDLs.

FISP
FISP is an interagency project with the USACE that provides calibrated isokinetic and water quality samplers used to obtain the bulk of quality assured sediment data, including the D-96 "Clean" Suspended Sediment Sampler. The D-96 sampler is used for collecting trace element data in addition to sediment. Additional information on FISP is available at http://fisp.wes.army.mil.

USGS Stream Restoration Workshop and New Samplers
After encouraging participants to contact USGS Hydrologist Tim Straub at tstraub@usgs.gov for a copy of the proceedings from the USGS Stream Restoration Workshop held in Urbana, IL from February 20–22, 2002, John Gray then listed the following emerging sediment measurement technologies:

- Acoustic techniques for measuring bed load and gravel transport
- Laser scattering to interpret sand concentrations, including the LISST-100
- Optical, including optical backscatterence (which is akin to turbidity) and digital technologies
- Differential pressure sensors, including the "Double bubbler"

Summary
After noting that a large amount of fluvial sediment and ancillary information is available, Mr. Gray cautioned that relatively little fluvial sediment data are currently being collected. After briefly mentioning data gaps, Mr. Gray stressed the importance of tying the data together and establishing nationally consistent data collection and analytical techniques. He closed by noting that new equipment and techniques appear promising, but that an organized approach is needed to reap the benefit of these innovations.

2.1.2 Overview of Agricultural Research Service Research on Suspended Sediments and Solids

Dale Bucks, USDA, Agricultural Research Service (ARS)

ARS is a branch of USDA that performs intramural research within a "farm-to-table" scope. Currently ARS employs 7,000 employees, including 2,040 scientists. It has an annual budget of 980 million dollars and has more than 100 laboratories throughout the US. ARS currently runs 22 national programs and is involved in more than 1,100 research projects. Although its main client is the Natural Resource Conservation Service (NRCS), ARS prides itself on the level of cooperation it has maintained with other research organizations, including partnerships with universities and industry.

ARS National Programs

ARS's 22 national programs are organized under three main categories: animal production, natural resources, and crop production. As suggested by the title, sediment-related research is mainly performed under the natural resources programs. Although there are seven national natural resources programs, the three largest programs are: 1) Water Quality and Management; 2) Soil Resource Management; and 3) Air Quality.

The Water Quality and Management Program's mission is to: 1) develop innovative concepts for determining the movement of water and its constituents in agricultural landscapes and watersheds; and 2) develop new and improved practices, technologies, and systems for managing the Nation's water resources.

ARS Suspended Solids and Sediment Research

According to the USEPA and the states, 40 percent of assessed waters in the US are impaired. Currently at least 21,000 water bodies nationwide do not meet water quality standards (WQS) and approximately 300,000 river and shore miles and 5 million lake acres are impaired. Although sediment loading is considered the biggest issue/problem, nutrients, pesticides, and pathogens can also attach to sediments.

ARS is performing suspended solids and sediment research at over 15 locations across the US. ARS suspended solids and sediment research activities include:

- Watershed hydrology, erosion, and sediment movement
- Irrigation-induced erosion
- Water quality TMDLs and clean sediment

<u>ARS Watershed Hydrology, Erosion, and Sediment Movement Research</u>

High priority ARS watershed hydrology, erosion, and sediment movement research areas include:

- Watershed hydrology and erosion processes
- Role of riparian areas, wetlands, and stream corridors in reducing sediment loadings
- Design of watershed flood control structures
- Sediment contamination associated with decommissioned watershed structures
- Watershed erosion databases, models and decision support systems

ARS is attempting to research these areas under the following efforts/progams.

National Soil Erosion Laboratory
The USGS is performing rainfall simulator experiments and erosion process research at the National Soil Erosion Laboratory in West Lafayette, Indiana. The data obtained from the rainfall simulatory experiments have led to the development of the Universal Soil Loss (USL) Equation. A revision to the USL Equation that can account for edge of field effects, etc., is expected to be available in USDA field offices in early 2004. The erosion process research is currently examining sediment processes and impacts of small structures.

The Water Erosion Prediction Project (WEPP) Model is also maintained and updated at the National Soil Erosion Laboratory. WEPP is a process-based, distributed parameter, continuous simulation, erosion prediction model which is used by the US Forest Service (USFS) for small watershed erosion applications. It can be used to produce Windows interfaced profiles that are depicted graphically in two-dimensional (2-D) or three-dimensional (3-D) views. Since the graphic image is "hot", the underlying parameters can be both viewed and edited. Erosion and deposition rates are typically displayed on the center profile layer in shades of red and green. WEPP is currently being updated to include a TMDL application.

Hydraulic Engineering Research Laboratory
The Hydraulic Engineering Research Laboratory in Stillwater, Oklahoma designs and analyzes vegetated earth spillways. The Stillwater facility is currently cooperating with NRCS to evaluate spillway erosion data and improve site erosion prediction computer design software. Initial data show that vegetated spillways are useful for initial flood control for 1st order streams.

The Stillwater facility is also actively evaluating the performance of overtopped earth embankments. In addition to testing vegetative covers to determine the extent of protection provided, this facility is also evaluating associated erosion processes that occur after a test embankment is breached and developing a mathematical model to describe the breach process. These vegetative structures, which replace concrete, are designed to fail under certain flow conditions.

Watershed Sediment and Water Quality Research and Deep Loess Research Station Watershed
Bank erosion has been compared to sheet and rill erosion at the Watershed Sediment and Water Quality Research facility in Ames, Iowa and Deep Loess Research Station Watershed facility in Treynor, Indiana. Over 34 years of historical records show that bank erosion is more than sheet and rill erosion from the watershed. Currently, a 1.5-year-old riparian buffer is being used to reduce the water table near the stream bank.

Southeast Watershed Research Laboratory
The Riparian Ecosystem Management Model (REMM) was developed by the Southeast Watershed Research Laboratory in Tifton, Georgia. This model predicts sediment load reductions for buffer scenarios, outputs to streams for different nonpoint source loadings, and changes in pollutant transport processes.

Northwest Watershed Research Center
The Northwest Watershed Research Center in Boise, Idaho characterizes the variability and factors influencing suspended sediment production on western rangelands. The center also evaluates the temporal impacts of wild and prescribed fires on infiltration and erosion.

Irrigation-induced Erosion Research
Irrigation-induced erosion research areas include:

$	Irrigation-induced erosion databases and models.
$	BMPs for reduced irrigation-induced erosion.

ARS is attempting to research these areas under the following efforts/programs.

U. S. Water Conservation Laboratory
Surface irrigation models and software, such as BASINS and SRFR, are being developed at the US Water Conservation Laboratory in Phoenix, Arizona to improve the design and management of flood and furrow irrigation systems and to predict soil losses associated with these systems.

Northwest Irrigation and Soils Laboratory
Untreated and polyacrylamide (PAM) treated irrigation furrows were compared at the Northwest Irrigation and Soils Laboratory in Kimberly, Idaho. The use of PAM in the irrigation water reduced sediment losses to the Snake River to nearly zero in 1974. Currently PAM is registered for use in 10 Western States.

Water Quality TMDLs and Clean Sediment Research Gaps
Water quality TMDLs and clean sediment research areas include:

$	Field scale erosion processes
$	Role of sediments in transport of nutrients, pesticides, and pathogens
$	Sediment effects on aquatic life
$	BMPs to reduce soil erosion
$	Clean sediment TMDL standards
$	Field scale erosion databases, models, and decision support systems

ARS is attempting to research these areas under the following efforts/programs.

J.P. Campbell, Sr., Natural Resource Conservation Center
During no-till farming at J.P. Campbell, Sr., Natural Resource Conservation Center in Watkinsville, Georgia organic matter went from 1% in the top 10 cm to 2.8% over 20 years. Not only is the increase in infiltration equivalent to an additional 20 cm of rainfall, but soil loss was 0.02 Mg/ha for the no-till crops as compared to 50 Mg/ha for conventional tillage. Also the no-till crops lost only 2% of the annual rainfall to runoff, whereas conventional tillage lost 16 % of annual rainfall to runoff.

Mississippi MSEA Oxbow Lake Water Quality Project
Mississippi MSEA Oxbow Lake Water Quality Project in Oxford and Stoneville, Mississippi has focused a significant amount of effort on assessing the dynamics of sediment, pesticide, and nutrient occurrence in lake water and determining the role of BMPs in improving water quality. The project is also concerned with evaluating the health and ecology of planktonic and fish communities in Delta oxbow lakes and establishing upper limits for suspended sediments. In particular, the following anticipated research products from three research efforts were noted: field-scale runoff cotton plots, ditch characterization and management, and edge of field structural practices. Additional details on these research products are listed below, under the appropriate research category:

- $ *Field-scale runoff cotton plots*
  - -Quantify sediment, nutrient, and herbicide loss from different cotton BMP systems in the Delta Region
  - -Demonstrate feasibility of conservation BMP systems for improved water quality and TMDL development
  - -Evaluate economics of conservation systems
- $ *Ditch characterization and management research*
  - -Recommendations for preserving and enhancing drainage ditches to reduce sediment and chemical movement in nearby water bodies
  - -Quantify the ability of ditches to remove chemicals and trap sediment from runoff water
- $ *Edge of field structural practices*
  - -Recommendations for constructing pipes, tile drains, and hedges for proper field drainage
  - -Recommendations for situations where tile drains work best
  - -Quantify extent to which each structural BMP improves quality of runoff water

Summary: ARS Suspended Solids and Sediment Research

As part of the ARS Water Quality and Management National Program, the component areas that relate to sediment research include: watershed hydrology, erosion, and sediment movement; irrigation-induced erosion; and water quality TMDLs and clean sediment. Major ARS locations include: Ames, IA; Boise, ID; Coshocton, OH; Fort Collins, CO; Kimberly, ID; Oxford, MS; Temple, TX; Tifton, GA; Tucson, AZ; Phoenix, AZ; Pullman, WA; Stillwater, OK; Watkinsville, GA, and West Lafayette, IN. Dr. Bucks closed by noting that the impact from ARS sediment research in the past has been outstanding.

2.1.3 Overview of the USACE Regional Sediment Management (RSM) Research and Development Program

Jack Davis, Engineering Research and Development Center, Coastal and Hydraulics Laboratory

The USACE emphasizes addressing sediments from regional perspectives. When commenting on the USACE water resource programs to the Senate Environment and Public Works Committee, LTG Robert Flowers stated "We need to move to a watershed approach as it applies to water resources projects so that each of our projects fits into the context of a regional plan." Thus, RSM involves "fitting" different sediment management actions into the context of a regional plan.

The primary goal of a project manager assigned to a site is to identify the best approach to managing sediment at that site. Since other sites also impact sediment issues in a region or coastal area, individual management actions also need to be addressed from a regional perspective.

Typically regulatory, real estate, operation and maintenance, natural resource, planning, and engineering personnel are involved in RSM projects. Partners and stakeholders in these efforts include: USEPA, Federal Emergency Management Agency (FEMA), NRCS, National Oceanic and Atmospheric Administration (NOAA), Navy, Air Force, USACE, USFWS, National Marine Fisheries Service (NMFS), Coast Guard, USGS, USDA, Minerals and Management Service (MMS), USFS, academia, state planning agencies, local governments, non-government organizations, and state GS, Department of Natural Resources (DNR), Department of Environmental Quality (DEQ), etc. Since each of these partners has a specific mission related to sediment management, collaborations can realize significant benefits. For example, although the USACE collects a lot of data, it is not mandated to archive this data. Thus the USACE would benefit from collaborations with agencies with the authority to archive data.

RSM's Research and Development (R&D) Programs provides the USACE and the Nation with tools and knowledge needed to holistically manage sediment on a regional basis to achieve high performance water resource projects that are economically and environmentally sustainable. The RSM R&D Program will receive 40 million dollars in funding from FY02 on. Since the program will spend up to 4 million a year, the program is expected to last until FY12.

The RSM R&D Program researches the basic processes, models, and various management solutions associated with a sediment issue. This information is then used to develop various "informatics" that RSM distributes to interested parties in the USACE and other organizations via various "Tech Transfer" mechanisms. "Flagship products" include:

- Geomorphic Framework - A conceptual model for RSM and education that identifies regional sediment sources, pathways, and sinks, and how sediment systems respond to changes caused by human intervention and natural events
- Engineering Solutions - Solutions that successfully manage sediment resources locally and regionally by using natural processes and engineering works
- RSM Tools Set - Multi-level examinations of processes and solutions by rapid screening, alternatives analysis, and morphological modeling, including a RSM protocol

The basic processes targeted by RSM R&D include:

- $ Geomorphic responses of regional systems. These are usually large scale and timeframe efforts.
- $ Spatial and temporal transport in a systems context, particularly with respect to the stability of streams or a watershed of streams.
- $ Sand transport during high energy events. This is particularly important for coastal areas.
- $ Mixing and deformation of alluvial bed surfaces including cobbles in small streams.
- $ Freeze-thaw on soil and bank erosion and stability. This is particularly important for assessing river failure.
- $ Effect of organics on fine sediment beds.

The RSM R&D Program is currently focussing their model research efforts on three models: 1) Regional Morphology Model, 2) Overland Flow, Transport, and Morphology Model, and 3) Multi-Dimensional Sediment Model. According to Dr. Davis, the Multi-Dimensional Sediment Model is a data intensive 2-D or 3-D model to which USACE is attempting to add a sediment transport element.

RSM R&D efforts supporting the development of a management solution to a sediment problem include:

- $ Integration of engineered solutions
- $ Technologies and procedures for measuring and monitoring sediments and sediment related factors at local scales and large scales, to include technologies for sediment collection
- $ Development of a morphologic response test bed database to record long-term changes in morphologic response

As noted previously, basic process, model, and management solution research is used to develop "informatics" used to store and utilize data, visualize or model a problem, and support a management decision. RSM R&D is currently developing the following "informatic" products:

- $ Database tools for data storage and mining
- $ Multi-level analysis frameworks
- $ A graphical user environment for RSM

These products are transferred to interested parties in the USACE and other organizations via various "Tech Transfer" mechanisms. Product life-cycle planning is offered by RSM.

After mentioning the System-wide, Modeling, Assessment, and Restoration Technologies (SMART) Program (which examines nutrient impacts on ecosystems) and the Dredging Operations and Environmental Research (DOER) project, Jack Davis encouraged participants to contact him at jack.e.davis@erdc.usace.army.mill or 601-634-3006 with any questions.

2.1.4 Managing Suspended and Embedded Sediments: USEPA OW's Perspective on Water Quality Criteria

William F. Swietlik, USEPA, OW, Office of Science and Technology (OST)

OST is focused on developing effluent guidelines for pollution from industrial groups, WQS, and water quality criteria under the Safe Drinking Water Act (SDWA) and the Clean Water Act (CWA). According to Mr. Swietlik, water quality and clean sediment criteria for states and tribes are essential to developing water and sediment management efforts.

When discussing suspended and embedded sediments issues, the following parameters and terminology are often used: "Clean Sediment" (e.g., not contaminated), suspended sediment concentration (SSC), total suspended solids (TSS), bedload, and turbidity. More specifically, suspended and embedded sediments refers to "particulate organic and inorganic matter that suspends in or is carried by the water, and/or accumulates in a loose, unconsolidated form on the bottom of natural water bodies."

Suspended and embedded sediments are considered an environmental problem when they are no longer in balance (e.g., there is either too much or too little sediment in a water body). The environmental objective with respect to sediments is to maintain natural or optimum suspended and embedded sediment regimes in the different types of water bodies found across the country in order to protect their designated uses (aquatic life, recreation, boating, industrial water, drinking).

Suspended and embedded sediments can affect aquatic life by abrading gills, inhibiting feeding, and smothering eggs and habitat. They can also impact wildlife by disrupting the habitat structure and altering flows. In addition to affecting the recreational value of a water body, either by impairing the aesthetics or impacting water depth (e.g., which impacts safety and access), suspended sediments can also have a significant impact on drinking water supplies, resulting in filtration, damage to intakes and pipes, and filtration system blockages.

Currently 15% of 303d listed waters are impaired due to sediments. According to 305b reports, sediment impaired water bodies include rivers and streams, lakes, reservoirs, ponds, and estuaries. Unfortunately, states and tribes are faced with controlling excessive sediment in water bodies without having the necessary tools to do so, including good water quality criteria, monitoring methods, modeling techniques and controls. As a result, many states and tribes have developed TMDLs even though good water quality criteria are not available. USEPA needs to provide good water quality criteria and monitoring, modeling, and control techniques, as soon as possible, starting with the highest priority needs.

Section 304(a)(8) requires that USEPA develop and publish information on methods for establishing and measuring water quality criteria. WQS includes designated uses, criteria to protect the uses, and antidegradation policy. Water quality criteria are designed to protect the designated use of a water body and provide limits on a particular pollutant or on a condition of a water body. According to Mr. Swietlik, these criteria are best developed in the context of the Water Quality Management Cycle. This cycle includes the following "steps": 1) determine the protection level and review/revise State WQS; 2) conduct water quality assessment; 3) establish priorities and rank/target waterbodies; 4) evaluate WQS for targeted waters and reaffirm/revise WQS; 5) define and allocate control responsibilities; 6) establish source controls; 7) monitor and enforce compliance; and 8) measure progress and modify TMDL if needed.

Forty-six states are developing TMDLs to address 303d impaired water bodies. Currently 13 states are using numeric standards, 13 states are using narrative standards, and 21 states are using a combination of numeric and narrative standards. Unfortunately in most cases the states are moving forward without good water quality data. Also a variety of different benchmarks are used to determine both impairment and TMDLs.

The “Gold Book” (1976) contains criteria for solids and turbidity and the “Green and Blue Books” (1968, 1973) suggest numeric turbidity criteria for drinking water purposes. According to the Gold Book, "Settleable and suspended solids should not reduce the depth of the compensation point for photosynthetic activity by more than 10 percent from the seasonally established norm for aquatic life."

When developing sediment criteria, USEPA needs to first determine what kind of criteria is needed, how many types of sediment criteria are needed, and what approach needs to be used to derive the criteria. According to Mr. Sweitlik, if at all possible, USEPA should try to identify numerical targets (e.g., for TMDLs, permit limits, effectiveness assessments). The criteria should also be related to different designated uses (e.g., aquatic life, recreation, shipping, industrial water, agricultural water, drinking water source, etc.) and be readily measurable and easily implemented. Finally, the criteria will need to apply to all water bodies including streams, rivers, lakes, reservoirs, wetlands, etc.

Before criteria are developed, however, research needs to occur that addresses the following key research questions:

- What are the most appropriate assessment methods and endpoints or thresholds for assessing the effects of sediment/suspended solids in each of the high priority water bodies?
- What are the best sediment/suspended solids classification methods for high priority waters that aid criteria development?
- What are the best approaches for establishing sediment and suspended solids reference conditions?
- What are the best methods for establishing sediment/suspended solids criteria?
- What are the stressor-response relationships when sediment/suspended solids are associated with toxic chemicals, nutrients, metals, alterations in temperature, dissolved oxygen (DO), etc.?

Ultimately a number of different approaches can be used to develop criteria. Theoretically these approaches can address one or more of the following: reference conditions, dose-response, habitat-hydrology, geomorphology, and function. Mr. Swietlik expects that criteria for aquatic life will need to address the water column (via TSS, turbidity, etc.) and bed condition (via embeddedness, bedload, etc.). He also expects that the criteria for aquatic life may include biocriteria or a habitat factor. Criteria for designated uses (e.g,. recreation, drinking water, industrial water, and agricultural water) and shipping will need to account for water column characteristics (via TSS, turbidity, etc.) and deposition/accumulation, respectively.

The USEPA Office of Research and Development (ORD) and National Health and Environmental Effects Laboratory (NHEERL) need to provide criteria research support in order to advance criteria development. In addition to a "state-of-the-science” review of available suspended sediment issues/procedures, USEPA applications also need to be undertaken. OW plans to draft the OW Criteria Strategy and submit it to the Science Advisory Board for review by June 2003.

Currently the development of effective water quality criteria is the highest priority for USEPA. In addition to evaluating controls and BMPs, USEPA also needs to focus on developing translator procedures for interpreting narrative criteria, methods for monitoring ambient conditions, and methods, models, etc. for estimating source, transport and fate.

2.2 Regional USEPA Sediment Issues and Approaches

2.2.1 Challenges of Clean Sediment TMDL Development—A Practitioner's Perspective

Bruce Cleland, USEPA Region 10

According to sediment TMDL survey results (Sullivan, Zabawa, and Shippen 2001), a wide range of approaches are used for sediment TMDLs. Although there is an array of methods available, Mr. Cleland encouraged the participants to look for common techniques that utilize a "bottom-up" approach. He also stressed the importance of targeted activities (e.g., reduction estimates) and timing, particularly with respect to watershed conditions, contributing areas, and delivery mechanisms. A number of regulatory considerations also need to be considered during TMDL development, including applicable WQS, loading capacity, source assessment, allocations, seasonal variation, and safety margins. Ideally, a practical approach, involving a problem solving framework, needs to be employed when developing a TMDL. This approach needs to consider why sediments are a concern, what reductions are needed, the locations of the sources, who needs to be involved, and when actions will occur.

Why the Concern?

When assessing why sediments are a concern it is important to consider the nature of the aquatic resource (e.g., stream, estuary, etc.) and its beneficial uses (e.g., to human health, fish and aquatic life, and recreation). This analysis will help identify key indicators of the water body's condition with respect to sediments including the water column, the sediment, aquatic organisms, flow, channel characteristics, and riparian conditions. Ultimately, this examination will help define targets or applicable WQS that are "free from suspended solids and other substances that enter the water as a result of human activity and settle to form objectionable sludge deposits, or that will adversely affect aquatic life" (OAC 3745-1-04). If done correctly, an indicator for water quality (e.g., secchi disk depth, percent eroding stream banks, or TSS) can be related to specific rationales (e.g., lake clarity, sediment source, or local fishery).

What Reductions Are Needed?

One of the biggest challenges faced when attempting to determine what reductions are needed is the fact that although there is a wide array of concerns, time, data, methods and resources are limited. As a result, identifying sediment sources is essential.

Identifying Sediment Sources

When identifying a sediment source, it is important to consider how disturbances (e.g., from land management) directly effect basic watershed processes (e.g., hydrology, vegetation, and erosion) and directly and indirectly effect source inputs (e.g., water, sediment, wood, chemical, biological, or energy). It is also important to look at how changes in source input will effect the key indicators.

In addition to determining what sources contribute to the problem, project personnel should identify how the sources should be grouped, identify technical/practical factors that affect analysis, define background or natural conditions, and determine how allocations will be expressed. Assessment methods that can be used to identify a sediment source include indices (e.g., for vulnerability and future erosion), erosion models (e.g., source loading and source loading and delivery), and direct estimation (e.g., sediment budgets, rating curves, and statistical extrapolation).

Who Needs To Be Involved?
It is important to consider who will be responsible for implementing or be impacted by possible control measures when identifying who needs to be involved in the TMDL process. For example, a number of agricultural activities can be seen as opportunities for sediment release or control, including nutrient application, pesticide application, grazing, irrigation, erosion and sediment control, and animal feeding.

General Approaches to TMDLs
A number of general approaches can be used to develop clean sediment TMDLs including empirical relationships (e.g., rating curves and comparisons of turbidity and TSS), models, sediment budgets, and load duration curves.

<u>Empirical relationships</u>
Empirical approaches (e.g., rating curves) to developing a sediment TMDL rely on the existence of sufficient water quality data to adequately describe important relationships. Often these techniques focus on instream indicators (e.g., an allocation expressed as a percent TSS reduction will be developed for turbidity based on correlations between turbidity and TSS data). Applying rating curves to different channel classes and then relating this information to biologic conditions is also a useful approach. Sites where empirical relationships were used to develop sediment TMDLs include the Lower Yakima and Nutrioso Creek. Additional information can be obtained about these sites at www.tmdl.net.

<u>Models</u>
Common modeling approaches include the Universal Soil Loss Equation (USLE)/Revised Universal Soil Loss Equation (RUSLE), HSPF, WCS, the Agricultural NonPoint Source Model (AGNPS)/Ann-AGNAPS, and SWAT. In addition to requiring climate, hydrology, land cover, erosion, and channel data, often these models require geographic information system (GIS) data/coverage and modeling expertise. Model users need to remember, however, that models are tools, not solutions. Not only do models not always yield a credible result, but both the users and the public need to understand how the model results were derived. It is also important to avoid the "paralysis through analysis" syndrome. Sites that used models that were used to develop sediment TMDLs include the Earlakill Run and Stekoa Creek. Additional information can be obtained about these sites at www.tmdl.net.

<u>Sediment Budgets</u>
Rapid sediment budgets are order of magnitude estimates that can be determined using a watershed analysis framework to identify hazard areas, examine delivery mechanisms, and assess where materials that affect beneficial use are entering the stream.

Simpson, WA
A rapid sediment budget was coupled with a bottom-up approach during the development of a sediment TMDL at a site in Simpson, WA. This TMDL was linked to the development of a habitat conservation plan for this 261,000-acre site. The habitat plan was developed to address the listed salmon issue and covered 1,400 stream miles.

Although the site was on the 303d list for temperature, this was only one symptom surrounded by many other concerns and relationships (e.g., solar radiation, shade, road and hill slope failures, etc.). The conservation plan, which focused on riparian management and erosion control, used a channel classification system. The habitat conservation plan included riparian reserves, a wetlands conservation program, road management, unstable slopes, and hydrologic maturity.

The channel classification system employed at the Simpson site used a two-tier landscape stratification approach. The first tier identified five lithotopo units within the 261,000 acre site based on the lithology and topography. The second tier identified 49 channel classes along the 1,400 mile stream. The channel classes were then used to develop seven dominant groups representing the processes that affected temperatures, including sediment.

In order to develop the sediment TMDL, key relationships related to the erosion process (e.g., mass wasting, surface erosion, channel transport, and floodplain storage/bank erosion) were analyzed. A rapid sediment budget was developed based on USGS data and targets/ allocations (that were linked back to a management activity) and on the project geologist's expert opinion regarding what could be controlled. The resulting targets were tied to erosion control efforts and linked to the sediment delivery targets. Although the company was committed to spending 500,000 dollars per year for road maintenance and abandonment, approximately 100,000 dollars is also being spent each year on monitoring, in part due to uncertainties associated with data gaps. Thus an adaptive management approach is being employed at this site involving landslide assessment and sediment monitoring.

Agricultural Issues

When load reduction estimates are developed for agricultural areas, source areas and delivery mechanisms need to be assessed with respect to possible erosion control opportunities (e.g., gully stabilization, bank stabilization, agricultural fields, and filter strips). Table1 lists various targeted activities associated with different erosion controls. This table also contains methods for calculating sediment load reductions from the different erosion control activities. It is also important to consider the following "challenges" to performing load reduction estimates: 1) total eroded volume versus suspended sediment; 2) site versus watershed area; and 3) channel storage (e.g., legacy sediments).

Table 1. Targeted Activities Associated with Different Erosion Controls

Gully Erosion		**Channel Erosion**		**Agricultural Fields**	
Targeted Activities	Calculation*	Targeted Activities	Calculation	Targeted Activities	Calculation
Grade Stabilization Grassed Waterways Critical Area Planting Control Basins	Gully Dimensions Formation timeframe	Trails & Walkways Channel Stabilization Bank Protection	Channel Dimensions Lateral Recession Rate	Residue Management Crop Rotation & Cover Critical Area Planting Strip Cropping	Contributing Area Delivery Ratio

*"Calculation" refers to methods that can be used to determine sediment reductions.

Load Duration Curves

Kansas has been using load duration curves as part of its TMDL development process for a number of years. Load duration curves can support a “bottom-up” approach through enhanced targeting. In addition to providing a context with which to interpret monitoring data, duration curves also help guide implementation by identifying targeted participants, programs, activities, and areas. For example, when a load duration curve is examined with respect to watershed conditions (hydrologic), it may be possible to identify targeted participants (e.g., point sources) by plotting *e.coli* data. When the load duration curve is examined with respect to contributing areas, project personnel may be able to identify targeted programs (e.g., programs concerned with riparian buffers like CRP) and targeted activities (e.g., contour strips or conservation tillage). It is also possible when a load duration curve is examined with respect to delivery mechanisms that project personnel will be able to identify targeted areas (e.g., streambank erosion or bank stability).

Problem Solving Framework

Adaptive Management

Adaptive management plays a key role in the implementation process for achieving load reductions. Using a value added "bottom-up" approach, TMDL development occurs using “best available data." Progress towards achieving load reductions are periodically assessed through phased implementation with measurable milestones. If data gaps exist, the missing data can be collected, analyzed, and incorporated into a watershed plan (if appropriate) without holding up the watershed plan. The focus of an adaptive management approach is to achieve cumulative reductions in loading.

Public Involvement

Public involvement is fundamental to successful TMDL development and implementation. Although an enormous effort, time, and resources may be needed to achieve meaningful participation, a genuine commitment to listen, consider, and utilize citizen input is very important to TMDL development. It is also a challenge to explain technical concepts and information in “plain English.”

Clean Sediment TMDL

Mr. Cleland closed by noting that an effective "clean" sediment TMDL will target problems, have a geographic focus, and consider environmental results. Participants interested in more information on this subject were encouraged to visit the America’s Clean Water Foundation website at http://www.acwf.org

2.2.2 Landscape Approach to Managing Agricultural Nonpoint Source Sediment

Thomas Davenport, USEPA Region 5

Agricultural activities and hydromodification are the leading source of sediment to rivers, streams, lakes, ponds and reservoirs. Municipal point sources and urban runoff/stormwater are the leading source of sediments to estuaries.

Agriculture impacts stream hydrology and chemistry through a number of different mechanisms. In addition to increasing erosion and siltation, farming and livestock grazing is often responsible for introducing nutrients, pesticides, and bacteria to nearby streams. Irrigation practices also impact stream hydrology in a number of different ways. Not only is water diverted from other basins, but often streams are channelized in order to serve as irrigation canals. Riparian forests are also often removed by agricultural operations.

The leading water pollutants are listed below by water body type and relative impact:

- Rivers and streams—Siltation, pathogens, and nutrients
- Lakes, ponds, and reservoirs—Nutrients, metals, and siltation
- Estuaries—Pathogens, organic enrichment, and metals

In general, a stream can be divided into three different zones along its longitudinal profile; upland/headwaters, transitional, and riparian. The first zone contains the headwaters and is typically where most sediment problems start. Sediment problems, however, are usually observed in the downstream zones, where sediment transfer and deposition occur. Typically flow, sediment, and channel size characteristics change with each zone.

Table 2 compares the goals, measures, and results of administrative and resource management approaches. As this table indicates, ideally a resource management outcome-based sediment approach should be employed.

Typically BMPs are implemented according to a hierarchical approach associated with the scale of the area to be addressed (i.e., watershed, community, subwatershed, or parcel). The management zones are based on the watershed boundary, proximity to a water body, and an integrated pollutant source and transport approach. Upland areas are typically managed to realize source reduction control (SRC). Transitional areas are managed in order to achieve SRC and to disrupt pollutant transport (DPT), often through the use of structural solutions. Riparian zones employ SRC, DPT, and sediment treatment approaches. Since technology-based approaches have not been developed to control non-point sediment sources, management approaches need to be used to ensure that SRC is occurring in each of the landscape zones.

Table 2. Outcome Based Management Approaches

Parameter	Administrative	Resource
Goal	Program performance	Environmental performance
Measure	Administrative actions	Indicator end-points
Result	Improved programs	Programs that are tools to improve the environment

Source reduction can be realized by employing a system approach (e.g., CORE 4) or establishing a pollutant of concern or a maximum pollutant production period. Table 3 contains a comparison of reductions in residue cover loss and water erosion associated with different tilling practices during corn and soybean farming. In both cases no-till agriculture experienced the most significant soil erosion reductions. Data from Sycamore Creek suggest, however, that land management factors affecting the riparian zone may have an equal or greater effect on suspended solids loads in Grand River Tributaries than no-till.

After noting that fields are typically planted for average conditions and that planting practices are determined by soil productivity, not water quality, Mr. Davenport noted that it is important to determine how much it would cost to get rid of the extra nitrogen that is applied as "insurance" by farmers. He then commented on the disconnect that exists between what happens at the edge of a field and potential column impacts. According to Mr. Davenport, this disconnect needs to be addressed in order to support the adoption of new BMPs. The off-field impacts of changes in land use also need to be addressed. He then cautioned that although riparian management can lead to significant sediment reductions, the rewards provided to farmers and other landowners for realizing these reductions are limited.

Table 3. Reductions in Residue Cover Loss and Water Erosion with Tilling Practices

Tillage	**Corn Residue (Nebraska)**		**Soybeans (Nebraska)**	
	Residue cover % Soil loss	Water erosion reduction (%)	Residue cover % Soil loss	Water erosion reduction (%)
Moldboard	7-7.8	---	2-14.3	---
Disk, plant	21-2.2	72	8-10.6	26
Chisel plow	35-2.1	74	7-9.6	32
Rotary-till	27-1.7	76	NA	NA
Till-plant	34-1.1	86	NA	NA
Field cultivate	NA	NA	18-7.6	46
No-till plant	39-0.7	92	27-5.1	64

NA = Not applicable

2.2.3 USEPA Region 4 Multi-Level Sediment TMDL Approach

James M. Greenfield, USEPA Region 4

Sediment TMDLs need to be developed that maintain state WQS. In addition to being technically defensible, these TMDLs need to focus on implementation and be accomplished within the available time frame and resources. The resulting TMDLs need to target stream biology and habitat goals which vary by ecoregion or watershed size. The protocols or procedures developed during these efforts will be based on actual Region 4 situations.

Ideally Region 4 would like to develop technically complex approaches with limited uncertainty. Due to time and budget constraints, however, the Region has had to prioritize TMDL development based on ecological and economic importance, court order deadlines (e.g., normally 5 to 8 years), and the availability of usable data. The result is a multi-level approach designed to identify water quality targets, major sources and their spatial location, and readily available data and additional monitoring needs. The goal of this approach is to allow implementation to start in a focused manner by identifying percent reductions needed for major sources. There are currently 4 levels of TMDL development:

$ Level 1: Watershed based sediment TMDLs which include average annual loads and locates and IDs major sources
$ Level 2: Improved water quality target
$ Level 3: Instream sources and BMPs
$ Level 4: Detailed watershed modeling

Level 1: Watershed TMDL Development
During a Level 1 TMDL effort the Region seeks to identify the allowable sediment delivery to stream (e.g., how much sediment is too much), where the sediment coming from, and the major sources. In order to answer these questions, Region 4 has partnered with the USFS, Region 8, NRCS, and Georgian Forestry and Agricultural Agencies under the Joint Southeastern Regional Sediment Project. The Joint Southeastern Regional Sediment Project was formed in response to lawsuits associated with USFS practices. A sediment tool was developed using the USLE. This tool was based on a GIS ArcInfo tool developed by USFS Coweeta Research Lab.

The goal of the sediment model was to:

$ Calculate potential source erosion from land uses and roads using GIS spatial data sets.
$ Calculate potential sediment delivery to streams.
$ Evaluate effects of land use change, BMP implementation, and road network on erosion and sediment delivery.
$ The model was also designed to be intuitive and easy to use.

The resulting sediment tool was an ArcView GIS extension of the Watershed Characterization System (WCS). (Note: WCS characterizes physical and hydrological properties, evaluates ambient water quality conditions, and assesses potential sources of impairment.) Land use, soil, road, stream, and BMP data are entered into the WCS/Sediment Tool. Erosion maps, sediment delivery maps, sediment delivery to assessment points, and automated reports (maps and tables) can be developed using the WCS/Sediment Tool.

The following steps are performed when developing a sedimentation TMDL using the WCS/sediment tool:

$ Identify eco-region stations (Level IV) by running the sediment tool on contributing watersheds and defining eco-region target sediment loads
$ Run sediment tool on all 12-digit Hydrologic Unit Code (HUC) within 8-digit HUC in order to establish existing annual average nonpoint loads
$ Establish existing annual average point source loads (typically less than 10 lbs/acre/year)
$ Identify percent reductions based upon reference watershed targets by eco-region

A future project is currently planned that will run the sediment tool using base data for each 12 digit (or similar) HUC for the various ecoregions. The goal of this project is to identify the unimpaired watersheds using biological and habitat data and identify any patterns.

Level 2: Improve Sediment Target
The ARS Oxford Sediment Laboratory National Project has used historical data to develop flow versus sediment curves for stable and unstable streams and has generated at least two papers addressing the development of ecoregion sediment flow relationships:

$ "Referenced" and "Impacted" Rates of Suspended Solids Transport for Use in Developing Clean Sediment TMDLs.
$ Development of Linkages Between Sediment Load and Biological Impairment for Clean Sediment TMDLs.
$ Estimates of effective discharge have also been developed by the ARS Oxford Sediment Laboratory National Project. Effective discharge, which is an integration of flow frequency and sediment transport (load), approximates discharge at the 1.5 year flow.

Flow versus sediment curves are developed for various streams, both stable and unstable, in each ecoregion during a Level 2 TMDL effort. Currently Region 4 plans to develop curves for Level 3 ecoregions and also sediment concentration ranges for various flow conditions. The Region also plans to calibrate delivery (e.g., annual load) obtained using the Sediment Tool to the sediment curves.

Level 3: Instream Process
Typically a stable river channel contains a healthy habitat and biology, transports an appropriate amount of sediment, and is not subject to incising or widening. An unstable river channel, on the other hand, typically contains a poor habitat and biology, produces excessive sediment, and experiences incising. During a Level 3 TMDL effort, project personnel attempt to predict how changes in flow and sediment load, instream alterations, and BMPs may impact stream stability.

A number of models are currently available that can be used to predict impacts on stream stability including:

$ EFDC sediment model, which may only be appropriate for large rivers.
$ QSTARS 2.1 (Bureau of Land Management, or BLM).
$ The Conservation Channel Evolution and Pollutant Transport System , or CONCEPTS (ARS), which is a promising model which evaluates flow changes, BMP impacts (instream dams), and sediment changes. It also predicts stream changes and identifies when a stream will become unstable.

In general, channels respond to hydrologic changes, changes in sediment loadings, and man-made changes. Typically channels adjust vertically via scour and aggregation and horizontally via widening migration. Conceptual channel evolution models include Schumm et al. (1984) and Simon (1989).

Sediment transport rates, on the other hand, are a function of flow hydraulics, bed composition, and upstream sediment supply. Typically sediment deposited on or scoured from the bed changes bed composition, flow hydraulics, and fractional transport rates. In general, transport, deposition, and erosion of cohesive sediments are extremely complex. Although erosion resisting forces vary according to grain size and electrochemical bonding between particles, bonding is also affected by local history of soil development and antecedent soil moisture conditions. Also, sediment transport capacity equals sediment load under equilibrium conditions, that is uniform flow and E=D.

During streambank erosion channel-width changes occur within a wide variety of geomorphic contexts. Since the channel adjustment process displays a wide variety of spatial and temporal patterns, equilibrium approaches are unlikely to accurately predict width adjustment over time. In general, the fundamental processes responsible for bank retreat include hydraulic erosion and mass bank failure.

Level 4: Watershed Models
A number of detailed Level 4 watershed models are currently available including:

- Annual AGNPS, which is currently being tested in Jame Creek, Mississippi by the Mississippi DEQ and ARS Sedimentation Laboratory
- HSPF, which will not work for loading sources because it is not spatial
- SWAT
- Updated Sediment Tool

Sediment Data Collection
The collection of sediment data has been prioritized by Region 4's Science and Ecosystem Support Division (SESD). In addition to collecting biological and habitat data for listing decisions and to identify impaired and unimpaired waters, the sediment and flow relationship data are also being collected for stable/unstable streams and ecoregions in order to develop flow versus sediment relations by ecoregion and effective flow. The Region is also performing stormwater/wet weather sampling.

ARS in Oxford, Mississippi is a national project which is developing sediment flow relationships using USGS historic data. USEPA Region 4 just recently funded a field effort to determine if streams with available data (e.g., 66% for Region 4) are stable or unstable. Qualitative observations and stream slope and particle distribution measurement will be used to evaluate stream stability.

2.3 Open Discussion

Steve McCutcheon (USEPA NERL) asked about the quality of the data obtained with Healy-Smith bed load samplers and how much training the USGS invests in ensuring that staff hydrogeologists are able to competently use these samplers. After noting that the Federal Interagency Bed Load Project promotes two different types of standardized bed load samplers, the Healey-Smith and BL-84, John Gray (USGS) noted that all samplers have limitations. Since both the BL-84 and Healy-Smith samplers have 3-inch diameter intake nozzles, they can only be used to collect sediments that are less than 3 inches in diameter. Also, not everyone agrees the samplers should be used for sand bed systems.

Operator error is also considered by many to be the single greatest variable in bed load measurements. In general, individuals are considered trained and allowed to collect data in the field on their own after they have completed a 1-week USGS training course and then worked with a trained individual for a couple of months. The amount of training needed for proficiency is largely dependent, however, on the nature of the system being sampled (e.g., how "flashy" it is) and the nature of the data to be produced (e.g., instant observations or data for calculating annual bed load transport).

Susan Cormier (USEPA NERL) questioned whether the Colorado Department of Public Health and Environment (CO DPHE) is using existing data to develop standard expected values for classifying streams. Robert McConnell (CO DPHE) confirmed that this is being attempted for biologic criteria, and that CO DPHE hopes to apply this to the sediment guidance. It is currently attempting to define expected and reference conditions.

In order to help set research priorities for the ORD over the next 8–10 years, Steve McCutcheon asked for input from James Greenfield (USEPA Region 4) about the different levels of TMDL analysis planned for Georgia and the Southeast. In Steve McCutcheon's opinion, a Level 1 analysis is a fairly simplified, spreadsheet-like approach, while a Level 4 analysis is a fairly complex process, involving Environmental Fluid Dynamics Code (EFDC) and sediment transport models. According to Dr. McCutcheon, a Level 4 analysis is used to assess a fairly complex problem (e.g., identifying the upland source of sedimentation to an estuary), and Level 2 and 3 analyses use methodologies similar to those being explored by Dave Rosgin and Andrew Simon. James Greenfield responded that given current constraints on state and regional budgets and schedules, approximately 80% of the first round of TMDLs performed over the next 5 years will utilize relatively simple (Level 1) approaches, 5% will be fairly complex, and 15% will probably range somewhere in the middle. He also clarified that, in his opinion, a Level 4 analysis would be used for smaller watersheds and would involve a detailed watershed and instream models. Also, most of the sediment problems identified in his region are associated with Level 2 or 3 streams, not estuaries. He also expects that, in general, a Level 1 analysis will be initially performed at most of the areas of concern, and that public opinion will determine whether a more complex effort follows.

Thomas Davenport (USEPA Region 5) encouraged ORD and OW to research and develop Level 4 analysis techniques over the next 8–10 years. According to Mr. Davenport, Region 5 will probably need to focus on Level 4 problems after it has taken care of the relatively major, but often simpler, lower-level problems (e.g., roads). James Greenfield also agreed that ORD should focus on developing tools to support more complicated levels of analysis since the regions and states are already developing the simpler Level 1 analytical techniques. He also expects that some of the sites that will undergo a Level 1 analysis in the next 5 years will also eventually go through a higher-level analysis.

After noting that much work needs to be done, Dale Bucks (USGS) encouraged participants to actively search for research partnerships and opportunities for collaboration. He then encouraged ORD to partner with the USDA ARS and to work from the bottom up to develop partnerships. Bruce Cleland (USEPA Region 10) then added that although he supported OW research efforts, he cautioned that those individuals responsible for conducting TMDLs are lucky to get 1 to 2 years to dedicate to a project. He also supported the importance of working from the bottom up and cited as an example how he developed a relatively crude sediment budget by comparing old USGS sediment transport data to landslide inventory and hill slope failure data.

Doug Norton (USEPA OW) then noted that Region 4 and Region 10 probably had more modelers working on their TMDL programs than many of the other regions. Thus, he encouraged ORD to develop some low-end analytical tools (e.g., spreadsheet approaches).

In response to Steve McCutcheon's request for state input on setting sediment research priorities, Mary Skopec (Iowa DNR or IO DNR) noted that although some of the states have staff that are capable of running the models, state staffs are limited. She then noted that many practitioners are experiencing "model overload" and have difficulty choosing from the available techniques to address an issue. Often there is a tendency, when trying to fill data gaps in an existing approach, to abandon the current approach and start over with a new approach. In response to Joseph Schubauer-Berigan’s (USEPA NRMRL) question regarding how data are obtained for parameterizing these models given state resources, Ms. Skopec noted that much more money has been put into the ambient program than the TMDL program. Since TMDLs need to be developed quickly, often data are used in models before good historical benchmark information is available.

Robert McConnell addressed Steve McCutcheon's request for input by noting that ORD should focus on developing criteria to protect designated uses and develop sediment standards. Also, although Colorado has staff that are able to use models, the staff could benefit from obtaining technical support (training, help) from USEPA. He also noted that Colorado leverages support from various stakeholder groups (e.g., universities) for some of its modeling efforts.

In response to Mr. McConnell's request for input on future clean sediment standards, Bill Swietlik (USEPA OW) responded that USEPA has invested significant resources towards developing nutrient criteria over the past 3 to 4 years. When this effort ends, in approximately the next 1 to 2 years, these resources will be transferred to clean sediment efforts. Hopefully, clean sediment criteria and standard procedures will be developed within the next 3 to 5 years that states can use to develop new TMDLs and examine established TMDLs. If a reference condition approach is used, however, USEPA cannot and will not be able to establish national sediment criteria, and states will have to develop clean sediment criteria on a classification unit-by-unit basis. Mr. Swietlik is looking for input from participants that would allow him to avoid having states develop these criteria using a reference condition approach.

Dale Bucks noted that although the NRCS has considerable technical expertise at the regional level, he expects that models will be developed and implemented by the agricultural community at the state and multi-state level. He encouraged states to work cooperatively in order to develop techniques to address watersheds with greater levels of impairment. Rather than relying on national or regional sources, he believes that states need to focus on improving their abilities to communicate TMDL modeling advances.

Joseph Schubauer-Berigan asked for input from the panel regarding how the environmental community can advance to the point that it is no longer just reacting to a problem (e.g., solving the TMDL issue), but is instead focusing on preventing a release through structural and nonstructural efforts.

Chih Ted Yang (US Bureau of Reclamation) then discussed four critical factors related to the suspended sediment issue: 1) time lags, 2) holistic systems, 3) preventative versus reactive approaches, and 4) “expected” versus “reference” criteria. The time lag between when land use changes and when a response is seen in suspended sediment concentrations is a critical element for consideration during the study of TMDLs. It is also important to utilize a holistic approach when assessing a watershed, both geographically and from a process perspective. Instead of reacting to a problem, identifying the source of the sediment should be the focus. A monetary value should then be placed on the effect of the source. According to Dr. Yang, “expected” criteria is a more appropriate term than “reference” criteria since pristine rivers are difficult to find and/or categorize. He expanded on this point by noting that expected conditions, which he defined as being what can be expected to be observed under a specific man-made or natural condition, can be based on science and are more reasonable to target/identify. He closed by noting that all of these factors need to be considered as part of a holistic approach when developing TMDLs.

Steve McCutcheon cautioned that it might take 15 to 20 years for those working on TMDLs to stop functioning in a reactive mode. In the interim, however, it is necessary to start developing predictive or forecasting tools that will help prevent suspended sediment problems from occurring. After noting that mechanistic tools that enable description of processes need to be developed, he then mentioned Earl Hayter’s discussion addressing the use of tools to solve the TMDL problem and practical stream geomorphology models. According to Dr. McCutcheon, these mechanistic models will help in the design of a stream bank restoration or bioengineering effort. Eventually predictive methods will be used to forecast urban effects on stream geomorphology.

John Paul (USEPA NHEERL) then asked Mary Skopec whether she believed some of the problems with current approaches are due to the fact that researchers have failed to interact with state personnel. Mary Skopec replied that most of the difficulties encountered with newly developed approaches are associated with the difficulties scaling up from a small-scale research project to a state-wide, institutionalized effort. States rarely have access to a reliable supply of graduate student support and often lack the resources needed for these very data-intensive efforts. Although there has been some interaction with researchers during different projects and some attempts to identify organizational-specific constraints, more interaction needs to occur.

Andrew Simon (USDA ARS) then stressed the need to link data (e.g., hydrologic, sediment transport, etc.) with the designated use in order to tell whether a stream is impacted or impaired. During efforts associated with impaired streams, the Institute for Natural Systems Engineering (INSE, at Utah State University) has attempted to link historical sediment data obtained by the USGS at different sites to biological data obtained by the states. Unfortunately it has had many problems finding biological data for the sites. He then suggested that a database be developed that links flow, sediment, and other USGS data with the state databases. Mary Skopec cautioned that because states often randomly select sites in order to perform a biologic criteria assessment, they sometimes pick a site with no flow. After noting that biologic criteria data are usually collected at low or base flow conditions, Dr. Simon then noted that peak flow conditions are harder to estimate.

Andrew Simon then stated that national or statewide clean sediment criteria are not likely to be generated and that criteria will probably be developed that address Level 3 or Level 4 ecoregions. It is also possible that watershed-level clean sediment criteria may be generated. According to Dr. Simon, some preliminary targets that he has assessed (e.g., stable streams in different ecoregions across the US) have varied by 4 orders of magnitudes at different regions. He then noted that although achieving pristine conditions is a nice thought, it is not realistic to expect that streams can be restored or restrained to pristine conditions. Instead the attempt should be to return streams to a re-equilibrated state.

Dale Bucks was very interested in finding out whether a reference, equilibrated system accounts for base flow conditions and sediment loads that are historically expected. Andrew Simon responded that base flow conditions have been factored into the approach used to delineate an equilibrated system. They not only assess how much sediment an equilibrated stream transports, but also how much is natural for a stream in a particular ecosystem and how much is too much or too little.

Andrew Simon then noted that it is not possible, given time and monetary restrictions, to do detailed analyses on every stream requiring TMDLs. Thus he has tried to link empirical approaches (e.g., reference conditions based on stable channel geography) to the more complex modeling scenarios and channel evolution concepts in order to model the amount of sediment from the channel boundary and the flow of sediments from the uplands. He has attempted to use this information to identify BMPs capable of meeting targeted levels.

Chris Nietch (USEPA) noted the main problem discussed to this point relates to the need to develop a TMDL and then relate it to a system that is valued, whether this system is defined by an expected or reference criteria condition. Risk managers are very interested in how a TMDL is developed because they will eventually be responsible for bringing a system back to that level. Also, no matter how detailed the model used to develop the TMDL, there is a certain amount of uncertainty associated with the TMDL that is developed. In response, Dr. Nietch proposed that a project be conducted that can be used to identify a load reduction range (e.g., either sediment or flow) for any impacted stream. He then noted that even when risk managers bring a stream back to the designated criteria/level, the expected biological response is not always observed. Because biology is not deterministic, it is difficult to link sediment reduction to a biological goal. Thus a non-deterministic approach is needed for biological assessments.

After Bruce Cleland agreed that readily apparent biological responses should not always be expected, Chris Nietch stressed the importance of putting a BMP in place and then collecting biological data in order to assess the impact of the BMP. After Chris Nietch encouraged participants to perform field tests to assess biological impacts from the implementation of BMPs, Joseph Schubauer-Berigan noted that some of these studies have already been started in Wisconsin. Thomas Davenport then added that USEPA has intensively monitored 23 sites that are employing BMPs, and 4 of these sites have collected some relatively detailed biological data. Dale Bucks then noted that the EQUIP and CREP Programs are utilizing BMPs and that the agricultural community is always looking for opportunities to add a research element to these efforts. He then noted that multiple BMPs will be investigated by the agricultural community for both public and private lands when the Conservation and Security Program comes in place in 2004/2005.

Although Bill Barfield agreed that the sediment legacy issue is very important and that measurable changes are not always obtained after a management practice is utilized, ultimately he believes that it is a channel regime issue that is being dealt with, and this issue involves more than the erosion of previous deposits, but also includes changes in sinuosity, etc. After stressing that it may take a relatively long time for a change in sediment loads to lead to a measurable change, he noted that both the quality and quantity of the sediment load are changing. He also believes that the focus needs to be on the issue of the changing morphology.

Bill Barfield then noted that German researchers are more interested in identifying what an impacted stream can be and maximizing its biodiversity. During a recent stream restoration project, German researchers used engineering and other science-based principles to control the flow of a stream (e.g., riffles and pools) over a several kilometer stretch. When compared to a downstream area that had not been restored, the difference in the level of biota regeneration was significant. According to Dr. Barfield, it is important when developing TMDLs to consider what can be done to maximize biodiversity, rather than just letting the river take its own course. James Greenfield cautioned that before attempts are made to restore a stream, the watershed problem responsible for the sediment problem needs to be corrected. Richard Field (USEPA NRMRL) then pointed out that in addition to identifying sediment sources, pollutant availability per sediment yield needs to be examined. Since clean sediments are something of a misnomer, multi-stressor analyses should be performed that examine more than just sediments. Not only would this approach help avoid the application of competing controls, but it could also help managers select a BMP for erosion that may be capable of controlling another stressor. He then questioned whether pathogenicity was really the major issue being investigated. Perhaps the major issue is the search for indicator bacteria that risk managers will use to evaluate pathogenicity.

Although it is unrealistic to attempt to return a stream to pristine conditions, John Gray stressed that it is important to quantify pristine conditions so there is an endpoint for an asymptotic analysis. He then noted that the USGS has operated a hydrologic benchmark network involving 58 relatively pristine watersheds for approximately 30 years. Although it stopped collecting sediment data about 7 years ago, data from this network can be used to assess natural conditions.

Mary Skopec responded to Richard Field’s comments about BMPs and multi-stressor analyses by noting that there appears to be a disconnect between hydrologic efforts and sediment control efforts. Although many resources have been focused on building wetlands and utilizing BMPs to control sediment, more tiling has taken place in the last 5 years than previously, in the last 50 years. Regarding the use of reference conditions, Ms. Skopec suggested employing a gradient of disturbance approach that identifies how form and structure slowly change as a wetland rises up the gradient (from Level 1 to 6). She then noted that it is possible for a system to get some function back with a small change in form.

Bill Barfield then stressed that pristine conditions should not always be considered the ultimate goal. Although a pristine reference condition can be targeted for one channel, it may be preferable to target a reference condition associated with a design function for which the biodiversity exceeds the pristine condition for a different channel. Bill Swietlik then stressed that test sites need to be compared to a known benchmark or reference condition. An empirical data set is needed that can be used to represent a gradient of ecological conditions, from undisturbed/natural to impaired. According to Bill Swietlik, it is important to be able to determine how far a reference data set strays from the original, undisturbed/natural condition. It is also important to know how far the data depart from the benchmark trying to be achieved.

Bill Swietlik then noted that his office has started to focus on identifying the least disturbed condition, which is similar to the expected condition approach used in Colorado. This condition is derived from the least disturbed sites in the landscape. Although these sites may be different from the historically undisturbed/natural condition, as long as the level of departure is understood, a large amount of valuable information can be obtained from these sites. His office is also considering using “minimally disturbed” as a type of reference condition. Data from minimally disturbed sites in the wilderness would be used to develop this condition. He ended by noting that the objective under Section 101A of the CWA is to restore (where feasible) the ecological integrity of the nation's waters. He then noted that the CWA does not require that rivers be restored to pristine conditions, and that because citizens are allowed to determine the designated use of a river or water body, they often choose to restore a water body to a different condition than pristine. If good reference condition data are available, however, citizens are able to choose aquatic life designated uses to which a water body can be managed.

According to Tim Canfield (USEPA ORD) the issue is not whether a site is disturbed, but whether it is anthropogenically disturbed. Since biologic conditions are not static during natural conditions, an acceptable range of fluctuation for identifying biologic criteria needs to be included. When sediment reductions are achieved, this change impacts other conditions in the stream. When aquatic invertebrates are involved, however, multiple factors (abiotic, food resources, and competition) are responsible for initiating a change. Thus, when only one factor is changed (i.e., sediment concentration) an aquatic response may not occur.

Tim Canfield then noted that it is important to consider biological variability when setting criteria and identifying TMDLs, since the ultimate focus is on achieving certain biologic criteria and designated use rather than sediment reduction. Unfortunately, biologic criteria are very complicated and difficult to develop. As a result, sediment criteria are a relatively simple factor to focus on relative to biologic concepts. Ultimately, however, since the systems being dealt with are interconnected, it is difficult to expect significant improvement through changes in the sediment input and the addition of riparian zones, if at the same time drainage tiles are being run underneath these areas.

After noting that it is not possible to develop biologic criteria for that habitat if the habitat is not available, Joseph Schubauer-Berigan stated that there has to be some way to quantify the habitats that are currently available. Although efforts involving biologic criteria are complicated and affected by multiple stressors, it is necessary to start assessing these habitats and determine whether they are degrading.

Florence Fulk (USEPA NERL) then noted that it is possible to detect changes in biologic indicators with a relatively narrow range of variability. During a West Virginia study that targeted the impact of mountaintop mining and valley fill on biological integrity, the variability around the unmined sites for the overall index of integrity was ± 10 to 15 percent. In order to achieve these results, however, it is important to carefully define the response in the biological community and be able to distinguish between natural and anthropogenically induced changes. The measure of the variability itself can also be an indicator that a system is moving from an acutely impaired state to a less impaired state.

According to John Paul, if 305b and 303d of the CWA were implemented more effectively and coordination across these programs was improved, some current TMDL problems would disappear or become easier to handle. Dr. Paul suggested that the information collected for TMDL and ambient programs be coordinated. In response, James Greenfield cautioned that although it would be useful for ambient and TMDL programs to look at some of the same parameters and use the same methods, one program is not a substitute for the other. He then noted that since ambient programs look at status and trends and TMDL programs look at changes, different amounts and types of data are often collected for these two programs. Bill Swietlik then added to this discussion by noting that USEPA Headquarters (HQ) is currently developing draft guidance called Consolidated Assessment and Listing Methodology (CALM) that recommends that similar methods and approaches be used for different programs.

Dale Bucks stressed the importance of identifying better measurement techniques, whether it is cause or effect that is being measured. In some situations, sediment, chemical, and biological information need to be collected and, according to Dr. Bucks, this information needs to be put together in a comprehensive fashion. He also encouraged the participants to focus on identifying and using better drainage practices, rather than focusing on discontinuing drainage. He then noted that riparian areas do not work in the Midwest unless the drainage system is managed. He closed by noting shallow drainage has replaced deep drainage in the Midwest.

Chris Nietch then stressed developing process-oriented sediment reference conditions that are based on physics and physical processes. After noting that value judgments need to be made by the public when biological criteria are used, he then noted that biologic reference conditions do not have “scientific truth.” Joseph Schubauer-Berigan closed by noting that improvements in surface and subsurface agricultural drainage are needed and that hydrology is a critical factor that can be lost when personnel become immersed in a model.

2.4 State Sediment Issues and Approaches

2.4.1 Protocol for Establishing Sediment TMDLs in Georgia

David Radcliffe, University of Georgia (UGA)

TMDLs are being developed in Georgia in response to a federal consent decree. These TMDLs are being developed on a 5-year rotating-basin schedule and the first rotation is due to be completed by 2003. Of the 625 Georgia TMDLs, 77 are sediment TMDLs.

In 2000 the Georgia Conservancy and UGA formed a Technical Advisory Group (TAG) for sediment TMDLs to develop a protocol for establishing sediment TMDLs in Georgia using the best available science. The TAG is composed of over 40 scientists from various state and federal agencies and universities. In February 2002 the TAG released a white paper on the Georgia Conservancy web site (www.georgiaconservancy.org) containing background information relevant to sediment TMDLs and the TAG's recommendations.

The federal government does not currently have a numeric WQS for sediment. Since Georgia also does not have a numeric standard, it currently uses the following narrative WQS: "To maintain biological integrity of the waters of the State." In general, streams that are placed on the TMDL list for sediment have low biological integrity survey scores which are attributed to a sediment problem.

The Biological integrity surveys are performed by the Georgia Wildlife Resources Division (WRD) using the Index of Biotic Integrity (IBI). IBI measures fish community structure and function. Although in general a high IBI score indicates a healthy, diverse fish community, there is some question regarding whether a low IBI score is directly related to sediment load.

Suspended sediment and turbidity

Sediment has historically been measured in terms of SSC or TSS, although turbidity has recently been used as a surrogate for SSC. Topically, SSC is measured in units of milligrams per liter (mg/L) and turbidity is measured in units of nephelometric turbidity units (NTUs). Although turbidity and SSC are correlated, however, they are not necessarily equal.

In general, SSC usually increases with streamflow (Q). Sediment rating curves are used to predict SSC as a function of Q. These log-log plots have suspended solids concentrations on the y-axis and normalized discharge (Q/Q_0) on the x-axis.

Many Piedmont streams received large inputs of sediment during the 19^{th} and early 20^{th} centuries. Since much of this sediment is still stored in stream banks and beds, state personnel are not clear whether stream impairment is due to current or historic sources. They are also not sure what should be done if the historic sediments are responsible for the impairment.

IBI and base flow SSC/turbidity

Several studies have shown a relationship between IBI and SSC or turbidity measured under base flow conditions. During the Etowah River basin study (Leigh et al., 2001; Walters et al., 2001) 31 tributaries were selected as representative of the Piedmont physiographic region. During this UGA study, which was funded by USEPA, IBI data were plotted against SSC and turbidity data to provide information on the relationship between the physical parameters and SSC and turbidity. The SSC and turbidity data used during these analyses were the geometric means of 5 measurements obtained at the same time.

The results of this and other IBI and base flow SSC/turbidity studies indicate that it may be possible to identify impaired streams by base flow SSC and that base flow SSC can be used as a surrogate for total sediment load. High base flow SSC is also indicative of high storm SSC. IBI and base flow SSC/turbidity data can also be used to distinguish between streams with historic and current sediment sources. Since fine sediments from historic sources probably flushed out of a stream long ago, these sediments would not be suspended under base flow conditions. Thus only historic sources would have low base flow SSC.

TAG Recommendations

TAG generated recommendations on the following topics:

$ Listing of water bodies
$ Load determination
$ Daily versus annual loads
$ Load allocation to construction sites
$ Historic sediment streams
$ Implementation plans
$ Monitoring requirements
$ Research requirements

Priority Listing of Water Bodies

Streams listed with only limited sampling or borderline survey values should be placed on the preliminary list and additional monitoring should be used during Phase I to confirm or deny impairment. In order to avoid indefinite stays on the preliminary list, a stream should be placed on the final list if sampling is not accomplished within 5 years.

Load Determination

Reference streams, which are representative of an eco-region and subject to minimal human disturbance, should be used to determine the TMDL sediment loads for impaired streams. Rating curves, monitoring, and sediment budgets can be used to determine sediment load in a reference stream.

If no reference stream is available, a target SSC_0 approach should be used to determine the TMDL sediment loads for impaired streams. Although under base flow conditions a SSC that is less than 10 mg/L is protective of fish habitat, the maximum sediment load (TMDL) can be calculated using the following formula:

$$TMDL = SSC_0 \bullet Q_0 \bullet \beta$$

Where,

SSC_0 = Estimate of the target long-term average SSC for protective stream.
Q_0 = Estimate of long-term average discharge.
β = Estimate of the rating curve bias factor.

Q_0 can be estimated using gaging station data for an impaired stream and can be based on the watershed area. β values are usually 1–3 (no units)and can be calculated exactly from a rating curve. It is important to remember, however, that mean annual load is not the simple product of mean annual Q and mean annual SSC (SSC_0). Finally, a range of 20–30 mg/L is recommended for the target SSC_0. In general, the target SSC_0 is adjusted up from 10 mg/L to account for Q_0 > average base flow Q. This was the most contentious issue for TAG and applies only to Piedmont, Blue Ridge, and Ridge and Valley physiographic regions.

Daily Versus Annual Loads
A TMDL should be expressed as an annual and daily load if possible since there is considerable uncertainty in daily load. Not only does the daily load vary with flow, the target SSC_0 approach only gives the daily load for approximately base flow conditions. Also, the reference stream approach with rating curve gives load at any flow.

Load Allocation to Construction Sites
Point-source allocation should include construction sites with more than 5 acres. Not only should each site require a National Pollutant Discharge Elimination System (NPDES) permit that specifies load allocation to site, but the sum of all permitted point-source loads (including construction sites) should not exceed total load allocated to point sources.

Historic Sediment Streams
The maximum practical limitations should be imposed on current inputs for streams where historic inputs are the primary source of impairment. Practices such as riparian buffers should be used to stabilize historic sediment sources. Storm water energy inputs should also be minimized.

Implementation Plans
TMDL implementation plans are critical to TMDL success. Given time the constraints in Phase I implementation plans will have to be developed separately in Georgia. At this point TMDL implementation is being considered as the subject of a new TAG and white paper.

Monitoring
Follow-up monitoring is a key component of TMDL process. Follow-up monitoring should include biological (IBI) and physical (SSC or turbidity) measurements and fish and invertebrate biological assessments. It is also important to determine how SSC or turbidity is affected by Q and to consider bed characteristics.

Research Needs
The relationship between biotic indices, SSC, and other physical parameters need to be identified in reference streams identified by WRD and USEPA in each ecoregion of Georgia. Standards for acute (storm driven) sediment loads, reference conditions based on bed characteristics, estimation techniques for sediment budgets, and methods to derive MOS from model uncertainty are also needed.

Concluding Remarks
Dr. Radcliffe closed by noting that Georgia plans to form two new TAGs for TMDL implementation planning and a protocol for bacteria TMDLs in August 2002. He then stressed that the TAG process successfully engaged the academic scientific community.

2.4.2 Sediment Monitoring in Iowa

Mary Skopec, IDNR

Ms. Skopec opened by noting that her presentation addresses the following topics: 1) Iowa's Water Monitoring Program, 2) the importance of sediment monitoring to Iowa, 3) the challenges of sediment, and 4) current and proposed activities.

Prior to 1999 no State money was spent on sediment water quality. In FY 1999 and FY 2000, 1 million and 2 million dollars, respectively, were appropriated to sediment water quality issues. In FY'01, FY'02, and FY'03 this rose to 2.5 million dollars. The driving force behind these allocations was a lack of information for setting appropriate TMDL standards and developing endpoints and expectations. Table 4 lists which water resources are prioritized in Iowa and the different program elements associated with that resource. Pathogens are also a high priority in Iowa.

Iowa's Water Monitoring Program

Iowa's Ambient Water Monitoring Program monitors water in surface waters, lakes, beaches, groundwater, wetlands, and cities (upstream/downstream). Biological (fish / benthic macroinvertebrates) and precipitation data are also collected. Although funding is available, staff are limited. As a result, this program utilizes volunteer monitoring support (IOWATER). Also, data management is done via STORET.

Surface Water Monitoring

Surface water monitoring is performed at 62 fixed ambient sites and 23 upstream/downstream sites in 10 cities. Monitoring is performed on a monthly basis or longer. Common water quality parameters, nutrients, bacteria, common herbicides, and priority pollutants (April-July) are monitored. Biological monitoring, which is a relatively new addition to this effort, takes place at 16 long-term sites and 225 random locations/times over a 4-year period. Because staff are limited, this program relies heavily on contractor labor, particularly from the University Hygienic Laboratory.

Table 4. Water Resource Priorities and Program Elements

Priority	Resource	Program Elements
Very high	Interior rivers	Coordination Data collection Database management
High	Border rivers Groundwater Lakes Small streams	Data access Data interpretation Public information Verification/follow-up
Moderate	Beaches Precipitation Wetlands	Citizen monitoring Emerging issues Fish tissue Impaired waters Permitted facilities Targeted source types

Lakes

Currently 132 recreational lakes are monitored under this program. Physical, chemical and biological data are collected three times a year for 5 years from each lake. After noting that Iowa is currently attempting to "dovetail" with new fish population, bathymetry and sedimentation studies, Ms. Skopec noted that historical data are limited. Some cores are being sampled and analyzed, however, in order to assess sediment/water quality.

Sediment Problem

Because Iowa is relatively flat, agriculture dominates the Iowa landscape, with 65 percent of the landscape dedicated to row crops. Not surprisingly, sediment is a major pollutant affecting Iowa's streams. Currently 45% of impaired water bodies on the 303(d) list were placed on this list due to excessive siltation. This is a serious water quality concern since sediment degrades aquatic habitat (e.g., covers coarse substrates, increases turbidity, etc.), inhibits biological growth and reproduction, and fills lakes and reservoirs.

Iowa WQS (IAC 1990)

Currently Iowa WQS (IAC 1990) do not contain criteria for either total suspended solids or other indicators of problems with sediment in streams despite the fact that the 305b report notes that "siltation threatens the support of aquatic life uses of most rivers and streams in the state." Since the State requires "credible data legislation," narrative standards cannot be used to assess impairment. Although the impact of siltation and sediment can be seen with other measures that may provide an indication of sediment impacts (e.g., phosphate concentrations), assessment efforts were "handcuffed" by the lack of sediment data older than 5 years.

Challenges of Monitoring Sediment

In addition to being expensive and labor intensive, sediment monitoring data need to be collected at appropriate times (e.g., flows) and using appropriate measures. Three case studies were then presented to highlight some lessons learned.

Ability to Detect Change—Sny Magill Watershed, National 319 Monitoring Program

A 10-year project (1991–2001) was performed at the 23,000 acre Sny Magill Watershed from 1991 to 2001. A paired watershed experiment was performed during this study for which the Bloody Run watershed served as the control. During this project the following management/treatment practices were implemented from 1991– 1998 at the Sny Magill Watershed:

$ Terraces: 270,000 feet
$ Sediment Control Basins: 60
$ Conservation Cover: 877 acres
$ Stream Bank Stabilization: 1,140 feet
$ Grade Stabilization Structures: 90
$ Conservation Tillage: 5,000 acres
$ Crop Rotation: 3,290 acres
$ Buffer Strips: 455 acres

A USLE estimate indicated that sediment delivery was reduced by approximately 50% during the course of the study, from 69,550 tons/year to 35,031 tons/year. Although an analysis of covariance showed an improvement in the biological communities, suspended sediments did not show an improvement. It is unclear at this time whether sediments failed to decrease or whether the monitoring approach failed to detect the change.

Influence of Lag Time and Temporal Scale—Walnut Creek Watershed Restoration and Water Quality Monitoring Project

The Walnut Creek Watershed Restoration and Water Quality Monitoring Project started documenting watershed restoration activities at the Neal Smith National Wildlife Refuge located near Prairie City, Iowa in 1995. Large areas of the Walnut Creek Watershed have been converted from row crops to native prairie by the USFWS.

A paired watershed approach was used during this project. The 12,890-acre Walnut Creek Watershed served as the treatment watershed and the 11,714-acre Squaw Creek Watershed served as the control watershed. Data were collected from upstream/downstream USGS stream gages on Walnut Creek and a downstream gage on Squaw Creek.

GPS Survey of Walnut Creek

A 7-mile reach of Walnut Creek was mapped during single traverse over a 5-day period during a GPS survey in October 1998. Channel features included bank erosion rates, channel substrate, debris dams, tiles, creeks, transects, cattle access, and PSA. Continuous channel features (i.e., bank erosion, channel substrate) were recorded in continuous line mode and discrete features (i.e., debris dams, tiles) were recorded as points.

Watershed Characteristics

Walnut Creek is located in the Southern Iowa Drift Plain landscape region. The soils in this watershed consist chiefly of silt clay to silt loams formed in loess and pre-Illinoian till. Since Walnut and Squaw Creek watersheds have similar basis characteristics, they are ideally suited for a paired watershed design.

Since 1993, 2,341 acres of prairie have been planted in the Walnut Creek watershed, mostly in the core of the watershed between two stream gages. Currently 4.5% of the watershed is rented to area farmers. From 1992 to 2000 row crop land use decreased from 69% to 61% in Walnut Creek and increased from 71 to 79% in Squaw Creek. Nitrogen and pesticide use was also reduced during this period by 12–37% and 28%, respectively. Unfortunately, despite the conversion from row crops to native prairie in the Walnut Creek Watershed, an Ancova Analysis failed to detect a change in the sediment loads, resulting in the decision to further investigate sediment storage within the channel.

GIS Analysis

A GIS analysis was performed. During this analysis GPS data were exported into a GIS Shape file. Field descriptions were also added to location data to create coverage. During this analysis, the channel was divided into 400-meter segments. Totaled or averaged results were then attributed to each segment. Added land cover (within a 200-meter buffer) was expressed as a percent.

Streambank Erosion Rates

Bank erosion was also “quantified” using a NRCS descriptive model. Conditions varied from slightly eroded in stable segments to severely eroded on meander bends and near debris dams. A positive correlation was observed with debris dams, bed thickness, channel width and sinuosity, and percent riparian forest. A negative correlation was observed with percent row crop riparian zone.

Streambed Sediment and Thickness
Streambed sediment and thickness were described qualitatively and measured by pushing a probe into the substrate. In general the channel consisted of bare or thinly mantled till in channelized segments and thick muck (greater than 1–2 feet) behind debris dams and downstream of cattle access. A positive correlation was observed with debris dams and percent forest conditions. In addition to determining that the volume of sediment in the channel equaled 6,900 cubic meters, project personnel estimated (based on mean discharge and sediment concentration data) that it will take 10.2 years to flush sediment stored in the channel bottom assuming no additional inputs.

Stream Survey Results
The results of the stream survey indicated that Walnut Creek is incised 10 feet into flood plain. Post-settlement sediment thickness is approximately 4 to 6 feet and bank erosion contributes 50% of annual sediment load in the watershed. Also, debris dams trap sediment and store it in a channel, and the streambed sediment varies from till in channelized reaches to thick silty muck.

Walnut Creek Conclusions
Project personnel concluded that discharge and sediment in Walnut creek are very flashy, which is typical of incised channels. Most of the discharge and sediment transport occurs during the 6-month period from February to July (e.g., 98% of the sediment transport occurs during this period). Major sediment sources include bank erosion and contributions from historical storage. Long-term monitoring is needed to detect improvements from land use changes; however, this is a very labor-intensive exercise.

Current and Proposed Monitoring Activities
Iowa’s current monitoring activities include:

- USGS Sediment Monitoring Stations (50K)
- Bathymetry and Sediment Mapping at special project office (SPO) Lakes
- Sediment Contaminant Chemistry at 132 Lakes (year 5)
- Sediment Contaminant Chemistry at Streams (225 sites)
- Event Monitoring by Ecoregion

Although these efforts are a good start, the State needs to move beyond traditional measurement approaches and embrace a more holistic approach. Iowa needs to develop a strategy that can be used to provide consistent, reliable information for decision-making but can be performed within the context of the State’s limited budget, Full-Time Equivalent (FTE) caps, and competing needs.

Iowa also needs to establish “benchmark” transects for geomorphology, to include statewide stream bank erosion estimates and volumetric estimates for various stream orders (e.g., valleys, channels, and particle size). Contaminant monitoring should also be expanded to valleys and targeted sampling needs to be used to maximize information. In-situ turbidity meters should also be used as sediment surrogates and sediment monitoring should be “tied” to biological monitoring efforts (Environmental Mapping and Assessment Program or EMAP probability based protocols).

2.4.3 Implementation of the Narrative Sediment Standard: The Colorado Experience

Robert McConnell, Colorado Water Quality Control Division

This presentation contains an introduction to Colorado's approach to implementing its sediment standard, including a discussion of what is and is not working. In addition to defining the Colorado Sediment Standard, this presentation discusses Colorado's guidance, Colorado's assessment approach, and the matrix for determining attainment of the sediment standard. A summary of experience with the guidance and a list of future challenges are also included.

Definition of the Colorado Sediment Standard

Colorado currently adheres to the Basic Standards and Methodologies for Surface Water Regulation. There are currently three types of standards, numeric, narrative, and antidegradation. Narrative standards require implementation guidance.

Colorado's narrative sediment standard states that "surface waters shall be free from substances attributable to human-caused point source or nonpoint source ... which can settle to form bottom deposits detrimental to the beneficial uses. Depositions are stream bottom buildup of materials which include but are not limited to anaerobic sludges, mine slurry or tailings, silt, or mud."

Sediment standards used by other states include:

$ Turbidity no more than 50 NTU above background
$ Suspended solids or settleable solids less than 90 mg/L
$ Percent fines no more than 25%
$ Bottom deposits free from contaminants that settle and damage or impair the normal and aquatic life or alter the physical or chemical properties of the stream
$ New Mexico approach

Guidance Overview

The Sediment Guidance Task Force was formed in 1996 and in 1998 its guidance was adopted as Provisional during the Water Quality Control Commission (WQCC) Informational Hearings. The Task Force was reconvened in 2000 and 2002, and the guidance was readopted as Provisional for an additional two and four years, respectively. The current guidance, the Provisional Implementation Guidance for Determining Sediment Deposition Impacts to Aquatic Life in Streams and Rivers, is expected to expire May 1, 2006.

The current guidance provides a consistent conceptual approach to determining attainment of the narrative standard for aquatic life in streams according to two sequential parts, deposition of materials and detrimental to use. Although it is not intended for suspended sediment, toxics, reservoirs, stream channel changes, load determination, or TMDL development, the guidance is significant to 305(b) reporting, 303(d) listing, Monitoring and Evaluation (M&E) listing, and TMDLs.

Currently eight stream segments are listed for sediment on the 1998 303(d) list (two segments for proposed 2002 list) and 82 segments on the M&E list for sediment. Thus far, however, Colorado has submitted five sediment TMDLs to USEPA.

Assessment Approach
The current assessment approach is site-specific and compares the actual conditions of a stream with the expected condition. Impacts are expressed as a percent of the expected condition for sediment deposition and percent of expected condition for aquatic life.

Attainment of the sediment standard is determined from the attainment matrix. The following steps are typically followed during an assessment:

$ Identify study stream (stream reach)
$ Identify expected condition criteria
$ Locate reference sites or determine expected condition
$ Measure sediment deposition and aquatic life condition
$ Compare study stream to expected condition as a percent of expected condition
$ Determine standards attainment in matrix

Expected Condition
Colorado has three tiers of expected conditions: 1) minimally disturbed (e.g., natural); 2) least disturbed, best available, or best attainable; and 3) no actual reference sites exist, causing state personnel to rely on models, historical data, or expert opinion. Usually a stakeholder process is used to reach consensus on an expected condition.

Typically a number of basin and reach attributes are evaluated when selecting a reference condition. The basin characteristics that are evaluated include area, perimeter, aspect, length, stream order, geology, vegetation, soils, ecoregion, climate, topography, discharge patterns, and land use. The reach attributes that are evaluated include the watershed area above, elevation, Rosgen Channel type, and stream morphology.

Substrate composition and aquatic life condition indicators are also evaluated. Substrate composition indicators include embeddedness, percent stream bed composed of fines (less than 2mm), V* for pools (Lisle and Hilton), and pebble counts (Wolman, Bevenger and King). Aquatic life condition indicators include macroinvertebrates (e.g, biomass, abundance, and community structure via USEPA Rapid Bioassessment Protocols) and fish inventory and population estimates using Division of Wildlife methods.

Matrix for Determining Attainment of the Sediment Standard
Table 5 contains the narrative sediment standard attainment matrix presented by Mr. McConnell.

Table 5. Narrative Sediment Standard Attainment Matrix

Substrate (% of expected)	**Biological (% of expected)**			
	0-17%	18-50%	51-79%	80-100%
0-58%	E	T	A	A
59-73%	T	T	A	A
74-100%	A	A	A	A

Experience with the Guidance
The USFS, Bureau of Reclamation, and Division assessments are currently using the guidance for 303(d) listings, TMDL development, 401 monitoring, and 319 monitoring. In general the guidance provides a relatively consistent framework with enough flexibility to allow it to be tailored to site-specific conditions. Stronger collaborative relationships with stakeholders and a high level of stakeholder participation are essential to the successful implementation of the guidance. Also, although technical collaborations with other organizations may increase the level of effort, ultimately a better technical approach results. The guidance has been used to develop TMDL goals and as a starting point for monitoring and assessment studies of sediment impacts.

Future Challenges
In addition to widening the scope of the current guidance (e.g., to address more than bottom sediments and biological issues), the workgroup needs to define, find, and agree on expected conditions. Also the two part test is burdensome and difficult. The percentages used in the standards attainment matrix also make it too difficult to show impairment. Not only are biological metrics that are specific to sediment needed, but more standard operating procedures (SOPs) or "cookbooks" for conducting assessments also need to be developed.

The workgroup also needs to address who makes decisions during the public process and determine how much data need to be collected and at what frequency. The workgroup also needs to explore the approaches used by New Mexico and other states and investigate statistical methods for determining the percent of expected condition (e.g., statistical significance).

2.5 Field Measurements and Field Data Availability

2.5.1 Sediment Data Quality, Availability, Analysis— Status and USGS Vision

John Gray, USGS, OSW

Mr. Gray opened by noting that all USGS research and remedial efforts rely on data collection and data quality.

Some Factors Affecting Suspended-Sediment Data Quality

Suspended-sediment data quality is affected by the accuracy of flow data (indirect), size factors (e.g., sands versus clays), and non-homogeneous mixing. Sampling issues, data density, and computational scheme(s) also affect data quality.

Streamflow Data Quality

The accuracy of computed sediment discharges and transport curves are a function of flow data. Thus if water discharge is variant, sediment transport data will also be variant. In general a "good" discharge measurement is rated at +/-5%. It is also important to consider the accuracy of daily streamflow records and whether they are the same for all days and at different sites.

Suspended sediment can be sampled using depth integrating isokinetic samplers. These samplers are deployed by lowering and raising the sampler from the water surface to the bed. Although the sampler is not able to obtain suspended sediment data next to the bed, the unsampled zone is relatively insignificant when compared to the measured depth. In order to work effectively, the velocity material entering the sampler nozzle needs to equal the velocity in the stream. If the velocity in the sampler nozzle is slower than the velocity in the stream, the concentration of suspended sediment in the nozzle will exceed stream concentrations and a super concentrated sample will be obtained.

Daily (and Annual) Sediment Records

Missing records (particularly samples and flow during high flows), the misapplication of the "Box Coefficient," flashy streams, and streams carrying coarse material are the main factors responsible for compromising the accuracy of daily (and annual) sediment records. A "seat-of-the-pants" assessment was performed by G.D. Glysson (USGS) and John Gray on the accuracy of the daily (and annual) suspended-sediment records. The result of this assessment are listed below according to stream and sediment loads:

$ Large streams with fine loads : +/- 15%, 25%
$ Large stream, coarse load: +/- 50%, 80%
$ Small stream, fine load: +/- 75%, >100% (perhaps)
$ Small stream, coarse load: undefined

Mr. Gray then noted that surrogate in situ techniques that provide time series data that can be used to infer sediment concentrations are needed to improve the accuracy of these measurements.

Examples of Erroneous Sediment Data

An analysis of historical annual suspended-sediment load and annual stream discharge data at a Green River station in the Colorado River Basin from 1930 to 1982 appeared to indicate that sediment transport had been reduced in the 1940s. Although a number of factors were hypothesized to be the cause of this reduction, including changes in land-use, vegetation, climate, and intrinsic tributary geomorphic processes, the USGS eventually determined that the Colorado River Sampler, which was replaced in the mid-1940s with the US-D43 Isokinetic Suspended-Sediment Sampler, had been providing suspended-sediment estimates that were three times larger than the actual load.

USGS National Sediment Lab Quality Assurance Program

The USGS National Sediment Lab Quality Assurance Program (http://sedserv.cr.usgs.gov/) provides training in lab procedures and performs on-site lab evaluations. In addition to operating single-blind and double-blind programs, the USGS National Sediment Lab Quality Assurance Program also evaluates quality-control data nationally and documents quality control plans and procedures. The USGS National Sediment Lab Quality Assurance Program also performs follow-up evaluations. For example, a study was performed in 1999 that evaluated the errors obtained during sediment analyses performed by USGS and other sediment laboratories. In general, a fairly wide variation was observed (e.g., +9% to -13%) in the psuedosigma obtained during the analysis of 75 mg/L samples. This range was much smaller (i.e., +3% to -4%), however, when 3,000 mg/L samples were analysed.

Comparability of TSS and SSC Data

Although TSS and SSC data are often used interchangeably, they use different analytical procedures and can produce substantially different results.

The analytical procedure used to measure TSS was developed for wastewater analyses in the mid 1970s. Although the procedure is relatively inexpensive and quick, often different techniques and equipment are used. Also the procedure, which uses an aliquot (sub-sample) of original sample, cannot be used to determine particle-size distribution.

SSC is measured using an ASTM Standard Procedure based on FISP (1941). Although this procedure can be used to determine particle-size distribution, if often takes longer and costs more than TSS. Also the whole sediment sample and the “mass of sample water-sediment mixture” are measured using prescribed equipment. Often, when the percentage of sand in a sample increases, SSC measurements are higher than TSS measurements of the same sample. After noting that the most influential samples, from a sediment perspective, are obtained during high flow and high sand conditions, Mr. Gray then noted that TSS often underestimates sand flow and is often biased low with respect to SSC data.

TSS is negatively biased with respect to SSC by 25–34 %. Since instantaneous sediment discharges can differ by orders of magnitude, TSS data are least reliable when the most influential flows are occurring (i.e., during higher flows that are transporting high concentrations of coarser sediments). Also, there is no simple or straight-forward method to adjust TSS data to estimate SSC without using paired data. Even when paired data are used, adjustments may be required on a site-by-site basis. Because of these issues, the USGS has concluded that TSS concentrations and loads for open-channel flows are unreliable. According to the USGS, the quality of the Nation’s sediment-concentration data would be greatly enhanced if these data were produced solely by the SSC method.

Mr. Gray then suggested that the relationship between TSS and SSC be evaluated starting with data from the USGS database (http://water.usgs.gov/nwis/qwdata). He also encouraged sediment labs to consider participating in the USGS NSLQA Program. He then suggested implementing a paired TSS-SSC data evaluation program that should include medium- and high-flow data.

Some USGS Observations on Transport Curves
Sediment transport curves are designed to examine the theoretical, physical, observational, and statistical foundations, including assumptions, upon which the sediment-rating procedure is based; and to describe use limits and possibilities for modification through illustration with a diverse data set.

According to Glysson and Gray (2001), “A well-defined, carefully constructed, and judiciously applied sediment-transport curve can be a useful tool for estimating sediment loads.” They also cautioned that the “Use of regression analysis to develop sediment-transport curves for estimating suspended-sediment loads can result in substantial errors.” This concern was further supported by USGS Research Hydrologist Ned Andrews who does not believe that any type of analysis based on sediment-transport curves and “stream types” has a high potential for success (February 2001).

Vision for Sediment Data Acquisition, Analysis, and Management
In an ideal world, the environmental community would have a single set of nationally consistent data-collection protocols and personnel involved in sediment, flow, and ancillary data-collection would be adequately trained. In addition to the quantification of data uncertainty, a single national database would be available that captured the TMDL and restoration project successes and failures. A new suite of tools would also be available to provide reliable unit-value time series data for suspended sediment (and bed load, bed material, bed topography).

A National Sediment Monitoring Program
Mr. Gray envisions the development of a national sediment monitoring program made up of a core network of sediment stations. According to Mr. Gray, a subset of the sediment station network would ideally focus on sediment research, including analytical equipment and methods and data-synthesis. This program would also develop and maintain a common database.

In order to begin development of a national sediment monitoring network, however, the environmental community first needs to develop and verify sediment-surrogate technologies in field and lab settings. This would allow for the expansion and funding of the fledgling “SuperGage” program by USGS and collaborators (e.g, government, university, and private).

Mr. Gray also believes that the following basic geomorphic parameters need to be collected at the gages:

$ Channel x-section geometry between terraces
$ Channel/water-surface slope
$ Bed-material size distributions
$ Benchmarked photography

After stressing the standardizing sediment terminology and adopting the “Terminology for Fluvial Sediment,” in ASTM D4410-97, Mr. Gray then noted that a SedStats web-based point-and-click application needs to be developed using the USGS StreamStats architecture as a template. This application should include estimates of uncertainty.

It is also important to elucidate “reference conditions” and provide reliable tools to identify them, perhaps by using the Hydrologic Benchmark Network and other “pristine” watersheds. The concept of the sediment-transport curve also needs to be reconsidered, particularly whether it is sufficiently reliable for scientific and legal purposes and what other options are available.

A thorough national synthesis of sediment data collected using quality-assured techniques should also be performed. This 5- to 8-year effort could be developed using the USGS NWISWEB Sediment Database (with 15K+ sites with sediment data) and by examining hard-copy USGS data available in the National Archives. In addition to marrying flow, transport and biotic models, Mr. Gray also recommended that the upgrade of the Reservoir Information System (RESIS-II) be completed. The completed database will eventually contain newly collected reservoir data.

He closed by noting that we also need to develop a comprehensive “toolbox” in support of “Clean” sediment TMDLs.

2.5.2 Empirical, Geographically-Based Thresholds of Effect (Criteria) Determined with Conditional Probabilities—A Proposed Approach

John Paul, USEPA, NHEERL

Dr. Paul opened by noting that the EMAP approach can be used to develop geographically-based criteria with field data. He then defined the following terms:

$ Criteria—desired conditions to describe unimpaired waterbody
$ Biological criteria—description of desired aquatic community
$ Survey—sites that are somewhat randomly selected with probability design
$ EMAP—USEPA's Environmental Monitoring and Assessment Program

Background

EMAP supports ecological/biological indicators and probability based sampling. There are four basic elements of the WQS: 1) designated use of water body; 2) water quality criteria to protect designated uses; 3) antidegradation policy to maintain and protect existing uses and high quality waters; and 4) general policies addressing implementation issues.

The USEPA's Draft Strategy for WQS and Criteria highlights the importance of strengthening and maintaining the scientific foundation of the programs used to protect the Nation's waters. The Nation's ability to protect its waters will be improved by coordinating research efforts on waterbody sedimentation and developing a criteria methodology. Research is also needed to identify sedimentation indicators, analytical methods, dose-response relationships, reference conditions, and waterway classification systems.

A number of issues need to be resolved in order to use field data (rather than lab data) to develop geographically-based aquatic criteria. Although some relatively common approaches for developing criteria using field data involve characterizing reference streams and then using best professional judgment, other approaches use either the 75th percentile of reference streams or the 5th to 25th percentile of all streams. (Note: Reference streams are defined by biological conditions metrics.) It is also possible to use existing predictive relationships. A number of issues need to be considered, however, when using these relatively common approaches for criteria development. For example, if the project attempts to use the available field data, the procedures for extrapolating results beyond the sites with data are unclear. Techniques to extrapolate to areas with no data and possible biases in the resulting criteria also need to be considered.

Application to Sedimentation Criteria for Streams in the Mid-Atlantic

EMAP assessed a number of Mid-Atlantic Highland streams. During this assessment, EMAP examined the status of biological resources (i.e., EMAP indicators) and sampled 100 stream segments in 1993 to 1994 using EMAP's probability design. The data obtained from these 1st to 3rd order wadeable streams were used to produce the Mid-Atlantic Highlands State of the Streams Report and are available on the EMAP website.

A Channel Sedimentation Index (CSI) model was used during the EMAP assessment of the Mid-Atlantic Streams. When applying this approach, project personnel assumed that excessive sedimentation is a major stress for streams, that benthic invertebrates respond negatively to increasing sedimentation, and that the CSI model is an adequate representation for sedimentation in streams. Based on the CSI, project personnel determined that there was an excess of substrate fines relative to expected conditions (regional mean). The reference was based on sediment transport capability of each reach (incorporates physical habitat data) and percent fines on stream bed shear stress were regressed. The resulting CSI, which is the percentage deviation (residual) from fitted curve (e.g., percent substrate fines versus stream bed shear stress), can be used to illustrate criteria development for stream sedimentation.

Conditional Probability Approach
The following assumptions were made when the conditional probability approach was used to develop criteria using survey data:

$ Numeric criteria were expressed as the likelihood (high probability) of impairment if the value of pollution metric was exceeded.
$ The ability to identify impaired biological conditions exists (e.g., Ephemeroptera, Plecoptera, Trichoptera or EPT richness is less than 9 for poor benthic conditions).
$ Survey designs provide the probability of occurrence (e.g., when 3/4 of the stream miles are impaired this means that the probability of observing impairment is 75%).

When using the conditional probability approach to develop criteria from survey data, Y equals the impaired biological condition and X equals the pollution metric used to develop criteria. Accordingly P (Y | > X) is calculated in two steps: 1) identify the subset of sampled resources for X > Xo; and 2) determine the fraction of the subset with impaired biology. P (Y | > X) is calculated for all observed values of X and is referred to as the "exceedance probability."

Impairment is reported as a probability with respect to the degree that the CSI exceeds an expected value. For example, there is a 75% probability of benthic impairment when CSI exceeds normal expectation by 20% or more.

Dr. Paul then presented a series of curves (probability of benthic impairment versus CSI) that addressed the probability of benthic impairment if the CSI is exceeded. Since criteria are based on breaks in the curves, the difference from the mean probability of benthic impairment, a benthic measurement is probably not appropriate for streams with relatively flat curves. Dr. Paul then presented Table 6, which contains stream sediment criteria for Mid-Atlantic wadeable streams.

Summary
The conditional probability approach can be applied to survey data to develop unbiased geographically-based criteria. After noting that the development of final criteria levels must be a management decision, Dr. Paul then stressed that this approach needs to be tested against other data sets and in other regions. He then encouraged participants to visit the EMAP website at www.epa.gov/emap and the MAIA website www.epa.gov/maia.

Table 6. Stream Sediment Criteria for Mid-Atlantic Wadeable Streams

	CSI Criteria
Typical Method—75 percentile of reference sites	-5
Typical Method—5th –25th percentile of all sites	-33 to -15
Conditional Probability—breaks in curve	15, 35
Conditional Probability—difference from geographic mean	15

2.5.3 Open Discussion

Bill Swietlik asked for clarification from John Paul on an issue associated with stream classification and its impact on setting criteria. In the Mid Atlantic Highlands there are very distinct differences in the biological communities found in different order streams (e.g., 1^{st} Order streams down to valley systems). After noting that the CSI relationship broke down for a 3^{rd} Order stream in John Paul's presentation, Bill Swietlik asked whether John Paul had an opportunity to further develop that SCI for 1^{st}, 2^{nd}, 3^{rd}, and 4^{th} Order streams. John Paul replied that he had.

Bill Swietlik also questioned why John Paul used EPT and whether enough data were available to use a broader index which uses more metrics. According to Bill Swietlik, EPT will change naturally for different order streams based on temperature, dissolved oxygen, and other gradients that are natural to those systems. John Paul responded that benthic invertebrates provide a very good representation of sediment conditions since they do not move around and often exhibit a direct response. John Paul then noted that he also used a fish IBI in the CSI, but that the relationship was not as strong (e.g., more scattering in the curves). After noting that much of the work he presented is relatively new, he agreed that more work needs to be done using different metrics.

Bill Swietlik then noted that John Paul appeared to be viewing sediment as a toxicant with a typical dose-response. Since he does not believe that sediment acts as a true environmental toxicant in natural ecosystems, Bill Swietlik then asked whether John Paul could use the same data with a broader IBI index. John Paul responded that CSI examined regional impacts/conditions. CSI assumes that there is some natural "value." He then noted that traditional dose-response toxicity bioassays cannot be used to develop criteria and that a broader range of data needs to be examined. An approach that combines data, uses different indices, and employs field data should be employed.

Doug Norton then noted that some of John Paul's findings in the Mid Atlantic Region appeared to be obtained from a post-aggregation step, and that John Paul did not appear to have stratified in advance along these site-specific characteristics. Doug Norton then asked John Paul whether he had post-aggregated by gradient since probability-based data sets help illuminate classification systems. John Paul responded that he had examined the gradients.

Joseph Schubauer-Berigan asked John Gray and John Paul whether they thought it was possible to "mine" the USGS data and look for trends (e.g., excess versus no excess) using the CSI. He was also interested in how frequently they sampled and what impact frequency had on the resulting relationships. John Gray responded that he thinks that the USGS database has a tremendous amount of potential for evaluating the spatial and temporal characteristics of the sedimentary characteristics of the nation's rivers. Regarding sampling frequency, John Gray responded that data collection approaches are predicated on the sampling objectives, thus more effort is needed to calculate a river's daily load than to determine sediment concentration of a stream at low flow.

Joseph Schubauer-Berigan then asked John Gray to comment on the weaknesses in the Dave Rosgen approach versus other approaches with which he was familiar. John Gray responded that although he believes the classification scheme is good, the USGS has not had an opportunity to determine efficacy of some of the applications. He also concurs with Dave Rosgen that his (Rosgen's) technique is not the only technique to be used around the country, and that it is just one tool in a toolbox.

John Paul then responded that CSI was developed at the USEPA facility in Corvallis. He also thinks that it would be very useful to use other data sets (e.g., USGS data) to apply the CSI, although he believes the efficacy of some of the techniques could be tested by applying them to some of these existing data sets, assuming, of course, that concurrent biological information about the impairment of the benthic communities is available. He then noted that the EMAP approach uses index sampling. Under this approach a 1-year period is chosen for which a major biological response is expected.

Chih Ted Yang then noted that John Gray's presentation showed that the sediment rating curve provides very little useful information. Dr. Yang actually published an American Society of Civil Engineers (ASCE) paper that concluded that there is not a well-defined relationship between discharges, sediment concentrations, or sediment load. In addition to stating that discharge cannot be used as an index for sediment transport rates or concentration, he also claimed that shear stress or velocity could not be used. According to Dr. Yang there is no one-to-one relationship between independent variables (e.g., discharge, shear stress, or velocity) and the dependent variables (e.g., sediment concentration and load). According to Dr. Yang, if the slope is multiplied by velocity, unistream power, which has a well-defined relationship to sediment concentration, is the result. A basic problem with the sediment transport studies is that researchers have concentrated on force approaches. Since force is determined by magnitude and direction and direction in a natural river cannot be defined, a power or energy approach should be used since it is scaler and direction is irrelevant. Also a number of sediment transport formulas published in recent years are based on the power approach.

2.6 Sediment Management Models, Tools, and Analytical Approaches

2.6.1 Reference Sediment-Transport Rates for Level III Ecoregions and Preliminary Links with Aquatic Indices

Andrew Simon, USDA ARS

USDA is currently studying techniques to estimate how much sediment should be occurring in streams across the Nation using a broad-based approach. A TMDL is required to evaluate impacts to the “designated use" of a water body. An impacted water body is not “impaired” unless the impact is detrimental to a “designated use” (e.g. biota). In general, an impact is determined as some “departure” from “natural,” “background,” or “reference” conditions. However, before an impact can be evaluated for a given geology, climate, hydrology, land use etc., a “reference” condition must be established. USGS ARS has determined that Level III ecoregions (Omernik, various) seem to be particularly well suited as a means of regionalizing waterbodies on a national scale.

During this study the USGS ARS has tested various methods for determining “reference” conditions and “departures" from those conditions. The USGS ARS has also attempted to demonstrate quantitative measures of sediment transport that can be functionally related to designated uses (e.g., biota). Two sediment parameters were focused on when determining impairment to a designated use by “clean sediment:” suspended sediment and bed material. Suspended sediment was chosen since high concentrations of "clean" suspended sediment over specified durations can be potentially lethal/sub-lethal to organisms. Bed material was considered because high rates of bed-material transport over specified durations (unstable bed) and loss of fines can lead to loss of habitat for benthic macro-invertebrates.

Rosgen uses form (e.g, width-to-depth ratios, etc.) to define reference conditions. Since a stable, background, or non-impacted condition is needed to represent a “reference” condition and some of the stream types defined by Rosgen are unstable (by definition), a “reference” condition for sediment transport cannot be identified for these stream types. Dr. Simon believes that form should be used to provide information on process.

Channel Evolution

Channel evolution models use form to provide information about the process (Schumm et al., 1984, Simon and the Hupp, 1986; Simon, 1989). As shown below, there are six stages of channel evolution, each occurring along the length of a stream and representing a shift in dominant channel processes:

- Stage 1 - Sinuous and premodified; the flow is transported through the reach without net aggradation, narrowing, widening, etc.
- Stage 2 - Constructed
- Stage 3 - Degradation; in response to some disturbance to the system (e.g., clearcutting of a forest, construction of a shopping mall, etc.) causing additional stream power for transport sediment
- Stage 4 - Degradation and widening
- Stage 5 - Aggredation and widening; occurs in response to upstream sediment adjustment migration
- Stage 6 - Quasi equilibrium

According to Dr. Simon Stage 1 and Stage 6 streams can be used as possible reference conditions for sediment transport. Since there are not many pristine streams left, a Stage 6 stream will probably be used as the reference condition.

“Departure” or impacts can be determined using transport-rating relations including:

- $ Slope of Rating Relation (Rate of increase in concentration/load): Indicates availability of sediment in the watershed and channel system. In general, the steeper the curve, the more sediment is being transported per unit of water.
- $ Coefficient of Rating Relation (Concentration/load at low/base flow): Indicates background levels from channel system. This curve provides information on how much sediment is being transported at low flows.
- $ Combination of Above: Analysis of frequency and duration of sediment transport/flows.
- $ Concentration/Load at the Effective Discharge: The effective discharge transports the largest amount of sediment over the long-term. It is the peak observed when plotting the product of flow frequency and the sediment discharge rating curve.

Currently USGS ARS has been focusing on using the concentration/load relation at the effective discharge to impacts.

Relationships Between Bed-Material Yield, Suspended Sediment, and Fish Communities to Stage of Channel Evolution

A graph of bed-material yield and stage of channel evolution indicates that the lowest yields are experienced in Stage 1 and peaks are experienced in Stage 3. There is also some relationship to suspended sediment and the stage of channel evolution, with the lowest rates at Stage 1 and a peak at Stage 4, during channel widening. Different fish communities have also been associated with different channel evolution stages. These communities may be functionally related to the transport characteristics exhibited by the stream during each stage.

Effective and Bankfull Discharge

Effective discharge is that discharge or range of discharges that transports the largest portion of the annual sediment load over the long term (Leopold and Wolman, 1960; Wolman and Miller, 1960; Andrews, 1980). According to the annual-maximum series, the effective discharge can be roughly approximated by a 1.5-year flow. Since only a few studies have been performed that used good data to define the effective discharge, effective discharge is generally accepted to represent a flow that occurs every 1.00–2.33 years. It is also generally accepted to be the bankfull discharge.

<u>Flow and Suspended Sediment Data Used To Estimate Effective Discharge</u>

Although mean daily flow values are readily obtainable from USGS gaging-station records and are useful for large rivers, 15-minute flow data are very useful when determining flow frequency. Unfortunately, however, they are very difficult to obtain since they are not generally stored by the USGS.

Instantaneous sediment concentrations (with corresponding flow data), rather than mean daily values, are needed in order to calculate effective discharge. These data are available from a wide range of streams and rivers and are now available at about 6,000 sites from USGS. Currently, however, only 2,900 sites have matching data for flow and sediment transport.

Flow Frequency Distribution
Flow frequency can be determined at sites with 15-minute flow data by separating the flows into 25 or 33 different logarithmic discharge classes based on the percentage of occurrence for different discharges.

Suspended-Sediment Transport Ratings
Although suspended-sediment transport ratings are useful (assuming the data are handled carefully), simple power functions often overestimate transport at high flows and underestimate transport at medium flows. Two- or three-stage ratings, on the other hand, use power functions that are separated by flow domains. These domain breaks often represent gross morphologic changes in cross-section shape.

Calculation of Sediment Load at the Effective Discharge
Since the effective discharge approximates the 1.5-year flow, it can be quickly calculated by obtaining and plotting the complete record of peak flow discharge data obtained for a stream versus the recurrence interval and then selecting the peak flow discharge associated with the 1.5-year occurance interval. (Note: This effective discharge then be applied to a log-log plot of load versus discharge (in cubic meters per second) to determine the sediment load (in tons/day) at the effective discharge.

Level III Ecoregions and Available Data
Currently USGS has calculated the sediment load at the effective discharge for all of the sites in the 84 ecoregions that have at least 30 matching samples of flow and sediment transport data. These resulting values for sediment concentration at Q1.5 were then sorted by ecoregion. A chart of median Q.15 concentrations for the Level III ecoregions indicates that peak concentrations (e.g, the highest sediment concentration at Q1.5) were obtained in the semi-arid Southwest and in the humid east (e.g, the Mississippi Valley). A graph of nationwide median Q1.5 sediment yields (in tons per day per kilometer squared) for Level III ecoregions indicated shows that the highest sediment Q1.5 yields were obtained in the humid areas that are highly erosive (e.g., the Mississippi Valley Loess Plains). The arid Southwest “dropped out” since there is not enough water to produce a large yield.

Reference Site Efforts
Locations With and Without Field Work Data
A number of field locations have been established to evaluate reference conditions. Although transport relations (e.g., Q1.5 discharges and related factors) have been developed at these sites using the available data, field work still needs to be completed at a number of ecoregions across the US in order to determine which sites are stable or unstable before progress can be made on determining reference conditions for those areas. Thus far, field work has been completed in only about a quarter of the country, mainly in the Southeast.

Preliminary References
A distribution of sediment yields at the Q1.5 for unstable sites was compared to distributions for Stage 1 and Stage 6 sites in the Mississippi Valley Loess Plains ecoregion in order to estimate an average sediment yield (e.g., 37.1 tons per day per square kilometer). The average sediment yield obtained during a similar analysis of the Southeastern US Plains was approximately two orders of magnitude lower (e.g., 0.41 tons per day per square kilometer) than the Mississippi Valley Loess Plains ecoregion, providing support to the use of the ecoregion concept to develop reference conditions. A similar analysis of sediment concentrations for different ecoregions indicates that very dissimilar average concentrations can be obtained for the stable streams in different ecoregions across the US, indicating that the same criteria cannot be used for different ecoregions.

Dr. Simon then presented Table 7, which contains preliminary "reference" transport rates for different ecoregions. These rates are considered preliminary pending the completion of field work and the assessment of stream stability during sediment collection based on channel morphology changes over time using discharge data.

Preliminary Reference Yields by Dominant Bed- Material Size Class

Since there is variability within a given ecoregion, USGS ARS has just started to develop preliminary reference yields based on dominant bed-material size class.

Aquatic Data

Ultimately the median suspended sediment concentrations and yields developed for different ecoregions have to be linked to biota by examining the frequency and duration of suspended sediment concentrations. Assuming a threshold condition could be defined, these factors could be analyzed by plotting sediment concentration by the fraction of time that threshold concentration was equaled or exceeded. Information could also be obained by plotting sediment concentration and expected annual durations of specific concentrations (e.g., a threshold concentration). Curves could also be developed that examined the relation between the annual duration of a high concentration and benthics (e.g., the total number of benthic macroinvertebrates).

Conclusions

Preliminary Findings

Not only are Stage I and Stage VI channel evolution models viable as TMDL references, but Level III ecoregions are good discriminators of hydraulic geometry, hydrologic relations and sediment-transport rates. Although sediment-transport distributions are well defined for each ecoregion (with medians varying over 5 orders of magnitude), median reference sediment yields are generally an order of magnitude lower than the median for the ecoregion. Streambank sediment is also probably the dominant contributor of sediment.

Table 7. Preliminary "Reference" Transport Rates for Different Ecoregions

Ecoregion No.	Ecoregion Name	States Included	Preliminary "Reference" Transport Rate in T/D/km^2
1	Coast Range	CA, OR, WA	30.5
15	Northern Rockies	ID, MT, WA	0.05
22	Arizona/New Mexico Plateau	AZ, CO, NM	2.24
28	Flint Hills	KS, OK	5.79
40	Central Irregular Plains	KS, IA, MO, OK	2.07
54	Central Cornbelt Plains	IL, IN	0.34
63	Mid-Atlantic Coastal Plain	DE, MD, NC, SC, VA	0.03
65	Southeastern Plains	AL, GA, MD, MS, NC, SC, TN, VA	0.41
72	Interior River Lowland	KY, IA, IL, IN, MO	0.19
74	Mississippi Valley Loess Plains	KY, MS, TN	37.1

Ongoing/Upcoming Tasks (July 2002)

In addition to determining the range of sediment-transport rates for "reference" conditions for other ecoregions, reference conditions need to be subdivided for each ecoregion by dominant bed-material size class. Dam-affected sites also need to be segregated from the database, and transport conditions need to be reanalyzed by ecoregion. Specific-gage analyses should also be performed on all sites to determine stability conditions (and stage of channel evolution) during the sediment-sampling period. In general, at least two impacted and two reference sites need to be identified in each ecoregion and evaluated to determine the frequency and duration of sediment transport.

What's Next

Not only should data be linked to biologic data (benthics/fish), but the magnitude-frequency-duration (MFD) relationship needs to be determined for reference and impacted conditions by ecoregion for sites with biologic data. Models are also needed that include bank failures for in-stream BMPs (CONCEPTS). Upland-erosion (AGNPS) and channel evolution (CONCEPTS) models also need to be coupled in order to evaluate BMP effectiveness.

2.6.2 GSTARS (Generalized Sediment Transport Model for Alluvial River Simulation) Models for River and Reservoir Sedimentation

Chih Ted Yang, US Bureau of Reclamation, Sedimentation and Hydraulics Group

Dr. Yang opened by noting that his presentation will address GSTARS Versions 2.0, 2.1, and 3.0.

US Bureau of Reclamation, Sedimentation and Hydraulics Group
The following issues have been prioritized by the US Bureau of Reclamation Sedimentation and Hydraulics Group:

1. The simulation of unsteady flow and sediment transport during dam breaks
2. TMDLs for sediment
3. Sediment issues associated with dam removal
4. Surveying reservoir sedimentation using GPS

GSTARS Models
The first version of GSTARS was published in 1986. This was followed by the release of GSTARS 2.0 in 1998. GSTARS 2.1, which is a more user-friendly version of 2.0, was released in 2000. The latest version of GSTARS, Version 3.0, was released in 2001. All of these models can be downloaded from the US Bureau of Reclamation website.

GSTARS uses energy and momentum equations to perform water surface profile computations of mixed flow regimes (subcritical, critical, and supercritical). GSTARS also uses the stream tube concept when simulating semi-2D flow and sediment conditions in the longitudinal and lateral directions. Channel width adjustments are predicted using the minimum energy dissipation rate or its simplified form, the minimum load power theory.

GSTARS is used to compute the hydraulic parameters for open channels with fixed and movable boundaries. It also computes water surface profiles in subcritical, supercritical, and mixed flow regimes. GSTARS simulates and predicts the hydraulic and sediment variations both in the longitudinal and in the transverse directions and simulates and predicts the change of the alluvial channel profile and cross-sectional geometry, regardless of whether the channel width is variable or fixed. This model also incorporates site-specific conditions such as channel side stability and erosion limits.

Stream Tube Computations
The stream tube concept divides the channel reach into stream tubes of equal conveyance. Since the water discharged from each stream tube is identical, but the sub-cross-sections of each stream tube differ, the velocity distribution along the stream tubes is different, indicating non-uniform velocities.

1-D Modeling Advantages
One-dimensional models are computationally faster, numerically simpler, and more stable than 2-D or 3-D models. In addition to requiring less data, the governing processes are simpler to grasp and represent mathematically. Not only are these models more reliable in producing long-term simulation results, the results are easier to interpret. It is also easier to make changes to 1-D model parameters and to analyze a variety of alternative scenarios.

Table 8. Comparison of 1-D, 2-D, and 3-D Models

	Dimension of the Model		
	3-D	*2-D*	*1-D*
Number of variables	11 variables total including flow variables (u, v, w), pressure (p), free surface (H), 6 turbulent stress components due to symmetry	6 variables total including flow variables (U, V), free surface (H), 3 turbulent stress components due to symmetry	2 variables total including flow (U), and free surface (H)
Typical set of equation solved	4 partial differential equations, 7 algebraic equations, and up to 13 differential equations	3 partial differential equations, 3 algebraic equations, and up to 5 differential equations	1 algebraic equation and up to 2 partial differential equations
Computational requirements	Very high	High to medium	Relatively low
Number of nodes in a typical problem	>50,000	~103	10 to 100

Why Use Stream Tubes Instead of Fully 2-D or 3-D Models?
Table 8 contains a comparison of 1-D, 2-D, and 3-D models. This table was provided to highlight some of the reasons why stream tubes are used instead of fully 2-D or 3-D models.

GSTARS 2.0

Model Overview
GSTARS 2.0 can be used for water surface profile computations (with or without sediment transport) and water surface profiles through subcritical and supercritical flow conditions, including hydraulic jumps, without interruption. GSTARS can also compute the longitudinal and transverse variations of flow and sediment conditions in a semi-2-D manner based on the stream tube concept. If only one stream tube is selected, the model becomes 1-D. If multiple stream tubes are selected, both the lateral and vertical bed elevation changes can be simulated.

The bed armoring process can be realistically simulated using computations based on sediment size fractions. The model can also simulate channel geometry changes to width and depth simultaneously based on the theory of minimum total stream power. The channel side stability option also allows the model to simulate channel geometry change based on the angle of repose of bank materials and sediment continuity.

Unique Features of GSTARS 2.0
GSTARS 2.0 uses steam tubes to compute flow velocities in a semi-2-D manner and channel geometry changes in a semi-3-D manner, without having the heavier data and computational demands of fully 2-D or 3-D models. It also uses the theory of stream power in conjunction with stream tubes in order to compute effective channel width changes.

Limitations

GSTARS 2.0 is a quasi-steady flow model. Since water discharge hydrographs are approximated by bursts of constant discharges, GSTARS 2.0 should not be applied to rapid, varied, unsteady flow conditions.

Since GSTARS is a semi-2-D model for flow simulation and a semi-3-D model for simulating channel geometry change, it should not be applied to situations where a truly 2-D or a truly 3-D model is needed in order to perform a detailed simulation of local conditions. GSTARS 2.0 should be adequate, however, for solving most river engineering problems.

Finally, since GSTARS 2.0 is based on the stream tube concept, the phenomena of secondary current, diffusion, and super-elevation are ignored.

Available Sediment Transport Models

The following available sediment transport models can be used in GSTARS 2.0:

$ Meyer-Peter and Muller's 1948 formula
$ Laursen's 1958 formula
$ Toffaleti's 1969 model
$ Engelund and Hansen's 1972 method
$ Ackers and White's 1973 method
$ Revised Ackers and White's 1990 method
$ Yang's 1973 sand and 1984 gravel transport formulas
$ Yang's 1979 sand and 1984 gravel transport formulas
$ Parker's 1990 method for coarse gravel transport
$ Yang's 1996 modified formula for sediment transport in sediment laden flows with a hyper concentration of wash load
$ Krone's 1962 and Ariathural and Krone's 1976 methods for cohesive sediment transport

Although there is no universal sediment transport equation, not all sediment transport equations are created equal, as demonstrated by the ASCE's rating of different sediment transport equations. Yang's 1973 equation was rated number one and provided the best overall predictions during this study. Also, all of the highly rated models were based on the power concept, not force.

Sediment Routing

Sediment routing is determined for each stream tube using a basic continuity equation. Water can be de-coupled from sediment routing computations by assuming that: 1) the change in suspended sediment concentration in a cross-section is much smaller than the change of the river bed; and 2) the parameters in the sediment transport function for a cross-section remain constant during a time step. Lateral inflows are also not considered in the current version of GSTARS.

GSTARS computes sediment transport by size fraction. Thus the total sediment carrying capacity for a particular river section is computed by multiplying the percentage of a specific size fraction of material available in the bed by the capacity for each size fraction for each of the different size fractions.

Non-equilibrium Sediment Transport

Although most of the available sediment models assume equilibrium sediment transport, GSTARS uses non-equilibrium sediment transport. Non-equilibrium sediment transport recognizes that sediment transport is not instantaneous and that the river does not respond immediately. This relationship is particularly important for reservoirs, especially when fine sediments are involved.

Bed Sorting and Armoring

Bed sorting and armoring uses the active layer concept. During net erosion two layers are used: an active layer and a layer of original bed material. During net deposition three layers are used: an active layer, a layer of inactive deposition, and a layer containing the original bed material. This concept accounts for sediment availability and capacity limited sediment transport and can be used to predict bed armoring and armor break up.

Total Stream Power Minimization

The minimum energy dissipation rate theory (Yang and Song, 1986) states that when a closed and dissipative system reaches dynamic equilibrium, its energy dissipation rate must be at its minimum value. The total rate of energy dissipation is the sum of the rate of energy dissipation due to water movement and the rate of energy dissipation due to sediment movement. The minimum value must be consistent with the constraints applied to the system. If the system is not at dynamic equilibrium, its energy dissipation rate is not at its minimum value. The system will adjust itself, however, "in a manner that will reuse its energy dissipation rate to a minimum value and regain equilibrium."

For an alluvial channel or river where the energy dissipation rate for transporting water is much higher than that required to transport sediment, the minimum energy dissipation rate theory can be replaced by the simplified theory of minimum stream power (Yang, 1992). For this case, a river will minimize its stream power per unit channel length subject to hydrologic, hydraulic, sediment, geometric, geologic, and man-made constraints.

Channel width adjustments can also be modeled using the minimum energy dissipation rate concept for channel scour/deposition due to bed elevation changes (e.g., vertical) or scour/deposition due to width changes.

GSTARS 2.0 Applications

Willow Creek Dam

A spill occurred at the Willow Creek emergency spillway in the spring of 2001. In addition to assessing whether the dam would break, Dr. Yang used GSTARS 2.0/2.1 to model scour in the unprotected channel located downstream of the spillway. The cross-sections developed with GSTARS 2.0/2.1 showed a dramatic change in channel geometry, from a roughly symmetrical shape to a cross-section similar to that encountered in the bend of a stream meander.

Lock and Dam #26

GSTARS 2.0/2.1 was applied at the Lock and Dam #26 replacement site near St. Louis in order to assess scour from construction activities that were partially blocking the flow of the river. Three stream tubes were used and velocity was determined to vary in both the longitudinal and lateral directions. The difference in the lateral direction of the predicted versus measured scour was within 1 foot. The results were used by USACE to construct the replacement lock and dam.

Lake Mescalero Emergency Spillway

A review of the bed elevation cross sections generated by GSTARS 2.0/2.1 downstream of the Lake Mescalero emergency spillway, both before and after a spill, indicate that the cross-sections predicted with minimization were closer to the actual cross-section than those predicted without using minimization.

GSTARS 2.0/2.1 Summary
GSTARS 2.0/2.1 are quasi-steady flow 2-D models that can be used for mixed flow regimes and flow transitions (e.g., hydraulic jumps) and fixed or movable bed channels and reservoirs. Sediments are routed using stream tubes and multiple sediment transport functions are used, covering a range of materials from clay to silt, sand, and gravel. GSTARS 2.0/2.1 accounts for non-equilibrium sediment transport and fractional transport, bed sorting, and armoring. The minimum energy dissipation rate is used to compute width changes. Bank slope stability is also an element of this model.

GSTARS 3.0
GSTARS 3.0 includes expanded reservoir sedimentation capabilities. This version assesses river delta formation, including delta movement in the longitudinal direction, the formation of subsurface density currents, and sediment transport across the stream tube. GSTARS 3.0 also addresses bed sorting and armoring downstream of a dam. Thus far, predicted gradations and profiles (e.g., downstream of the dam) agree favorably with actual gradation and profiles. The results also accurately matched the published results in the literature. GSTARS 3.0 can also be used to predict the knickpoint behavior, particularly upstream movement. Comparisons of the predicted and measured delta movement showed good agreement.

Unsteady Flow and Transport in Dam Break Analysis
GSTARS 3.0 is capable of fully analyzing unsteady flow and transport during a dam break. In addition to including a component that accounts for unsteady total load sediment routing, GSTARS 3.0 also includes an unsteady routing model that is capable of modeling super-critical flow, subcritical flow, tributaries, and flood plains. The minimum energy dissipation theory is also used to calculate changes in morphology following a dam break.

Sediment Issues Associated with Dam Removal
GSTARS 3.0 is currently being used to simulate sediment impacts due to dam removal, including upstream erosion and downstream fill. Sediment issues associated with dam removal include: riverbed aggradation; flooding of residential/commercial properties; delta growth; marine habitat burial; water quality for aquatic habitats; water quality for municipal/industrial water supplies; diversion infrastructures for municipal/industrial water supplies; and river hydraulic and riverbed substrate changes and their impacts on fish migrations and spawning success.

Unit Stream Power
A physically-based equation for sheet erosion that is based on unit stream power is currently being used. This equation relates the rate of energy dissipation used in transporting sediment to the rate of sediment being transported.

Conclusions
Dr. Yang closed by noting that the GSTARS model has been demonstrated for rivers and reservoirs both in the laboratory and in the field. After stating that there is some evidence that GSTARS can also be applied to model watershed erosion, Dr. Yang noted that his office will start a 5-year project this year that is designed to develop GSTARS ability to model watershed erosion. The resulting model will be focused on processes and will not distinguish between point and non-point sources. Time lags will also be addressed.

2.6.3 Sediment Transport Modeling—Tools for TMDL Analysis

Earl Hayter, USEPA NERL

When Are Sediment Transport and Fate Models Needed in TMDL Analysis?

Sediment transport and fate models are needed in TMDL analysis when estimates of time-varying instream sediment loads (from both instream and watershed sources), deposition or erosion rates, and channel morphology are necessary for development of sediment TMDLs (e.g., Level 4 or Level 5 streams). Although there are methodologies that can be used to estimate average annual sediment loads, e.g., WARSS, these methodologies do not generate the time-varying parameters listed previously.

USEPA-supported Instream Sediment Transport Models

Currently USEPA has supported the development and maintenance of the following instream sediment transport models: Environmental Fluid Dynamics Code (EFDC, a sediment transport and hydrodynamic model), EFDC1D, GSTARS, and Hydrodynamic, Sediment and Contaminant Transport Model (HSCTM2D).

<u>EFDC</u>

EFDC solves the 3-D, vertically hydrostatic, free surface, turbulent-averaged equations of motions for a variable density fluid using a stretched or sigma vertical coordinate and Cartesian or curvilinear, orthogonal horizontal coordinates. EFDC also solves the dynamically coupled equations for turbulent kinetic energy and length scale, salinity and temperature. The turbulent kinetic energy and length scale equations are solved using the Mellor-Yamada level 2.5 turbulence closure scheme as modified by Galperin.

EFDC also simultaneously solves the Eulerian transport-transformation equations for dissolved and suspended materials, e.g., sediment, toxic contaminants, and water quality state variables.

The sediment transport module can represent the transport and fate of multiple size classes of both cohesive and noncohesive sediments. Cohesive sediment transport processes represented include resuspension, advective and dispersive transport, suspension concentration dependent settling, deposition, and bed consolidation. Noncohesive sediment transport processes represented include erosion, advection and dispersion of suspended load, bed load transport, grain-size dependent settling, deposition, and bed armoring.

EFDC development was supported by USEPA Region 1, Region 5, OW, and ORD. EFDC is being tested in rivers throughout the Nation and is scheduled to be released on the CEAM web site (www.epa.gov/ceampubl/) in January 2003. Hydrodynamic, toxic transport, sediment transport, and eutrification modules will be included in this release.

<u>EFDC1D</u>

EFDC1D is a one-dimensional (1-D) version of the 3-D version of EFDC that is designed to be used in conjunction with a watershed loading model. EFDC1D can simulate hydrodynamics and sediment transport in low-order stream networks and bi-directional unsteady flows. In addition to being able to accommodate unsteady inflows and outflows associated with upstream inflows, lateral inflows and withdrawals, groundwater-surface water interaction, evaporation and direct rainfall, EFDC1D also includes representation of hydraulic structures such as dams and culverts. For sediment transport, the model simulates settling, deposition and resuspension of multiple size classes of cohesive and noncohesive sediments. The cross-sectional bed changes during the simulation. The sediment bed can be represented by multiple layers of mixed sediment classes.

A bed consolidation module is included in EFDC1D to predict time variations of bed depth, void ratio, bulk density and shear strength. The sediment bed model is dynamically coupled to the cross-sectional area representation to account for area changes due to deposition and resuspension. External linkage software to HSPF has been developed.

It is currently being applied to a 19-km reach of the Housatonic River and is scheduled to be released on the CEAM web site (www.epa.gov/ceampubl/) in November 2002.

GSTARS 2.0
GSTARS 2.0 is currently being applied to a 19- km reach of the Housatonic River.

HSCTM2D
HSCTM2D is a finite element modeling system for simulating 2-D, vertically-integrated, surface water flow (typically riverine or estuarine hydrodynamics), sediment transport, and contaminant transport. The modeling system consists of two modules, one for hydrodynamic modeling (HYDRO2D) and the other for sediment and contaminant transport modeling (CS2D).

The HSCTM2D modeling system may be used to simulate both short-term (less than 1 year) and long-term scour and/or sedimentation rates and contaminant transport and fate in vertically well-mixed bodies of water. This model (version 2) is currently being applied to a reach of the Housatonic River. HSCTM2D B Version 1 is currently on the CEAM website. Version 2 , which is designed to address cohesive and non-cohesive sediment transport, will be available in June 2003. (www.epa.gov/ceampubl/swater/hsctm2d/index.htm).

USEPA-supported Watershed Loading Models
USEPA has supported the development and maintenance of the following watershed loading models: TMDL USLE, Hydrological Simulation Program B FORTRAN (HSPF), and TOPLATS

TMDL USLE
The USEPA's TMDL USLE model is a Windows-based software application for estimating diffuse (i.e., nonpoint) average annual sediment source loads within a watershed using the RUSLE. Applications of this software can vary from a simple computation of the annual edge-of-field sediment loading from a single parcel of land to more extensive applications designed to estimate grouped sediment sources throughout a watershed. Estimates of sediment loadings for grouped sources are particularly useful for TMDL analysis, since similar control measures can be considered for similar sources throughout the watershed.

The strength of the RUSLE methodology is in estimating sediment loadings generated by erosion on agricultural lands. However, the RUSLE has also been applied to rangeland, forest lands, landfills, construction sites, mining sites, reclaimed lands, military training lands, parks, and other land uses where mineral soil material is exposed to the erosive forces of raindrop impact and overland flow. More information on the model is available at www.epa.gov/ceampubl/swater/usle/index.htm.

HSPF
HSPF is a watershed hydrology and water quality modeling system for both conventional and toxic organic pollutants that enables the integrated simulation of land runoff processes with instream hydraulics

and fate and transport, including sediment-chemical interactions, in 1-D stream channels. It uses the lumped-parameter approach for representing variations in land-uses, soil types, etc., throughout the modeled watershed. HSPF can also simulate the transport and fate of up to three types of sediment (clay, silt, and sand) and the transport and transformation of a single organic chemical. It can be used to provide a time-series detailing sediment and pollutant transport off the watershed. HSPF is widely used in the US and world-wide and is currently available on the CEAM website (www.epa.gov/ceampubl/swater/hspf/index.htm).

TOPLATS

TOPLATS is a spatially-distributed, physically-based, continuous simulation hydrologic model. It consists of two components: 1) TOPMODEL, which computes the lateral redistribution of subsurface water in the saturated zone (variable contributing area concept) as a function of both soil type and topography, and 2) a water and energy balance model which computers flux across the surface-atmosphere interface. This computationally intensive model currently does not contain sediment rating routines. TOPLATS has recently been applied to the Middle Swamp watershed in North Carolina. It is scheduled to be released on the CEAM website in September 2003.

Modeling Framework Application

A Sediment Transport Modeling Framework that can be used to evaluate sedimentation in waterways, e.g., low-order stream networks, is described. The framework consists of coupled models that simulate both watershed and instream physical processes. Watershed sediment loads are represented as nonpoint source loadings in the sediment transport model, and can be calculated in units of tons of sediment per acre per year (for performing baseflow analysis) or tons of sediment per acre per hour (for performing rain-event analysis).

The watershed portion of the framework consists of: a) the USEPA's TMDL USLE model for baseflow simulations, or b) the USEPA's HSPF model for rain-event simulations. The instream portion of the framework consists of the EFDC1D model.

This modeling framework is currently being applied to a reach of the Housatonic River in Massachusetts.

NERL/ERD Sediment-Related Research Plan

Over the long term, NERL/ERD plans to develop modeling approaches and protocols for developing sediment TMDLs for impaired streams, rivers, lakes, reservoirs and estuaries. NERL/ERD also intends to evaluate sediment effects on biological endpoints and develop first-principles-based models for stream and watershed geomorphology.

In order to achieve these goals, however, NERL/ERD needs to evaluate the OW TMDL protocol and proposed criteria documents for sediments (in progress) and the applicability of the OW protocol to determine sediment TMDLs on the Housatonic River (in progress). NERL/ERD also needs to develop a sediment model based on the USLE for use in determining aggregate sediment loads off land surfaces and a new 1-D flow and sediment transport model to link to HSPF (EFDC1D). GSTARS 2.0 and the sediment transport routines in EFDC for use in rivers, lakes and estuaries (by the time EFDC is released on the CEAM web site in January 2003) also need to be updated.

NERL/ERD also needs to develop sediment TMDL modeling protocols to supplement the protocols for determining sediment TMDLs published by the OW. The new protocols should contain specific recommendations related to the use of sediment transport models and guidance in determining when modeling is necessary, both of which should be discussed in detail in the modeling protocols. These protocols will be delivered to the OW in September 2004.

Finally, NERL/ERD plans to develop a web-based or spreadsheet-based, user-friendly version of Rosgen's WARSS methodology (by September 2003), a first-principles -based 3-D instream geomorphological model, and a first-principles-based 2D watershed geomorphological model.

2.6.4 National Center for Computational Hydroscience and Engineering Sediment Models: Capabilities and Applications

Sam Wang, National Center for Computational Hydroscience and Engineering

NCCHE and Its Mission

NCCHE has been federally funded through the USDA ARS since 1989. NCCHE is Congressionally mandated "…to develop the state-of-the-art Numerical-Empirical Models to support the DEC (Demonstration Erosion Control) Project." Currently NCCHE's Numerical-Empirical Models are being beta-tested by a large number of researchers world-wide. NCCHE expects to release these models shortly.

Model Development Process

The following process is followed when a new technology or model is developed:

$ The new model is developed utilizing new technological advances.
$ The analytical methods are verified and improvements and corrections are performed.
$ The physical model and field data are validated and refinements are incorporated.
$ The model is integrated with GIS and/or GUI systems and documentation is developed.
$ Alpha and beta testing occurs and further refinements are incorporated. The user friendliness is enhanced and documentation is revised.
$ The model is released to US federal government agencies and other professionals.

In general, computational simulation models need to meet the following basic requirements:

$ Satisfy physical principles
$ Predict essential physical processes
$ Be stable and consistent
$ Be convergent and achieve tolerable accuracy
$ Have acceptable numerical dissipations, waves, etc.
$ Agree reasonably well with physical model results
$ Agree reasonable well with field observations

Model Verification and Validation

The ASCE-EWRI Task Committee on 3-D Flow Model Verification/Validation verifies analytic methods by analytic solutions (linear) and manufactured solutions (non-linear). In addition to scaled model experiments, the ASCE-EWRI Task Committee also validates 3-D flow models through laboratory experiments that examine the basic physical process and physical principles. The ASCE-EWRI Task Committee also validates 3-D flow models using field measurements.

Verified and Validated Capabilities of NCCHE Models

<u>Free Surface Flows</u>

NCCHE free surface flow models have been verified/validated. These models have the following features: solving full Navier-Stokes equations; several turbulence closures; truly free surface and unsteady; without hydrostatic pressure assumption; efficient numerical solution; robust mesh generator; and wetting and drying nodes and boundaries. NCCHE free surface flow models can also be used for depth-averaged (2-D) and cross-section averaged applications.

These models have been verified/validated for 3-D flow around submerged dikes, exposed dykes, submerged weirs, piers, and during dam breaks and over-topping flows. A comparison of simulated and measured flow velocities at different points in the Victoria Bendway in the Mississippi River showed good agreement. (Note: The Victoria Bendway is a very complicated bend with two exposed dykes and six submerged weirs.) A 3-D flowfield simulation containing six submerged weirs was also developed for the Victoria Bendway to aid in the development of the weir designs. Two-dimensional flows have also been simulated using the NCCHE 2-D flow model for streams with islands and through a complex group of bridge piers. Promising results have also been obtained when modeling dam break and overtopping flows.

Sediment Transport

NCCHE sediment transport and morphodynamic process models have been verified/validated. These models have the following features: utilize the unsteady advection-diffusion equation for suspended sediment; sediment transport capacity functions; conservation of mass; non-uniform sizes; the non-equilibrium transport equation; and cohesive and non-cohesive sediments. Morphodynamic capabilities that have been validated/verified include: local scours; bed aggradation/degradation; head-cut migration; bank erosion, channel widening, etc.; and channel meandering.

The non-equilibrium bed-load material transport model accounts for suspended load transport, bed load transport, and bed change. Sediment transport capacity is assessed using the SEDTRA module (Garbrecht, 1995); Wu, Wang and Jia's formula (2000); the modified Ackers-White formula (Proffitt & Sutherland, 1983); and the modified Englehund-Hansen formula (with Wu et al's correction factor, 2000). Both non-equilibrium sediment transport and pollutant transport equations are used. These equations are very similar to each other.

Channel degradation, bed channel armoring, local scours (piers, bridges, abutments, spur-dikes), and meander migration have been verified/validated with NCCHE models. Reasonable comparisons of calculated and measured water and bed surface elevations versus distance downstream of the inlet were obtained during SAFHL's 1995 laboratory experiment. Comparisons between measured and simulated bed elevations along the length of a stream also showed reasonable agreement. Channel bed armoring tests showed that the NCCHE model provides a good prediction of gradation disturbance. Not only was the NCCHE model able to estimate the final maximum depth of the scour hole that formed around a bridge pier during validation testing, it was also able to simulate the development of the scour hole.

Pollutant Transport and Water Quality

NCCHE recently started to develop pollutant transport and water quality models. These models address sediment transport (clean and contaminated), pollutant transport (with and without fate processes), and water quality modeling (considering interactions between sediment and contaminants). Suspended sediment and channel simulations have been performed that examine heavy metal transport in a channel. During this study, the concentration of heavy metal dissolved in the water and absorbed by suspended sediment and bed sediment, both for clear but contaminated water flowing into a clean region and for clear and clean water flowing into a region with contaminated bed sediment.

Pollutant, water quality, and ecosystem models in development include the following:

$ Pollutant Transport Model which assesses nitrogen, phosphorus, carbon, and pesticides
$ Water Quality modeling for temperature, BOD/DO, and eutrophication (algae)
$ Ecosystem models to include TMDL and BMP analysis

NCCHE also hopes to use these models to simulate the adsorption and desorption of contaminants to and from the sediment.

Applications
NCCHE has developed a number of different applications, including:

- $ CCHE3D: CCHE3D can be used to simulate flow over submerged weirs in a bendway, local scour, and meander development and migration.
- $ CCHE2D: CCHE2d can be used to simulate flood control, flows around structures, and water quality and contaminant transport.
- $ CCHE1D: CCHE1D can be used to simulate dam break and over-topping flows and routing of water and sediment in a channel network of a watershed.

Additional details on different sediment management models and the Watershed Sediment Management Model are included below.

Sediment Management Models
The following NCCHE models for sediment management can be used to model terrains, submerged conditions, channel networks, 2-D or 3-D flows near localized reaches, and to predict water quality. A brief description of the different NCCHE sediment management models is included below:

- $ TOPAZ: TOPAZ is a terrain model that can be used to develop a digital representation of a watershed river basin including subwatershed and channel networks.
- $ SWAT and AGNAPs: Subwatershed modeling can be performed using SWAT and AGNAPs in order to develop rainfall water and sediment/pollutant yields from subwatersheds to be used as boundary conditions of the channel network model.
- $ CCHE1D: CCHE1D is a channel network model that simulates long- and short-term routing water, sediment and pollutants in a channel network including morphodynamic processes, instream structures, and vegetation effects.
- $ CCHE2D and CCHE3D: CCHE2D and CCHE3D provide more realistic and accurate simulations whenever needed at a localized reach where the natural phenomena are definitely 2-D or 3-D respectively.
- $ CCHE WQPT: CCHE WQPT predicts the water quality of a surface water system due to pollutant and sediment transport and their interactions.

Watershed Management Model
The Watershed Management Model is being developed to access the cost-effectiveness of engineering designs including the short- and long-term engineering merits, environmental/ecological impacts, and cost effectiveness. It is also being developed in order to evaluate the effectiveness of remedial measures by identifying the sources of excessive sediments and/or pollutants and evaluating the effectiveness of remedial policies, practices, etc. Ultimately, however, NCCHE hopes to develop the Watershed Management Model into a decision support system that is capable of simulating the outcomes of different scenarios, select BMPs, and determine TMDLs and compliance.

Integrated Basin-Channel Network Modeling
To highlight how different models have been applied thus far, Dr. Wang then presented a schematic of an integrated basin-channel network modeling approach. When using this approach, outputs from a Digital Elevation Model are applied to channel network and a sub-basin definition model (i.e., TOPAZ) to isolate the watersheds and subwatersheds. Rainfall-runoff and upland soil erosion are also simulated using AGNAPS 2001 or SWAT in order to determine the boundary conditions for the channel network model. The outputs from TOPAZ and AGNAPS/SWAT are then used to simulate channel network flow and

sediment routing via CCHE1D.

Summary

Dr. Wang summarized his presentation by noting that NCCHE has just completed developing, verifying, validating, and refining a series of state-of-the-art sediment (pollutant) transport models. Numerous validation and application tests have proven their validity and applicability to a large number of sediment/pollutant transport, morphodynamic problems. These models are available to scientists and federal agencies.

Water quality models (1-D, 2-D, and 3-D) and a regional sediment/pollutant management decision support system are currently under development. Scientists from federal agencies are invited to collaborate with NCCHE on the development of these models, so that they can be ready for application as soon as possible.

2.6.5 Open Discussion

Steve McCutcheon asked about the state-of-the-science in geomorphology modeling. He was particularly interested in how CONCEPTS compares with GSTARS. Steve McCutcheon was also interested in how the basic principles in the models being developed by National Center for Computational Hydroscience and Engineering (NCCHE) are related to GSTARS, unit stream power, and the second law of thermodynamics. He was also looking for more information on how bank erosion is being simulated in the model being developed by NCCHE.

According to Sam Wang (NCCHE), NCCHE's approach is based on momentum, rather than power. Bank erosion is simulated based upon shear force, which is calculated by using velocity, direction, and magnitude to calculate shear stress and then multiplying by the area. The gravitational force of the mass of the bank material is also included. If the erosion is excessive when the angle of the bank is steeper than the reposed angle, then the bank will slide into the bed and the bank will retreat. He then noted that NCCHE has applied a very simple model to simulate larger-scale meandering in the natural direction by assuming that the width of the channel remains constant. It is able, with this model, to simulate the meander until it has evolved to the point that it is about to cut off. NCCHE uses a non-traditional approach to simulate scour hole that occurs around a bridge pier or an abutment. Since it was not able to get good results using the shear stress model, it included downwash effects at the front of the bridge pier of an abutment. It also considers the strength of the vortices and the intensity of the turbulence kinetic energy, which cause the bed to be loosened and carried away. The intensity of the turbulence kinetic energy actually correlates well with turbulent fluctuations observed by Kyoto University.

Chih Ted Yang opened by noting that GSTARS is based on the theory of minimum energy dissipation rate. The theory of minimum energy dissipation rate was derived in 1971 based on the thermodynamics law. The rate of energy dissipation, dy/dy, is the product of velocity and slope. Regarding application, Chih Ted Yang praised Sam Wang's development of the 3-D model and computer simulation techniques.

Chih Ted Yang then noted that he adheres to the theory of minimum energy dissipation rate when addressing river morphology. After noting that he derived his unistream power equation for sediment transport indirectly from the theory of minimum energy dissipation rate, he then stressed that rate of energy dissipation of the unistream power dominates the whole phenomenon. After stating that river systems observed today are the cumulative results of erosion, sediment transport, and deposition, he then noted that sediment concentration is a function of unit strength power and that the product of velocity and slope can describe both sediment transport and erosion. Thus when studying river morphology, Dr. Wang uses the theory of minimum energy dissipation rate rather than shear strength to determine the direction of river movement.

According to Chih Ted Yang, two approaches are used during the study of river hydraulics. The first approach is based on Newton's Law of Motion. When this approach is used, a set of partial differential equations is solved based on initial and boundary conditions. Since boundary conditions are part of the answer obtained in fluvial river hydraulics, this approach is not suitable for river hydraulics. The second method uses a variational approach based on the minimum energy dissipation rate. Since the variational approach does not need boundary conditions, it is possible to solve for river hydraulics using the minimum energy dissipation rate subject to a constraint function for sediment load, water discharge, and geological constraints.

Andrew Simon opened by noting that unit stream power and energy minimization is a very powerful tool that his group has used to compare channel adjustment streams in a diverse set of streams. After noting that most of his comments on GSTARS versus CONCEPTS will be from an operational perspective, Andrew Simon noted that he tried to add a bank stability algorithm to GSTARs. Although both models are 1-D, since GSTARS uses the stream tube concept it is able to develop a pseudo 2-D output (e.g., hydraulic and sediment transport parameters within each tube). Although Andrew Simon believes that USGS ARS could benefit from the addition of a 1-D stream tube approach, it is currently attempting to make CONCEPTS workable for sinuositic channels in a deterministic fashion.

Andrew Simon then noted that one advantage of CONCEPTS model over the GSTARS model is that it uses a deterministic bank stability algorithm. Since bank processes are controlled by hydraulic and geotechnical engineering principles, deterministic processes are needed to model lateral changes (e.g., bank failures). In order to use this algorithm, the cohesive properties of the bank, the friction angle, etc., need to be measured. He then noted that the CONCEPTS model handles pore-water pressures, the variability of the changing strength as pore-water conditions change, confining pressure effects, etc.

Since streams have about 5 or 6 degrees of freedom (widening, depth changes, slope changes, bed sorting, armoring, meandering, etc.), Steve McCutcheon wanted to know which of these conditions CONCEPTS addressed. According to Andrew Simon, CONCEPTS can address all of these conditions except meandering. He also noted that meandering is currently the highest research priority of USDA ARS. Also, the effects of riparian vegetation have been tested in support of the bank stability algorithm. Both the effects of root reinforcement and moisture uptake by the vegetation were studied. Ted Yang then noted that GSTARS accounts for meandering in principle. He then noted that although meandering is the result of the minimum energy dissipation rate theory and is, therefore, automatically incorporated in the model, this aspect of the model is not publicized as being handled within this model.

Lee Mulkey (USEPA NRMRL) asked whether the panel had considered performing a value of information analysis. Both Ted Yang and Andrew Simon agreed that although they could collect the cost information, they would have difficulty assessing value since these factors are based on socioeconomic issues and value judgments.

2.7 BMPs and Models

2.7.1 Urban BMP Models: Accuracy and Application

Bill Barfield, Oklahoma State University

Increased runoff from urbanization can yield increased sediment in streams. Although a number of BMPs can control peak discharges and settleable solids, none of the available BMPs effectively control runoff volume or TSS. Existing technologies need to be improved and new technologies need to be developed in order to develop BMPs that control runoff volume. Hydrologic and sediment parameter data also need to be collected for urban conditions, particularly during and after construction activities.

The Problem

Stormwater channels are used to drain urban areas that have been made relatively impervious following development. Land use changes often result in changes to the width and the depth of a stormwater channel due to scour and deposition. Changing land uses and the addition of impervious covers can also indirectly impact aquatic biota (sensitive species). Modeling results indicate that stormwater discharge, sediment production, and channel width and depth increase as land use becomes more developed/urbanized.

What Can Be Done About Sediment and Stormwater Problems

A number of post construction stormwater/sediment controls can be used to minimize the impact of construction land use changes.

<u>Stormwater BMPs</u>

The following practices are used to "manage" stormwater and can either increase or decrease land use impacts on streams:

$ Stormwater basins
$ Infiltration basins
$ Porous structures
$ Buffer strips
$ Bioswales
$ Bioretention cells
$ Filters

Stormwater Basins

Stormwater basins are the most commonly used technology for controlling urban runoff. Table 9 details some of the parameters that are considered when developing and evaluating stormwater basins to control peak discharges, runoff volumes, and nutrients.

Summary of Stormwater BMPs

In general, ponds and infiltration basins can easily control peak discharge but do not effectively control volume. Although nutrient reduction is limited, heavy metal reduction can be high. Vegetative buffer strips, on the other hand, are less effective than ponds in nutrient removal but are relatively effective at sediment removal. Bioretention cells have the theoretical potential to control runoff volume to predisturbed levels and have shown some effectiveness at controlling heavy metals, phosphorous, and some organics. Although they are not effective at controlling nitrates, their potential needs to be modeled and evaluated in better detail.

Table 9. Stormwater Basin Effectiveness —SC Upland

Peak Discharge		**Runoff Volume**		**Nutrients**	
A =	100 ac	*A =*	100 ac	*A =*	100 ac
Predisturbed =	forest	*Predisturbed =*	forest	*Predisturbed =*	forest
Post disturbed =	60% imp	*Post disturbed =*	60% imp	*Post disturbed =*	60% imp
Predisturbed peak discharge =	42.3 cfs	*Predisturbed runoff volume =*	4.52 ac-ft	*Predisturbed Phos EMC =*	0.1 mg/l
Post disturbed peak discharge =	311.5 cfs	*Post disturbed runoff volume =*	24.4 ac-ft	*Post disturbed Phos EMC =*	0.4 mg/l
Area required to match peak flows =	4 ac	*Area required to match predisturbed using infiltration*	66 ac	*Trapping efficiency for 5 acre basin - Dry*	20 %
Percent of development required for basin =	4%	*Percent of development required =*	66%	*Trapping efficiency for 5 acre basin- Wet*	30 %

Sediment BMPs
A number of sediment BMPs are used to minimize the construction impacts.

Sediment Ponds
Sediment ponds are the most frequently used BMP during construction activities. These typically small ponds detain flow and provide detention time to allow sediment to settle. They also provide storage for trapped sediments and a limited amount of stormwater control. Although sediment ponds have difficulty meeting the suspended solids standards, they are able to meet the settleable solids standards, assuming that they are appropriately sized. Chemical treatment and flocculation can be used in a sediment pond to remove fine sediment. These techniques are difficult to use in uncontrolled stormwater situations and are often very sensitive to variations in flow, sediment properties, and chemistry.

Vegetative Filter Strips
Vegetative filter strips retard flow allowing the off-site sediments time to settle. Sediments that reach the surface are trapped and infiltration carries sediment into soil matrix.

Ditch Checks and Rock Fill Dams
Ditch checks and rock fill dams can also be used to control off-site sediments. The rocks stabilize channel grade and retard flow, allowing ponding to occur and sediments to settle behind the ditch check. Trapping occurs in the ponded area and in the rock. Overtopping can result, however, in decreased trapping. Although ditch checks and rock fill dams are a good idea, they often “wash out” due to poor installation.

Filter Fences
Not only are filter fences difficult to install properly, but their effectiveness has not been established. Although laboratory studies have shown high trapping efficiencies, field trapping efficiencies are usually near zero. There are a large number of reasons for this difference, including the fact that filter fences cannot be installed on a contour (causing lateral flow to be a problem) and problems during linear construction. In addition to providing inadequate detention time to trap fines, the fabric elongates easily (up to 50%), causing opening of pores as well as overturning. Vandalism and destruction by construction operations and lack of maintenance also contribute to their poor performance.

Summary of Construction Sediment Controls
On-site controls prevent sediment from becoming suspended and are therefore preferred to off-site controls. Sediment ponds can trap settleable solids, but not colloidal clays without flocculation. Vegetative filter strips likewise can trap settleable solids but have limited storage capacity. Rock-ditch checks unfortunately have a limited impact on sediments.

On Site Construction Sediment Control Practices
A number of on-site practices can be employed during construction to control sediments, including keeping the sediments in place and limiting sediment exposure. Stabilizing drainage channels and limiting exposure using mulch and vegetation are also encouraged.

Analytical and Design Tools for Sediment BMPs
A number of analytical and design tools are available for sediment BMPs including: 1) empirical and "rules of thumb" models, similar to those developed by NRCS and TVA that examine runoff volume and acres disturbed; 2) reactor based models including DEPOSITS, CSTRS, BASIN, WEPPSIE, and USEPA; and 3) hydrodynamic models including the k-e model from Colorado State and Reynold's Stress models.

DEPOSITS
DEPOSITS divides hydrographs into plugs and each plug into multiple layers in order to calculate the sediment removed from each layer. The average prediction error associated with the predicted trapping efficiencies obtained using DEPOSITS is 4.7%. Although DEPOSITS does a reasonable job of predicting trapping efficiency, this model ignores mixing and tends to over predict effluent concentrations.

CSTRS Model
CSTRS divides reservoirs into a series of continuous stirred reactors in order to evaluate mixing impacts. Although CSTRS predicts trapping efficiency, TSS, and settleable solids, it does not predict resuspension. The average prediction error associated with the predicted trapping efficiencies generated by CSTRS is 3.8%. Sediment graph timing and concentration predictions are better than the DEPOSITS model. Also CSTRS is included in SEDIMOT II and III.

BASIN Model
Although the BASIN model can handle resuspension, it is no more accurate that CSTRS at predicting effluent concentrations and timing.

USEPA Model
The USEPA model uses a modified overflow rate, accounts for turbulence, addresses settling in a basin between storms, and predicts the trapping efficiency. More information is needed regarding this model's accuracy.

WEPPSIE Impoundment Model
The WEPPSIE Impoundment model, which is part of the WEPP Continuous Simulation Model, predicts sediment settling between storms. This model is applicable to drop inlets, open channels, culverts and trickle tubes, rock fill, perforated risers, weirs, and skimmers.

Impoundment Models
Hydrodynamic impoundment models, which are also known as computational fluid dynamic models, solve turbulent equations of motion and continuity. Since there are more unknowns than equations, these models are indeterminate and must resort to auxiliary relationships to be determinate. The k-e model from Colorado State and Reynold's stress models are both impoundment models.

The ratio of momentum of inflow to weight of water to be displaced is small. Although small perturbations in boundaries cause major deflections of flow, these perturbations are generally not known deterministically. Hence hydrodynamic models tend not to be any more accurate than reactor models, and are much more complex.

Alternatives to Complex Impoundment Models—Ditch Checks
Ditch checks trap mostly coarse material and the hydraulics are often difficult to predict with any accuracy due to the heterogeneity of material. Sediment trapping by ditch check can be predicted with CSTRS model in SEDIMOT III and WEPPSIE. Trapping can also be predicted with design aids developed for SC or new TR55 aids.

Alternatives to Complex Impoundment Models—Vegetative Filter Strips
Vegetative filter strip models were developed and validated in Kentucky in the 1970s and 1980s. These models were based on fundamentals of hydraulics and sediment transport and included the impact of channelization. Other models are also available from ARS.

Although vegetative filter strips can be very effective in trapping sediment, they have limited storage capacity. In addition to being readily available and well validated, the models of their performance have been incorporated into watershed stormwater and sediment programs. These models have also been coupled to nutrients.

Summary
Although models are available for many BMPs (i.e., ponds, ditch checks, vegetative filter strips), good models are not available for silt fences. Models also need to be developed for new technologies (e.g., swirl concentrators, storm sewer inlet filters, treatment trains, flocculation, wetlands, and bioretention cells).

After noting that models work best when predicting relative values rather than absolute values, Dr. Barfield listed the following needs:

$ New technologies plus improvements in old technologies to control runoff volume.
$ Hydrologic and sediment parameters data for urban conditions, including construction and post construction.

2.7.2 Agricultural BMPs and Modeling for Sediment

James Bonta, USDA North Appalachian Experimental Watershed

Dr. Bonta's presentation addresses agricultural BMPs and models for sediment.

Erosion

Erosion degrades the soil resource and can affect nutrient and pesticide application rates and transport through the soil profile and in direct runoff. USLE estimates soil loss (erosion) from fields just prior to deposition according to the following equation:

$$Erosion = R\ K\ L\ S\ C\ P$$

Where,

R = rainfall factor (product of energy and intensity)
K = soil erodibility
L = slope length
S = slope
C = cover management
P = supporting practice

Dr. Bonta presented a series of pictorial examples during his presentation of sheet erosion and rill erosion, highlighting the loss of nutrients, topsoil, and plants.

Agricultural BMPs

The USDA is concerned with controlling erosion and sediment transport on agricultural fields. Dr. Bonta presented a series of pictorial examples of applications of the following agricultural BMPs during his presentation. He also recommended reports by Stewart et al. as references for agricultural BMPs that are currently used for erosion, nutrients, and pesticides.

No-till planting in prior crop residues, on long, steep slopes, or into cover crops—Although no-till farming provides year-round sediment control and reduces machinery passes over a field, it requires more pesticides, delays soil warming, and has some soil/climate restrictions. Overall, however, no-till farming greatly reduces runoff and erosion.

Ridge-till planting—Ridge-till planting concentrates runoff flow in mulch-covered furrows.

Terraces—Terraces support other erosion-control practices by reducing slope lengths and decreasing the concentration of runoff. They also allow more intensive cropping, but involve a substantial initial cost.

Buffers—Riparian buffers are located next to streams, lakes, and wetlands and contain perennial vegetation (grass, shrubs, and/or trees). In addition to filtering sediment from agricultural land runoff, buffers also stabilize eroding banks and provide other benefits.

Grassed waterways—Grassed waterways and other outlets facilitate the drainage of graded rows and terraced channels with minimal erosion.

Contour strip cropping—Contour strip cropping is accomplished by using row crops and hay (other) in alternate strips. This technique reduces soil loss to ~50% with contouring alone. Soil losses are also nonuniformly distributed over time.

Change in land use—Permanent grass or woodland is usually used when other control practices are inadequate.

ARS Erosion Control Research

Pictorial examples of the following erosion controls currently being researched by ARS were also presented:

Stiff grass hedges—Stiff grass hedges reduce surface slopes by ponding water. They also allow water to flow through thick vegetation, forcing sediment deposition.

PAM and gypsum —Gypsum decreases soil dispersion at the soil surface, increases infiltration, and reduces erosion. PAM strengthens aggregates, increases infiltration, and reduces erosion. Combining gypsum and PAM reduces erosion more than if each practice is used alone.

On-site erosion control using bulldozer imprints— Bulldozer imprints trap sediment in small depressions on slopes. This technique has been patented by a couple of companies.

ARS Sediment Models

ARS has developed sediment models that address the following issues:

- Erosion versus sediment yield
- Erosion or soil loss for overland flow areas and no deposition
- Watershed sediment yields for erosion as well as deposition and channel and gully processes (Note: These models are used to estimate what passes through the entire watershed.)

In addition to three weather models, ARS has developed 13 sediment models that simulate (or plan to simulate) erosion and/or sediment yield including:

- RUSLE—For overland flow areas
- AnnAGNPS—For distributed large watersheds
- WEPP—For hill slopes
- SWAT—For distributed large watersheds

SEDCAD and ANSWERs are two other models that can be used to simulate erosion and/or sediment yield.

ARS is also involved in a joint project with USGS and NRCS to develop an Object Modeling System (OMS). The goal of this project is to develop a library of tested natural-resource routines (e.g., evapo-transpiration or ET, infiltration, routing, etc.). When finalized, a user will be able to construct a custom model needed to solve a problem by selecting individual model components. Issues of spatial resolution and time steps will be invisible to the user. Thus far OMS is still under development, but RZWQM has been successfully incorporated

Weather drives all watershed models and weather must be simulated because long data records for all locations are not available. Accordingly ARS has developed the following three weather-related models:

CLIGEN—A widely used model.

GEM—More realistic than CLIGEN, and the parameters are cross correlated. Will eventually replace CLIGEN.

Storm generation—Seasonally simulates storms, resulting in the removal of 24-hour and design storm constraints.

Possible Future Research

In addition to validating models using ARS small watershed data and improving model components (interflow, infiltration, macropore flow), ARS needs to continue to develop and test innovative BMPs. ARS should also consider evaluating BMPs at the field scale using ARS watersheds as test beds. A database of BMPs that is in a uniform format should also be developed.

More models for TMDL evaluation also need to be incorporated into OMS, including both ARS and non-ARS models. Interdisciplinary studies also need to be performed using vegetation for sediment and runoff control on overland flow areas, in urban areas, in stream channels, and in gullies. In addition to working with NRCS's plant materials group, ARS should field test and evaluate vegetation effectiveness. ARS should also consider incorporating weather data into the plant selection decision and consider pathogens and pests that might limit the successful, sustained use of plants (e.g., stiff grasses).

2.7.3 Sediment Yield and Quality Assessment using Flood Control Reservoirs

Sean J. Bennett, USDA-ARS National Sedimentation Laboratory

Mr. Bennett opened by noting that since 1948 the USDA-NRCS and its cooperators have constructed nearly 11,000 flood control dams with a design life of 50 years. These dams represent a 14.5-million-dollar investment and provide over 1 billion dollars in benefit annually. Within the next 10 years, however, nearly 2,000 of these dams will need to be rehabilitated.

Reservoir Sediments

Reservoirs are an effective sink for sediments (approximately 82% to 98% for small reservoirs). Sedimentation rates average between 0.1 to 1% per year or more and since a number of reservoirs are at least 50 years old, they can provide a nearly complete, uninterrupted record of deposition. These records can be used to examine linkages between the sink and source, quality, geomorphology, land use, and hydrology. In general, sands are restricted to near-tributary sources, and silt and clay dominate the deposit in many impoundments.

Currently there are over 75,000 dams nationwide. Since many of these aging impoundments need to be assessed and rehabilitated (e.g., to remove sediments), opportunities are available to test new data collection technologies. In addition to quantifying post-impoundment deposition (via vibracoring, dating techniques, and geophysical techniques), sediment quality will also need to be assessed in order to quantify sediment-associated agrichemicals, contaminants, and nutrients (phosphorous and nitrogen) and address geochemical considerations.

Discrimination of Impounded Sediment

Vibracoring is an in situ sediment sampling technology used to collect continuous, undisturbed cores up to 4 m long. This fairly inexpensive technology penetrates the parent material through vibration (e.g., 2,000 to 3,000 rpm). In addition to providing material for chemical analysis, the cores also provide information on the stratigraphy. Since relatively significant cesium 137 (Cs_{137}) deposition first occurred in 1954/1955 and peaked in 1964, it is also possible to discriminate between pre- and post-impoundment deposition by analyzing the sample for Cs_{137} and correlating the data to stratigraphic changes.

A multi-frequency acoustic profiler (linked with a Differential Global Positioning System or DGPS and navigation system) is a geophysical technique that can be used to map/identify the base of the pre-and post-impoundment profiles. This technique measures the subsurface acoustic characteristics of the sediments and maps bulk density variations. The thickness of deposited sediment can be deduced from core and acoustic survey data and sediment yields since dam construction can be deduced from bulk density values. Comparisons between sediment volumes estimated with cores and the acoustic system sediment yield good agreement (e.g., within 2% of each other).

Sediment Quality Assessment

When assessing the quality of an impounded sediment, it is important to evaluate the concentration of both recent and historical agrichemicals (e.g., pesticides, dichlorodiphenyltrichloroethane or DDT, dichlorodiphenyldichloroethane or DDD, dichlorodiphenyldichloroethene or DDE, and herbicides), contaminants (e.g., PCBs, heavy metals, and oil and grease) and other known contaminants.

Table 10 contains depth-averaged agrichemical and metal data from samples obtained from reservoirs in Oklahoma and Mississippi. In general, depth averaged agrichemical data can be obtained for approximately 200 dollars per sample. The data ignores temporal variation in use (e.g., DDT was banned in 1972) and the dilution of the signal may result in false sense of security. Depth averaged metal data are developed from digested sediments (via nitric acid, hydrogen peroxide, and hydrochloric acid). The metals data presented in Table 10 are typical values for soils, both across the nation and worldwide.

An analysis of the over 40-year record of sediment-associated metal deposition at the Mississippi reservoir indicated some minor variations in metal concentrations with depth, but no significant change in source. Data from the Mississippi reservoir also indicated that metal and nutrient concentrations are strongly related to material texture (i.e., most of the elements of interest were associated with the clay fraction). It is also important to determine if elements are mineralogical in origin or a crystalline structure adsorbed to the clay. The impacts of bioaccumulation should also be assessed.

Geochemical Considerations
With respect to geochemical issues, since a sediment may be in a reduced or oxidized state, changing its state may mobilize elements and compounds and impact water quality. During geochemical analyses, pore waters are extracted from the sediments and examined for pore water chemistry parameters and the potential mobilization of environmentally harmful elements during oxidation.

Conclusions
Mr. Bennett closed by listing the following conclusions:

- Reservoirs can act as nearly perfect sink for sediments and can provide a relatively long and continuous record of deposition.
- Techniques such as vibracoring, radioactive dating, and geophysical systems can easily discriminate pre-impoundment material from post-impoundment sediment deposition.
- Sediment yields since dam construction can be also deduced from volumetric and bulk density surveys.
- Over long time periods, representative concentrations of sediment-associated agrichemicals, metals, and nutrients can be derived and interpreted.

Table 10. Depth-averaged Agrichemical and Metal Data from Sediments Obtained from Oklahoma and Mississippi Reservoirs

Location/Agrichemical	Concentration
Small reservoirs in Oklahoma	
DDD	up to 14 ppb
DDE	up to 125 ppb
Methyl parathion	up to 5 ppb
Large reservoir in Mississippi	
Aldrin	up to 100 ppb
BHC-beta	gamma up to 500 ppb
DDD	up to 13 ppb
DDE	up to 17 ppb
DDT	up to 4 ppb
Heptachlor	up to 115 ppb

Location/Metal	Concentration
Oklahoma and Mississippi Reservoirs	
Arsenic	up to 7 ppm
Barium	up to 230 ppm
Cadmium	up to 5 ppm
Chromium	up to 30 ppm
Copper	up to 50 ppm
Lead	up to 15 ppm
Mercury	up to 0.3 ppm
Selenium	up to 0.6 ppm
Silver	up to 0.3 ppm
Zinc	up to 50 ppm

2.7.4 Open Discussion

In response to John Paul's question about the effectiveness of straw bales, Bill Barfield (Oklahoma State University) responded that straw bales are not effective in part because they are not installed correctly. According to Bill Barfield sediments are not being controlled at construction sites using current techniques (curtains, straw bales, and silt fences).

Lee Mulkey then asked whether NRCS is concerned with farm ponds. Sean Bennett (USDA ARS) responded that it was currently focusing on flood control reservoirs. He then noted that some of the technologies developed for flood control reservoirs may be applicable to farm ponds.

Chris Nietch noted that most of the models presented for the different BMPs were field scale models. Since most of the watershed level models that are being developed are going to be applied to much larger sites, Chris Nietch questioned how these models can be scaled up so that they can address these large land areas. After noting that this issue had been discussed during his biocomplexity project, Bill Barfield noted that if a reasonable size GIS cell is used (e.g., for a 20-square-mile watershed), BMP effects will average out and the BMPs will not appear to have had an impact. It is, therefore, important to determine how a large-scale watershed study can be performed without having to use a GIS cell for every acre. Bill Barfield believes that a self-correcting or self-calibrating model approach can be used in which smaller elements are selected from the larger watershed. A response-surface analysis would then need to be performed to develop a correction factor that could be applied to the averaged value obtained from the larger grid cell in order to predict BMP effectiveness.

Joan Colson (USEPA NRMRL) was interested in whether groundwater contamination was considered when bioretention cells and other excavated holding ponds were examined. Bill Barfield responded that this is a major concern with infiltration trenches, porous pavements, etc., since contaminants are washed off and can potentially enter the groundwater. It is more of an issue in areas like Florida.

James Bonta (USDA) then responded to Chris Nietch's question by noting that cells are not always independent of each other. For example, there are at least four clay layers with perched water tables in the Coshocton area. If annual runoff volume is plotted on the Y axis and watershed area is plotted on the X axis, the resulting curve will plateau at some runoff value. This curve implies that the upland areas do not experience much runoff and that the larger, downstream areas receive increasing amounts of runoff. Because streams have cut through the topography in this area, the clay layers are exposed at different elevations, allowing the perched water to contribute to the base flow and runoff. Thus downstream cells are not necessarily independent of upstream cells. He then noted that the relationship he just described between annual runoff volume and watershed area is not uniform throughout the US.

After noting that the coring technique discussed by Sean Bennett appeared to have been used for man-made reservoirs, Bill Swietlik asked whether Sean Bennett planned to use this technique on natural lakes and whether he planned to analyze for diatoms. Bill Swietlik was also interested in whether Sean Bennett was planning to perform whole effluent toxicity tests on the pore water.

Sean Bennett responded that he has used the coring techniques in every possible depositional, unconsolidated environment imaginable. He then noted that although it is possible to sink the core in just about any unconsolidated media, it is not always possible to retrieve the cores. When sampling in a lake environment, he usually drives the core 1 to 2 inches into the dry environment and the dry material then acts as a seal for the core. Regarding dating techniques, he is actually more interested in using geochronometers than naturally occurring data techniques such as diatoms due to cost. Although toxicity tests are “out of his realm”, he plans to take the sediment, which is collected in a nitrogen environment, freeze-dry the sediment, place the sediment in distilled water in an oxygen-free environment, let it sit for 2 days, and then extract and analyze the water. He also plans to analyze the pore water.

2.8 Facilitated Open Discussion and Brainstorming

Lee Mulkey opened with four observations. First he noted that every US government institution interested in sediment policy attended this workshop, including representatives from USEPA, USDA, USGS, USACE, states, regions, academia, etc. The disciplines included hydraulic engineers, ecologists, economists, biologists, and watershed planners.

He then noted that although all the participants share a common goal, they represent different constituencies. Although the interests of these constituencies when dealing with an issue at the policy level can be somewhat contentious, Lee Mulkey was pleased to note that many research interests are commonly shared. He then noted that litigation has been either settled or prevented by identifying a common research agenda that allows the parties to collaboratively solve/reduce uncertainties.

Mr. Mulkey then remarked on the number of different data sets discussed during the workshop that reflected different dimensions of the suspended sediment problem. Although often the parties that collected the data control the data sets, many of these data sets are available and posted on the web. Mr. Mulkey then questioned how often participants that express an interest in a data set at a meeting successfully access the data set after the meeting.

After noting that the suspended sediment TMDLs have received a good deal of interest, Mr. Mulkey then observed that it is "time to deliver the goods." Although TMDLs have catalyzed a number of the discussions at this workshop, they are driven to a large extent by litigation rather than research. With the President's announcement of the Performance Management Agenda, organizations with demonstrated performance will receive funding. After noting that some of this funding will come from other parts of the federal budget where the performance was not considered successful, Mr. Mulkey then noted that the Office of Management and Budget (OMB) is looking at costs, benefits, cost-effectiveness, and performance.

Mr. Mulkey then proposed that workshop participants attempt to continue to meet and work together over time in order to exchange information and develop collaborations. He then suggested that the participants consider "hypothesis generating activities" during the open discussion. For example, since it is difficult at this time to unequivocally state the benefits and water quality impacts of BMPs, Mr. Mulkey believes that a "hypothesis generating group" could help identify the research needed to respond to this issue. After expressing interest in John Paul's conditional probability use of EMAP to address reference conditions, Lee Mulkey asked participants to consider a conditional probability view of BMPs. He then speculated that once BMPs had been stratified, it could be possible to identify a way to collect biological samples that would allow researchers to make "more robust statements" and solve the time series problem. After noting that experimental watersheds have been developed since the 1960s and that modeling has been performed in response to experimental limitations, he then noted that time series efforts may be a "3rd way."

Joseph Schubauer-Berigan then encouraged the participants to comment on Lee Mulkey's remarks and to voice suggestions for future activities. In particular, he asked the participants to voice their suggestions regarding how a group could be formed that could attack the issues and move the process forward. He then noted that many of the modelers have already started to evaluate how well the models meet our needs.

After strongly endorsing Lee Mulkey's suggestion, Bill Swietlik then suggested that the Water Quality Management Cycle may be a good way to begin organizing these efforts. He then noted that the sediment issue will not succeed unless all the pieces that fit into the management cycle are considered, including criteria, monitoring techniques, TMDL approaches, enforcement, etc. He then suggested that the workshop form small subgroups relative to critical pieces of the Water Quality Management Cycle. After identifying the critical needs of each of those pieces, each subgroup could then attempt to address the research gaps and periodically reconvene with other subgroups to share information and research advances.

A participant then questioned whether Lee Mulkey wanted to develop frequency distributions (e.g., loads and concentrations) of different BMPs. Lee Mulkey responded that he was more concerned with examining how USEPA experimentally studies the effectiveness of watershed management practices. It is often difficult to obtain institutional support over a long enough period of time to enable researchers to perform unequivocally robust experiments that examine the water quality benefits of watershed management. Since many natural processes cycle at different rates (some are very rapid, and others take decades or longer), it may not be possible to address these issues using simple input/output experiments. Considering how EMAP has examined the current biological condition using geographic sampling, Mr. Mulkey suggested that perhaps there are gradients across a watershed of different watershed management trajectory points that can be sampled, allowing spatial gradients to be substituted for temporal gradients. Mr. Mulkey is hopeful that further discussion on this topic may result in the development of a hypothesis to test whether the community is on the right path regarding different BMPs. He also believes that this is a good group to work through these issues over time and through future interaction. Hopefully different experimental approaches will yield more robust answers for OMB.

James Bonta agreed that BMP effectiveness has not been evaluated. EPA recently funded an effort that attempted to develop a database of BMPs based on a relatively comprehensive literature search. Unfortunately project personnel had difficulty finding information that was very useful. Dr. Bonta then suggested that a uniform method needs to be developed to examine BMPs and re-evaluate the BMPs used at Coshocton and other sites using existing data in order to provide useful information to EPA and other regulators.

Chris Nietch then noted that he considers BMP effectiveness a NRMRL issue, and that the objective of this conference was to obtain input on other aspects of BMPs. The following two issues requiring outside input were identified in NRMRL's management plans for BMPs: 1) scaling up from individual sites to a watershed level; and 2) selecting from multiple options. One goal of this workshop is to ensure that BMPs can be applied to the assessment models that are being developed. After noting that it is important to move away from using percent reduction coefficients for BMPs, Dr. Nietch stressed the importance of using a process-oriented approach.

Chris Nietch then discussed a study that attempted to do a probabilistic analysis of BMPs for nitrogen loads in the Long Island Sound in 1995. According to Chris Nietch, project personnel identified acceptable removal effectiveness ranges for different BMPs and the relative area that was affected by the BMP. Unfortunately the management scenario that was determined to be capable of ensuring a "no net increase in nitrogen" would have required that BMPs be utilized all over the entire watershed and therefore could not be implemented. According to Chris Nietch, too little is currently known about BMPs and methods for analyzing their impact to effectively use BMPs within the landscape. He then stressed the importance of incorporating the eco- and stream-restoration work being performed by Joseph Schubauer-Berigan's group and others.

Joseph Schubauer-Berigan responded that the purpose of the meeting was to bring experts together to better understand the indicators, consider policy issues, and identify what the states were doing in order to focus and maximize the impact of the work being done by USEPA NRMRL. In addition to encouraging interaction and future collaboration, it is necessary to use every expert's area of expertise in order to ensure that useful data are being generated during future projects. He then mentioned that one purpose of yesterday's workgroup meeting was to identify how the different USEPA offices and groups can focus their efforts in order to work more effectively.

Doug Norton then clarified that a NPDES permit will not be granted for a point source emitter for a blended water (e.g., waters with point and non-point sources) unless the water can meet WQS. After noting that it is difficult to assess how non-point sources will impact water quality, Doug Norton cautioned if a TMDL is being used and BMP effectiveness is unknown, this may prevent the NPDES permit from being issued. It is also possible that uncertainty regarding the impact of the non-point sources could cause the whole TMDL to collapse, resulting in the performance of a use attainability analysis that may result in a degraded use for the water body. In addition to possible reductions in the water quality, plans to use BMPs may be halted. He presented this anecdote to provide a perspective on how the CWA can affect water bodies, TMDLs, and water quality.

He then noted that restoration and BMP effectiveness was identified as one of the top 20 TMDL science and research needs in the 20 Needs Report developed by Doug Norton last year. According to Doug Norton, the regions considered restoration and BMP effectiveness research as the most important research need/area.

Doug Norton then mentioned that USEPA has a tech loop addressing clean sediments on the internal USEPA lotus domino directory called "techloopcleansediments". This directory contains the names of USEPA personnel interested in clean sediment issues. He plans to update this list to include all the workshop participants from USEPA and encouraged the USEPA participants to use this directory to exchange information. Doug Norton and Joseph Schubauer-Berigan agreed to look into developing a smaller list that includes both USEPA and non-USEPA participants.

After remarking on the poor performance exhibited by some of the BMPs discussed during the workshop (e.g., sediment fences), Joseph Schubauer-Berigan then questioned why money was being spent on BMPS that do not work. He then suggested that there should be an attempt to improve upon the non-structural aspect of BMPs (e.g., the organization of elements in watersheds) in order to move ahead of a problem rather than just react to it.

Bill Swietlik responded that BMP effectiveness was an area of the Water Quality Effectiveness Cycle that the participants at the workshop should focus on addressing. He then noted that USEPA funded an ASCE project to develop a BMP database designed to determine "what are we getting for our money." The database was developed to address questions posed by the regulated municipalities responsible for implementing stormwater BMPs. This database used very stringent criteria regarding how BMP performance was measured. After stating that this database currently contains 30 or 40 BMPs, Bill Swietlik noted that any organization could add BMP effectiveness data/results in the database if it met the data quality criteria. Ultimately this database is intended to serve as a source of BMP effectiveness data for both urban and rural/agricultural BMPs.

Bill Swietlik then noted that an international group that addresses BMP effectiveness met in August 2001 in Snowmass, Colorado. The purpose of this conference was to allow researchers to provide information on how effective different BMPs are at improving receiving water quality. A number of the key issues associated with how this issue should be addressed were developed (e.g., what should be monitored and how). According to Bill Swietlik, BMPs are typically considered a technology-based control designed to remove pollutants. Typically technology-based controls assume that removing pollutants will have a good effect on the receiving water body but often do not assess the BMP's actual impact on receiving water quality. Water quality-based controls are designed using the WQS and their effectiveness is assessed to ensure that the WQS are met. Although the conference indicated that it is very difficult to show receiving water improvements from BMPs, the participants suggested that it is necessary to ensure that BMPs are designed to provide ecological improvements to water quality, not just remove pollutants. Bill Swietlik then offered to forward information on how to obtain the proceedings from this conference.

After noting that the proceedings document contains a paper that analyzes the effectiveness of a BMP database for ponds and wetlands, Chris Nietch asked Lee Mulkey to comment on the use of non-structural BMPs (e.g., source control) to meet removal and ecological goals which cannot be met using structural controls. When dealing with sediments, these non-structural changes may involve changes to zoning laws or percent imperviousness controls. Although he expects that a good deal of effort will be spent developing and assessing structural controls to trap sediments, etc., he believes that many non-structural sediment controls (e.g., limiting pavement in an area) will be better at controlling sediments and make more economic sense. He then noted that sometimes BMPs can also cause problems, as demonstrated by a paper that showed that BMPs used to trap sediments caused major problems with channel bank erosion and stream stability because they increase the duration of a flow event. He then asked Lee Mulkey for input on how USEPA can raise awareness of non-structural controls.

Although the research community informs policy, Lee Mulkey believes that some policy-relevant research projects should be performed. Often communicating a politically relevant scientific conclusion through the correct channels is essential to ensuring that adaptive policy change occurs. Regarding nitrogen, the Hypoxia Assessment Report proposed that the agricultural community should reduce nitrogen use and that a couple of million acres of wetlands should be built. Unfortunately, this report did not include an "insurance policy alternative" for reducing nitrogen application for the farmers.

According to David Radcliffe erosion from construction sites has been a high profile issue for a couple of years in Georgia. The Dirt 1 committee examined erosion control approaches for construction sites in the 1970s. This committee eventually developed water quality criteria that limited increases to 25 NTUs. Following pressure from the environmental community, Dirt II was formed. Dirt II monitored the effectiveness of BMPs at three different construction sites using various techniques. The data obtained by Dirt II indicated that none of the different controls was very effective. In response to these poor results, Dirt II collaborated with a developer responsible for building a county high school near Atlanta. During this project the developer attempted to implement structural and non-structural controls that would allow the site to meet the erosion/runoff standards. In addition to attempting to limit soil disturbances, the developer used an onsite mulcher to break down any trees that had been removed from the site and then spread the mulch on the disturbed soil to cover it. Ultimately the contractor was able to meet the erosion/runoff standards using structural practices and by emphasizing soil disturbance/exposure. David Radcliffe encouraged participants to search under Dirt II on the web for a copy of the group's report.

After noting that the second half of this report addressed modeling, David Radcliffe noted that one member of Dirt II had a model called SEDCAD, which is a USLE-based model which can predict erosion and runoff from a site. These estimates can then be used to calculate suspended sediment concentrations for a design storm. He closed by noting that Georgia currently requires that a site with a NPDES permit (e.g., more than 5 acres) needs to perform upstream and downstream monitoring and that suspended sediment concentrations cannot increase more than 25 NTUs during a storm larger than 1 inch.

According to Chris Nietch new effluent guidelines were developed for construction sites by the Office of

Science and Technology (OST). Although numerical criteria were originally considered, it is now considering two other approaches. Bill Swietlik responded that the removal efficiency of 80% for the performance of BMPs from construction sites had been removed from the guidelines. According to Bill Swietlik, the removal efficiencies were deleted due to an OMB cost-benefit issue. Although the new construction site guideline will apply to 1-acre sites, it will only require conformance with a NPDES permit. Thus, sites will need to develop either a stormwater pollution prevention plan or an erosion sediment control plan, but will not need to provide data demonstrating removal efficiencies or conformance with WQS. The draft guideline should be available on the website.

Joseph Schubauer-Berigan then questioned what locations should be developed in a watershed and what type of structures should be built in order to limit the impacts. It should be possible to identify the places not to be developed, as well as densities to avoid. He then noted that many BMPs installed at newer developments do not have a chance to be effective because they are not properly installed or maintained. After encouraging participants to continue assessing the effectiveness of the different controls used, he then noted that future work is needed by the workshop participants to further develop the databases discussed during the workshop.

Bill Shuster (USEPA NRMRL) believes that USEPA's national research laboratories need to take a leadership role in establishing affiliations with other agencies rather than act reactively. For example, ARS and NRMRL are studying the effects of urbanization effects on the site hydrology at the Coshocton watershed. He then noted that data are not available that address how urbanization affects site hydrology or sediment production under various development scenarios (e.g., construction, old impervious surfaces, etc.). If USEPA took on a leadership role in developing good quality data to fill this gap, some major fundamental questions ought to be able to be addressed (e.g., what data should be put into models, what BMPs are needed, are structural BMPs needed, etc.). He closed by noting that more enhanced collaborations need to occur between USEPA, USGS, ARS, USACE, etc.

Joseph Schubauer-Berigan then closed the session by encouraging the participants to continue to communicate and sustain the momentum achieved during the workshop. Ultimately he believes that the collaborations that are developed during a workshop are one of the workshop's most important results.

Appendix A. Agenda

FINAL AGENDA

Workshop on Suspended Sediments and Solids
July 11-12, 2002

IRS Training Center
Room 1703/1704
36 East Seventh Street
Cincinnati, Ohio

<u>Thursday, July 11</u>

Welcome and Opening Remarks

8:00 – 8:30	Sally Gutierrez, Laurel Staley, Joe Schubauer-Berigan, National Risk Management Research Laboratory

Federal Sediment Research Programs

8:30 - 8:50	*USGS Support for "Clean" Sediment TMDLs* John Gray, USGS, Office of Surface Water
8:50 – 9:10	*Overview of ARS Research on Suspended Solids and Sediments* Dale Bucks, USDA-Agricultural Research Service
9:10 – 9:30	*Overview of US Army Corps of Engineers Regional Sediment Management R&D Program* Jack Davis, Engineering Research and Development Center, Coastal & Hydraulics Laboratory
9:30 – 9:50	*Office of Water Perspectives on Clean Sediment Research Needs for Criteria Development* Bill Swietlik, USEPA Office of Water, Office of Science and Technology
9:50 – 10:15	**BREAK**

Regional USEPA Sediment Issues and Approaches

10:15 – 10:45	*Challenges of Clean Sediment TMDL Development -- A Practitioner's Perspective* Bruce Cleland, USEPA Region 10 (America's Clean Water Foundation)
10:45 – 11:15	*Landscape Approach to Managing Agricultural Nonpoint Source Sediment* Tom Davenport, USEPA Region 5
11:15 – 11:45	*Region 4 Sediment TMDL Methodology: Combining Watershed Runoff and Instream Impacts* Jim Greenfield, USEPA Region 4

11:45 – 1:00 **LUNCH**

State Sediment Issues and Approaches

1:00 – 1:30 *Protocol for Establishing Sediment TMDLs in Georgia*
David Radcliffe, University of Georgia, Crop and Soil Sciences Department

1:30 – 2:00 *A Holistic Approach to Sediment Monitoring and Assessment in Iowa*
Mary Skopec, Iowa Department of Natural Resources

2:00 – 2:30 *Implementation of the Narrative Sediment Standard: The Colorado Experience*
Robert McConnell, Colorado Department of Public Health and Environment

Open Discussion

2:30 – 4:00 Open Discussion

4:00 **Adjourn**

Friday, July 12

Field Measurements and Field Data Availability

8:00 – 8:30 *USGS Perspectives on Sediment Data Quality and Stream Restoration*
John Gray, USGS, Office of Surface Water

8:30 – 9:00 *Empirical, Geographically-Based Thresholds of Effect (Criteria) Determined with Conditional Probabilities* - *A Proposed Approach*
John Paul, USEPA National Health and Environmental Effects Research Laboratory

9:00 – 9:30 Open Discussion

9:30 – 9:45 **BREAK**

Sediment Management Models, Tools, and Analytical Approaches

9:45 – 10:15 *Reference Sediment-Transport Rates for Level III Ecoregions and Preliminary Links with Aquatic Indices*
Andrew Simon, USDA- Agricultural Research Service

10:15 – 10:45 *Generalized Sediment Transport Model for Alluvial River Simulation*
Ted Yang, US Bureau of Reclamation, Sedimentation and River Hydraulics Group

10:45 – 11:15 *Sediment Transport Modeling* - *Tools for TMDL Analyses*
Earl Hayter, USEPA National Exposure Research Laboratory-Athens, GA

11:15 – 11:45	*National Center for Computational Hydroscience and Engineering Sediment Models: Capabilities and Applications* Sam Wang, National Center for Computational Hydroscience and Engineering
11:45 – 1:00	**LUNCH**
1:00 – 1:45	Open Discussion for Sediment Management Models, Tools, and Analytical Approaches Session

Best Management Practices and Models

1:45 – 2:15	*Urban BMP Models: Accuracy and Applications* Bill Barfield, Oklahoma State University
2:15 – 2:45	*Agricultural BMPs and Models* James Bonta, USDA North Appalachian Experimental Watershed, Coshocton, Ohio Don Wauchope, Southeast Watershed Research Center, Tifton, GA
2:45 – 3:30	Open Discussion for Best Management Practices and Models Session
3:30 – 3:45	**BREAK**
3:45 – 4:15	*Assessment and Management of Reservoir Sedimentation* Sean Bennett, USDA- Agricultural Research Service

Facilitated Open Discussion and Brainstorming

4:15 – 5:00	Where we are, where we need to go, structural versus nonstructural BMPs, collaborative efforts, further communication, etc.
5:00 – 5:15	Closing Remarks Joe Schubauer-Berigan
5:15	**Adjourn Workshop**

Appendix B. List of Speakers and Participants

USEPA Workshop on Suspended Sediments and Solids
July 12 – 12, 2002
Cincinnati, Ohio

LIST OF SPEAKERS

Bill Barfield
Professor
Oklahoma State Univ., Department of Biosystems and Agricultural Engineering
109A Agricultural Hall
Stillwater, OK 74078-0497
Phone: 405-744-5431
Fax: 405-744-6059
E-mail: bill@okstate.edu

Sean J. Bennett
Research Geologist
USDA-ARS National Sedimentation Laboratory
598 McElroy Drive, PO Box 1157
Oxford, MS 38655
Phone: 662-232-2926
Fax: 662-232-2915
E-mail: sjbennett@ars.usda.gov

James Bonta
Res. Hydraulic Engineer
USDA ARS, North Appalachian Experimental Watershed
Box 488
Coshocton, OH 43812
Phone: 740-545-6349
Fax: 740-545-5125
E-mail: bonta@coshocton.ars.usda.gov

Dale A. Bucks
Senior National Program Leader, Water Quality and Management
USDA – Agricultural Research Service
5601 Sunnyside Avenue
Beltsville, MD 2005-5140
Phone: 301-504-7034
Fax: 301-504-6231
E-mail: dab@ars.usda.gov

Bruce Cleland
TMDL Technical Coordinator
America's Clean Water Foundation
25919 – 99th Avenue S.W.
Vashon, WA 98070
Phone: 206-463-2596
Fax: 206-463-2582
E-mail: b.cleland@acwf.org

Thomas E. Davenport
National Nonpoint Source Pollution Expert
US EPA Region 5
77 W. Jackson Blvd.
Chicago, IL 60604
Phone: 312-886-0209
Fax: 312-886-7804
E-mail: davenport.thomas@epa.gov

Jack E. Davis, PE
Research Hydraulic Engineer
US Army Corps of Engineers
US Army Engineer R&D Center (CEERD-HC-SE),
3909 Halls Ferry Rd.
Vicksburg, MS 39180-6199
Phone: 601-634-3006
Fax: 601-634-3008
E-mail: jack.e.davis@erdc.usace.army.mil

John R. Gray
Sediment Specialist/Hydrologist
US Geological Survey, Office of Surface Water
415 National Center, 12201 Sunrise Valley Drive
Reston, VA 20192
Phone: 703-648-5318
Fax: 703-648-5722
E-mail: jrgray@usgs.gov

James M. Greenfield
Environmental Engineer, EPA R4 TMDL Coordinator
USEPA Region 4 Water Division
61 Forsyth Street, 15th Floor, Sam Nunn Federal Center
Atlanta, GA 30303
Phone: 404-562-9238
Fax: 404-562-9224
E-mail: greenfield.jim@epa.gov

Sally C. Gutierrez
US EPA NRMRL WSWRD
MS 689
26 West Martin Luther King Drive
Cincinnati, OH 45268
Phone: 513-569-7683
Fax: 513-569-7658
E-mail: gutierrez.sally@epa.gov

Earl J. Hayter
Research Environmental Engineer
US EPA National Exposure Research Laboratory
960 College Station Road
Athens, GA 30605-2700
Phone: 706-355-8303
Fax: 706-355-8302
E-mail: Hayter.Earl@epa.gov

Robert P. McConnell
Monitoring Unit Manager
Colorado Department of Public Health and Environment, Water Quality Control Division
4300 Cherry Creek Drive South
Denver, CO 80246-1530
Phone: 303-692-3578
Fax: 303-782-0390
E-mail: robert.mcconnell@state.co.us

Scott Minamyer
US EPA National Risk Management Research Laboratory
26 West Martin Luther King Drive
Cincinnati, OH 45268
Phone: 513-569-7175
E-mail: minamyer.scott@epa.gov

John F. Paul
Research Environmental Scientist
US EPA National Health and Environmental Effects Research Laboratory
Mail Drop: B205-01
Raleigh, NC 27711
Phone: 919-541-3160
Fax: 919-541-4621
E-mail: Paul.John@epa.gov

David E. Radcliffe
Professor
Crop and Soil Sciences Department, University of Georgia
Athens, GA 30602
Phone: 706-542-0897
Fax: 706-542-0914
E-mail: dradclif@uga.edu

Joseph Schubauer-Berigan
US EPA National Risk Management Research Laboratory
26 West Martin Luther King Drive
Cincinnati, OH 45268
Phone: 513-569-7734
E-mail: schubauer-berigan.joseph@epa.gov

Andrew Simon
Research Geologist
USDA-ARS National Sedimentation Laboratory
P.O. Box 1157, 598 McElroy Drive
Oxford, MS 38655
Phone: 662-232-2918
Fax: 662-232-2915
E-mail: asimon@ars.usda.gov

Mary Skopec
Acting Section Supervisor – Water Monitoring Section
Iowa Department of Natural Resources
109 Trowbridge Hall
Iowa City, IA 52242
Phone: 319-335-1579
Fax: 319-335-2754
E-mail: mskopec@igsb.uiowa.edu

William Swietlik
Program Manager
USEPA, Office of Water, Office of Science and Technology
Health and Ecological Criteria Division (4304T),
1200 Pennsylvania Avenue, NW
Washington, DC 20460
Phone: 202-566-1129
Fax: 202-566-1140
E-mail: swietlik.william@epa.gov

Sam S.Y. Wang
F.A.P. Barnard Distinguished Professor and Director
National Center for Computational Hydroscience and Engineering
The University of Mississippi, Carrier Hall, Room 102, P.O. Box 1848
University, MS 38677-1848
Phone: 662-915-5083
Fax: 662-915-7796
E-mail: wang@ncche.olemiss.edu

Chih Ted Yang
Manager, Sedimentation and River Hydraulics Group
US Bureau of Reclamation, Sedimentation and River Hydraulics Group
Denver Federal Center Building 67, PO Box 25007, D8540
Denver, CO 80225
Phone: 303-445-2550
Fax: 303-445-6351
E-mail: tyang@do.usbr.gov

US EPA Workshop on Suspended Sediments and Solids
July 12 – 12, 2002
Cincinnati, Ohio

FINAL LIST OF PARTICIPANTS

USEPA PARTICIPANTS

Jason Ammerman, USEPA NRMRL
Ben Blaney, USEPA NRMRL Immediate Office
Mike Borst, USEPA NRMRL WSWRD
Tim Canfield, USEPA NRMRL SPRD
Joan Colson, USEPA NRMRL TTSD
Susan Cormier, USEPA NERL-CIN
Bernie Daniel, USEPA NERL-CIN
Michael Elovitz, USEPA NRMRL WSWRD
Richard Field, USEPA NRMRL WSWRD
Joeseph Flotemersch, USEPA NERL-CIN
Florence Fulk, USEPA NERL-CIN
Haynes Goddard, USEPA NRMRL
Vince Gallardo, USEPA
Michael Goss, USEPA NRMRL WSWRD
Mohamed Hantush, USEPA NRMRL
Terry Hoagland, USEPA NRMRL LRPCD
Christopher Impellitteri, USEPA NRMRL LRPCD
Eric Kleiner, USEPA NRMRL LRPCD
Don Klemm, USEPA NERL-CIN
Michael Kravitz, USEPA NCEA-CIN
Beth Lemberg, USEPA
Steven McCutcheon, USEPA NERL-ATH
Marc Mills, USEPA NRMRL LRPCD
Scott Minamyer, USEPA NRMRL TTSD
Matt Morrison, USEPA NRMRL LRPCD
Lee Mulkey, USEPA NRMRL Immediate Office
Chris Nietch, USEPA NRMRL WSWRD
Doug Norton, USEPA OFFICE OF WATER OWOW
Paul Randall, USEPA NRMRL LRPCD
David Risley, USEPA NRMRL TTSD
Greg Sayles, USEPA NRMRL LRPCD
Joseph Schubauer-Berigan, USEPA NRMRL LRPCD
Chris Schultz, USEPA NRMRL LRPCD
Bill Shuster, USEPA NRMRL STD
Laurel Staley, USEPA NRMRL LRPCD
Hale Thurston, USEPA
Dennis Timberlake, USEPA NRMRL LRPCD
Joe Williams, USEPA NRMRL SPRD
Steve Wright, USEPA NRMRL LRPCD

NON-USEPA PARTICIPANTS

Paul Braasch
Clermont County
Office of Environmental Quality
2379 Clermont Center Drive
Batavia, OH 45103

John Mathews
Ohio Department of Natural Resources
Division of Soil & Water Conservation
4383 Fountain Square Drive, Building B-3
Columbus, OH 43224
Phone: 614-265-6685
Fax: 614-262-2064
Email: John.Matthews@dnr.state.oh.us

John McManus
Environmental Information Technician
Clermont County
Office of Environmental Quality
2379 Clermont Center Drive
Batavia, OH 45103
Phone: 513-732-7894
Fax: 513-732-7310
Email: jmcmanus@co.clermont.oh.us

Daniel E. Mecklenburg
Ecological Engineer
Ohio Department of Natural Resources
Division of Soil & Water Conservation
Fountain Square, Bldg. E-2
Columbus, OH 43224
Phone: 614-265-6639
Fax: 614-262-2064
Email: dan.Mecklenburg@dnr.state.oh.us

Appendix C. Abstracts

USGS Support for "Clean" Sediment TMDLs—Present, and Future?

John R. Gray
Office of Surface Water, Water Resources Discipline
jrgray@usgs.gov; http://water.usgs.gov/osw/techniques/sediment

The U.S. Geological Survey (USGS) has the mandate to coordinate the Nation's water information acquisition, storage, and dissemination activities, including surface- and ground-water quantity and quality, fluvial sediment, and constituent transport (Office of Management and Budget Memorandum M-92-01, 1991). According to the National Research Council, "...several federal water quality protection efforts with practical applications would ...benefit from improved sediment sampling data, such as the USEPA's TMDL Program" (NRC, 2002, "Opportunities to Improve the USGS National Water Quality Assessment Program").

Following is some information on USGS monitoring and research activities, and some potential future directions in the acquisition of fluvial-sediment and ancillary data and related activities in support of USEPA's Total Maximum Daily Load (TMDL) program, stream restoration efforts, and other fluvial-sediment endeavors.

Infrastructure and Selected Programs and Products of the USGS

Infrastructure and General Monitoring**:** Data acquisition takes place as part of four Disciplines (formerly "Divisions") within the USGS: Water Resources (WRD), Biology, Geology, and Geography. Most hydrologic monitoring (flow, sediment, water quality, precipitation) is performed from more than 200 WRD offices located in every State. USGS-WRD operates a total of ~6700 continuous-record streamgages, ~3,300 water-quality stations, and ~140 daily suspended-sediment monitoring stations nationwide. Additionally, periodic records of suspended-sediment are collected at ~600 sites; for bedload at ~50 sites; and for bed material at ~110 sites (statistics from Melvin Lew, USGS, written commun., 2000, for period October 1999 through September 2000). There is no—and has never been—a comprehensive U.S. national sediment monitoring program.

See http://www.usgs.gov/ for general information on the USGS; http://water.usgs.gov/ for information on the USGS Water Resources Discipline; http://water.usgs.gov/osw/ for information on the Office of Surface Water (OSW); http://water.usgs.gov/osw/techniques/sediment.html for information on fluvial sediment from the OSW; and http://water.usgs.gov/osw/techniques/workshop/ for information on USGS sediment research capabilities in 1997.

USGS Streamflow Data**:** See http://water.usgs.gov/osw/data.html.

USGS Sediment Data**:** For instantaneous sediment data, see http://waterdata.usgs.gov/nwis/qwdata and http://water.usgs.gov/osw/sediment/index.html. These web sites were developed through partial support from USEPA's Office of Water. For daily-value sediment data through September 1994, see http://webserver.cr.usgs.gov/sediment/.

Protocols for Sediment- Water-Quality, and Flow-Data Collection: The USGS has more than a century of experience in hydrologic measurements, and long-standing protocols for collection, storage, and dissemination of those data (http://water.usgs.gov/osw/techniques/sedimentpubs.html for protocols for collecting sediment data; http://water.usgs.gov/owq/FieldManual/ for water-quality measurement protocols; and http://water.usgs.gov/pubs/wsp/wsp2175/ for flow measuring protocols).

National Streamflow Information Program (NSIP)**:** The NSIP represents a permanent, national program of regional streamflow assessment, with base study units by physiographic provinces. One of the five NSIP objectives is to provide a "backbone" or core of streamgages that are of such critical importance to the National Streamgage Network that their operation should be assured with Federal funds (http://water.usgs.gov/nsip/index.html).

National Research Program (NRP)**:** The NRP comprises 7 percent of WRD's human resources, and performs basic and applied research in hydrology. It includes surface-water hydrology, ecology, and a geomorphology and sediment transport disciplines, and includes considerable modeling expertise (http://water.usgs.gov/nrp/).

National StreamStats Program (NSSP)**:** The USGS Office of Surface Water (OSW) is developing a national Web-based application for serving streamflow statistics to the public. Streamflow statistics, such as the 100-year flood and the 7-day, 10-year low flow, are used for water management, permitting, and design by all levels of government, and by engineers, consultants, and scientists. The Web application will provide users with improved access to published streamflow statistics and the ability to estimate streamflow statistics for ungaged sites on streams (http://water.usgs.gov/osw/programs/streamstats.html).

USGS SPARROW Model**:** The SPAtially Referenced Regressions On Watershed Attributes (SPARROW) model relates in-stream water-quality measurements to spatially referenced characteristics of watersheds, including contaminant sources and factors influencing terrestrial and stream transport. The model empirically estimates the origin and fate of contaminants in streams, and quantifies uncertainties in these estimates based on model coefficient error and unexplained variability in the observed data. The model is being applied to national estimates of sediment transport (http://water.usgs.gov/nawqa/sparrow/).

HYDRO21- New Technologies for Hydrologic Data Collection**:** The USGS is organizing an initiative intended to identify and incorporate new technologies and the associated instruments and procedures into the USGS hydrologic data network. Many of the present procedures for making hydrologic field measurements have been utilized for over 50 years and are labor intensive and expensive to maintain and operate. To reduce data collection costs, provide accurate and timely hydrologic information, and further the science of hydrology, a Hydro 21 Committee has been formed to search out new technologies that may replace present field procedures for collection of physical and chemical data. The focus of Hydro21 is on streamflow measurements (http://or.water.usgs.gov/hydro21/).

National Sediment Laboratory Quality Assurance (NSLQA) Program**:** The NSLQA Program is part of an overall quality assurance program for sediment analyses operated by the USGS that combines and augments several existing quality-assurance activities. The Program provides quantitative information on sediment-data quality to sediment laboratories and their customers. The focus of this project is on all quantitative analyses done on water-sediment mixtures to derive concentrations, sand/fine splits, and particle-size distribution completed by the visual accumulation tube and sieve/pipette, Sedigraph, and bottom withdrawal methods. The overall quality assurance program also includes onsite qualitative reviews of sediment laboratory operations, procedures, and equipment (OSW Memo 98.05, 1998) (http://sedserv.cr.usgs.gov/).

***Reconfigured Channel Monitoring and Assessment Program (RCMAP)*:** The USGS is engaged in a program to monitor and assess the long-term geomorphic behavior of selected river and stream reaches that previously have undergone some physical modification. These modifications include natural channel adjustments to floods as well as intentional channel reconfigurations to alter the function or appearance of a river reach. Geomorphic surveys, photographic records, and sediment characteristics of selected river reaches are available from the RCMAP data base maintained and periodically updated by the USGS Water Resources Discipline (USGS Water-Resources Investigations Report 99-4111, and http://co.water.usgs.gov/projects/rcmap/rcmap.html).

***Sediment TMDL Information*:** The USGS, with support from the USEPA Office of Water, has developed a shell for a searchable archive system on studies on Sediment Total Maximum Daily Loads (TMDLs). This archive contains selected information describing studies on TMDLs including many items such as the method used to estimate existing sediment loads, method used to monitor the collection of data, and several other important features conducted during these Sediment TMDL studies. The interactive features of this website, not yet available to the public, will be designed to help investigate methods used in determining, estimating and monitoring sediment TMDLs through the USEPA website (currently available as a demo project at http://oregon.usgs.gov/sed_tmdl/).

USGS Stream Restoration Workshop: The workshop, held in Urbana, IL, February 20-22, 2002, brought together a diverse group from government, university, and the private sector. The proceedings, including papers and presentations, are available on CD-ROM by contacting USGS Hydrologist Tim Straub (tdstraub@usgs.gov).

Federal Interagency Sedimentation Project (FISP): The FISP, co-located at the U.S. Army Corps of Engineers, Waterways Experiment Station in Vicksburg, MS, provides to any buyer the calibrated isokinetic sediment and water-quality samplers required to obtain the bulk of quality-assured sediment data (http://fisp.wes.army.mil/).

***ASTM Fluvial Sediment Definitions*:** Nomenclature continues to be a problem in the field (for example, the words, “sedimentation,” “siltation,” “total” (as in TMDL) and “load” can be construed to refer to different processes or phases. USGS recommends adoption of ASTM D4410-97, “Terminology for Fluvial Sediment.”

***Develop a SedStats Program in the Image of the USGS StreamStats Program*:** Some work is underway by the USGS, other Federal agencies, and several universities relating digital land overlays to streamflow and sediment transport. USGS envisions a pilot project to confirm the efficacy of developing regionalized sediment statistics and serving the data via point-and-click application.

***Reference Conditions*:** Expand on M.S. thesis by R.T. Chang (2001; USGS and Duke University) to equate sediment transport to land use at relatively pristine sites represented by the Hydrologic Benchmark Network (HBN, http://water.usgs.gov/hbn/); and on M.S. thesis by L. M. Turcios on characteristics of HBN sediment-transport curves (2002; USGS and George Washington University). Additionally, a reversal in the decline in data collection at the HBN sites should occur, to again include fluvial-sediment data collection.

***Sediment-Transport Curves*:** USGS and University of Arizona submitted an unsuccessful NSF proposal, “Developing the Science and Technology of Sediment Rating Curves.” USGS recommends an early, thorough evaluation of the efficacy of sediment-transport curves in TMDL studies.

National Synthesis of Sediment Data**:** Perform a National Synthesis of the USGS NWISWEB Sediment database (perhaps per proposal by Gray and Gellis, August 31, 2001) for TMDL and stream restoration applications. A first task in the synthesis would be to evaluate requirements for accessing historical paper-copy sediment and flow data.

Reservoir Information System (RESIS)**:** Complete the RESIS-II effort led by USGS NRP researcher Robert Stallard (see Proceedings of the 7th Federal Interagency Sedimentation Conference).

Marry flow, transport, and biotic models**:** A major goal should be to improve and link models describing discrete but interrelated aspects of the hydrologic and biotic system.

Develop a Comprehensive "Toolbox" in Support of "Clean" Sediment TMDLs**:** We propose development and application of a suite of hydrological and sedimentological tools to bring to bear on TMDL projects that would include but not be limited to techniques recommended by Dave Rosgen of Wildland Hydrology, Inc.

Regional Sediment Management Research Program Fact Sheet

February 2002

1. Purpose: Provide basic information on a Corps of Engineers strategic R&D initiative to provide regional sediment management capabilities and tools to the Corps.

2. Facts:

Problem: Excessive sediment erosion, transport, and deposition are estimated to cause damages of approximately $16 billion annually in North America (Osterkamp et al., 1998). The Corps alone spends more than $700M per year dealing with problem sediments, mainly for dredging and placement. Many water resource projects are designed to remedy local sediment problems, but sometimes at the expense of creating even larger problems some distance away. Successful project design and operation requires that sediment issues be resolved at both the local and regional levels, yet resource managers lack the information and tools they need to make informed decisions. These challenges adversely affect water resource projects for navigation, flood and storm damage reduction, and environmental quality ranging from the upper reaches of watersheds to the sea.

The Solution: Regional Sediment Management (RSM) employs natural processes and human activities to ensure that water resources projects throughout a sediment region affect sediment, and are affected by it, in an economically and environmentally sustainable manner. It recognizes that the region and embedded ecosystems respond beyond the space and time scales of individual projects, and that a proactive regional planning and engineering approach can produce significant national benefits.

Objectives: The Regional Sediment Management Research Program (RSMP) will provide knowledge and tools the Corps will need for effective water resource projects in which sediment resources are managed holistically in an environmentally and economically sustainable manner for the life of the projects. The end products will be focused on water resource project design, operation, and maintenance methods that:

$ Minimize disruption of natural sediment pathways and processes
$ Mediate natural processes that have adverse environmental or economic impact

Approach: The RSMP will produce targeted R&D serving multiple Corps business areas. It will employ ongoing project experience (including Demonstration Projects) to provide data and lessons learned. It will use enabling technologies of local-scale products and tools, including those generated by other R&D programs within and outside the Corps. It will generate technologies that integrate the best available knowledge on sediment behavior and regional morphology into management decision support tools for: a) regional and basin scale analyses, and b) evaluation of the impacts of projects and management decisions on and by long-term, large-scale sedimentation processes.

A key element of the program will be full coordination with other organizations with sediment management or monitoring expertise.

Funding: The RSMP has been funded at $2M for Fiscal 2002 by Corps Headquarters under the General Investigations R&D Program.

Benefits: By making Corps projects more effective and efficient with respect to sedimentation processes and impacts, those projects will perform better (e.g., full channel dimensions available for longer periods, stable and productive shorelines and wetlands); dredging volumes in the most severely affected channels will be reduced or displaced so that the Corps budget will cover more projects more thoroughly; and opportunities for environmental enhancement will be maximized. Saving even a tiny fraction of estimated sediment-related costs will amount to tens of millions of dollars per year. Public trust in water resource projects will improve when they are seen to maximize national benefits by coordination across business area, agency, and political boundaries, enabling the Corps to accomplish its missions in a less confrontational environment.

3. POC:

Jack E. Davis, Program Manager, jack.e.davis@erdc.usace.army.mil
William H. McAnally, Technical Manager; william.h.mcanally@erdc.usace.army.mil

Reference

Osterkamp, W. R., P. Heilman, and L. J. Lane, “Economic Considerations of Continental Sediment Monitoring Program,” *International Journal of Sediment Research*, (4) December 12-24, 1998.

Overview of ARS Research on Suspended Solids and Sediments

Dale A. Bucks
Water Quality and Management
Natural Resources and Sustainable Agricultural Systems
5601 Sunnyside Avenue, Room 4-2290
Beltsville, Maryland
301-504-7034
dab@ars.usda.gov.

Agricultural production practices and systems that sustain and protect our national water resources while satisfying our needs for clean water and a safe, dependable food and fiber supply are paramount national issues. However, agriculture has been identified as a major non-point source of sediment contamination where 40 percent of our Nation’s rivers, streams, and lakes are impaired. The primary mission of the Agricultural Research Service (ARS) Water Quality and Management National program is twofold: to develop innovative concepts for determining the movement of water and its associated constituents in agricultural landscapes and watersheds; and to develop new and improved practices, technologies, and systems to manage the Nation's agricultural water resources.

Advances in suspended solids and sediment research will provide food and fiber producers, local communities, and resource management agencies with the tools they need to improve the management and restoration of diverse watersheds; to protect rural communities from the ravages of floods and droughts; to improve water conservation and water use efficiency in irrigated and rainfed agriculture; to recycle freshwaters and wastewaters in irrigated agriculture; to enhance water quality at the field, farm, and watershed scale; and to prevent the degradation of riparian areas, wetlands, and stream corridors. The three components of this national program related to suspended solids and sediment research are watershed hydrology, erosion, and sediment movement; irrigation-induced erosion; and water quality TMDLs (Total Maximum Daily Loads) and clean sediment.

The major ARS locations involved in this research are Ames, Iowa; Boise, Idaho; Coshocton, Ohio; Fort Collins, Colorado; Kimberly, Idaho; Oxford, Mississippi; Temple, Texas; Tifton, Georgia; Tucson, Arizona; Phoenix, Arizona; Pullman, Washington; Stillwater, Oklahoma; Watkinsville, Georgia; and West Lafayette, Indiana.

Challenges of Clean Sediment TMDL Development—A Practitioner's Perspective

Bruce Cleland
America's Clean Water Foundation
25919 – 99th Avenue S.W.
Vashon, WA 98070
(206) 463-2596
E-Mail: b.cleland@acwf.org

A strength of the total maximum daily load (TMDL) program is in its ability to serve as an information-based strategy. If done properly, a TMDL can inform, empower, and energize citizens, local communities, and States to improve water quality at the local, watershed level— the basic information derived from a sound TMDL can liberate the creative energies of those most likely to benefit from reduced pollutant loadings to their own waters (Tracy Mehan, November 2001). With this in mind, tools are needed which promote effective communication between TMDL developers and those responsible for implementing the actions that will lead to measurable water quality improvements. With the large number of TMDLs that must be completed, limited resources, and the complex, inter-related nature of water programs—the "two Ps" are critical to success— *practical* approaches and *partnerships*.

Much has been written on erosion processes, the delivery of sediment to aquatic systems, and the subsequent effects on beneficial uses such as fisheries, water supply systems, or recreation. As a result of extensive research, there is currently a wide range of approaches that have been used to develop clean sediment TMDLs across the country. Some techniques focus on in-stream indicators, which often utilize empirical relationships. These methods generally seek to develop some numeric interpretation of narrative water quality criteria that are intended to reflect desired conditions associated with key beneficial uses (e.g., fisheries). Other common approaches build upon watershed scale loading analyses, which typically employ any one of a number of models (e.g., USLE, SWAT, AGNPS, GWLF, HSPF, etc.).

From a practitioner's perspective, there are a number of challenges associated with most technical methods. Empirical approaches rely on the existence of sufficient water quality data to adequately describe important relationships. Models require the availability of a unique expertise, information on pollutant source and delivery processes as well as watershed specific data, such as geographic information system (GIS) coverages. Furthermore, public involvement is fundamental to successful TMDL development and implementation. Key stakeholders in the watershed must be engaged in the process in order to achieve meaningful results with measurable water quality improvements. It is also a challenge to explain technical concepts and information in *"plain English."* For instance, models are should be viewed as tools, not solutions—the use of a model does not guarantee environmental improvement. Both the users and the public must understand how analytical results were derived, in order to avoid the *"paralysis through analysis"* syndrome.

"Bottom Up" Approaches

An important key to the success of the TMDL program, in terms of engaging the public, is building on linkages to other programs, such as nonpoint source (NPS) management. Many of the successful efforts to develop TMDLS have, for example, involved the §319 program as a way to utilize local groups in data collection, analysis, and implementation. Watershed analysis has also been used to build a *"bottom up"* approach towards TMDL development as another way to establish a meaningful, value-added framework which links water quality concerns to proposed solutions. TMDL development using a *"bottom up"* approach considers the interaction between watershed processes, disturbance activities, and available methods to reduce pollutant loadings, specifically Best Management Practices (BMPs). A *"bottom up"* approach takes advantage of networks of programs and authorities across jurisdictional lines. Information on management measures related to both source control and delivery reduction methods can be incorporated into the allocation part of TMDL development.

Example – The Simpson HCP/ TMDL
An example from the Pacific Northwest illustrates one way in which technical information regarding erosion processes, sediment delivery mechanisms, and control options was considered in a *"bottom up"* approach towards TMDL development. Specifically, the Simpson Northwest Timberlands TMDL, established by the State of Washington with technical assistance from EPA Region 10, contained allocations based on information contained in a Habitat Conservation Plan (HCP) developed in accordance with the Endangered Species Act [ESA §10]. The Simpson HCP describes a suite of management, assessment, and monitoring actions. Simpson's conservation program emphasizes the protection of riparian forests coupled with erosion control as a primary strategy to satisfy ESA §10. Specific management prescriptions designed to reduce the input of pollutants into streams within the plan area include: riparian conservation reserves; road management; unstable slope protection; and a wetlands conservation program. Riparian management strategies in the HCP are designed to eliminate temperature increases due to human activities and to prevent delivery of excess sediment to the streams. Allocations in the TMDL are designed to achieve similar results. The allocations were derived using effective shade and sediment delivery targets based on information from the HCP. These targets were based on an analysis of expected results from implementing the HCP management prescriptions. Effective shade allocations were based on achievability estimates using channel classification information combined with characteristics of mature riparian vegetation and buffer widths associated with the HCP prescriptions for each channel class. Similarly, sediment delivery allocations were based on estimates of the percent of the load that could be controlled through implementation of HCP prescriptions using a rapid sediment budget. Thus, TMDL development took advantage of the work underway. The measures were linked to specific source areas and to appropriate actions needed to solve identified water quality problems. This "*bottom up"* approach gives major consideration to the actions that can be implemented. Any gaps can be readily identified and filled using the concept of *"adaptive management.*"

Load Duration Curves
Load duration curves can support a *"bottom up"* approach through enhanced targeting. Kansas has been utilizing load duration curves for the past several years as a key part of their TMDL development process. The initial focus in Kansas was to provide a way to identify whether point or nonpoint sources are the major contributors of concern to water quality problems. The expanded use of the load duration curve has since demonstrated its utility as a targeting tool. In particular, load duration curves can add value to the TMDL process by identifying targeted participants (e.g., NPDES permitees) at critical flow conditions, targeted programs (e.g., Conservation Reserve Program), targeted activities (e.g., conservation tillage or contour farming), and targeted areas (e.g. bank stabilization projects). The recurrence intervals from load duration curves can be used as a general indicator of watershed condition (i.e., wet versus dry and to what degree). This indicator can help point problem solution discussions towards relevant watershed processes, important contributing areas, and key delivery mechanisms. These are all important considerations when identifying those controls that might be most appropriate and under what conditions. In addition, duration curves also provide a context for evaluating both monitoring data and modeling information, particularly when used to estimate load reductions. This offers another way to look at identifying data needs where adaptive management is being considered or utilized.

Adaptive Management

Adaptive management plays a key role in the implementation process for achieving load reductions. Using a value-added *"bottom up"* approach, TMDL development occurs using the best available data. Progress towards achieving load allocations is periodically assessed through phased implementation using measurable milestones. Under adaptive management, a watershed plan should not be held up due to a lack of data and information for the *"perfect solution."* The process should use an iterative approach that continues while better data are collected, results analyzed, and the watershed plan enhanced, as appropriate. Thus, implementation can focus on a cumulative reduction in loadings under a plan that is flexible enough to allow for refinement, which better reflects the current state of knowledge about the system and is able to incorporate new, innovative techniques.

Landscape Approach To Managing Agricultural Nonpoint Source Sediment

Thomas E. Davenport
United States Environmental Protection Agency
Chicago, Illinois

States report that about 40 percent of the waters they assessed do not meet water quality goals. About half of the Nation's more than 2,000 major water bodies have serious or moderate water quality problems. There are a multitude of anthropogenic sources of sediment that are likely to enter and degrade our Nation's water resources. Agriculture in its several forms is by far the largest generator of pollutants. The present approach of addressing agricultural pollutant sources on a site-by-site basis has not been totally effective and in a number of cases has resulted in further degradation downstream. Most programs used to control agricultural nonpoint source pollution are modeled after the traditional agricultural stewardship efforts that focus on infield best management practices based on a land manager's interest and operational constraints. An approach that integrates the spatial juxtaposition and dynamic interaction between potential pollutant generation and movement with agricultural management is needed to comprehensively address water quality concerns. This approach must include a combination of activities that promote the prevention, mitigation and treatment of agricultural pollution. To enhance the effectiveness of the landscape approach a new way to prioritize areas within the landscape needs to be adopted that is based upon site-specific conditions and takes in to account the potential for causing off-site impacts. Utilizing the landscape approach and this new prioritization process together, we can focus available resources and implement effective strategies to solve agricultural related problems.

To make the landscape approach effective the existing approach to field level planning must be changed. The present approach of planning on a rotation must be replaced with a potential pollutant generating approach based upon the pollutant of concern. In addition the field level focus must be expended to include more than just the field itself. This paper will present a landscape approach to agricultural management on a watershed basis to implement sediment management goals, and a revised approach to field level planning and implementation for sediment management.

Protocol for Establishing Sediment TMDLs in Georgia

David E. Radcliffe
University of Georgia

Alice Miller Keyes
The Georgia Conservancy

Total Maximum Daily Loads (TMDLs) are being developed in Georgia under a consent decree that specifies a five-year rotating basin schedule. The first rotation must be completed by 2005. There are over 600 streams requiring TMDLs in Georgia and many of these are for sediment.

In January 2000, the first sediment TMDL documents developed in Georgia were released by the United States Environmental Protection Agency (EPA), Region 4. After reviewing the proposed TMDLs, staff at The Georgia Conservancy (TGC) and researchers at the University of Georgia Institute of Ecology (IOE) concluded that the legal and technical challenges associated with TMDL development were preventing good science from guiding their establishment. As a result, TGC and IOE sponsored a forum to discuss the best way to establish sediment TMDLs. Participants at the forum recommended the formation of a TMDL technical advisory group (TAG) composed of scientists from universities, federal and state agencies and non-governmental organizations with interests in sediment-related water quality problems. The goals of the TAG were to identify general characteristics of scientifically-based sediment TMDLs and to recommend a protocol for establishing sediment TMDLs in Georgia. The TAG met its goals by developing a white paper (Miller et al., 2002). This white paper consists of four sections: section I briefly explains the TMDL legal requirements and history of the TAG; section II defines the relationship between water and its sediment load; section III outlines objectives of TMDLs and the TAG's recommendations; section IV identifies research needed to improve our understanding of sediment and its impact on aquatic ecosystems. The white paper also includes references, a glossary of terms, and sample calculations.

Section II of the white paper addresses a number of difficult scientific issues associated with sediment TMDLs. The streams requiring that sediment TMDLs be established were listed in Georgia because surveys by wildlife biologists with the Georgia Wildlife Resources Division (WRD) indicated that fish biologic integrity was low, and the apparent cause was excessive sediment. However, the exact level of sediment that causes impairment in a particular stream cannot be determined from scientific literature. One of the difficulties is that there are several forms of sediment in streams, including suspended sediment. Another difficulty is that the capacity of a stream to carry suspended sediment varies with the amount of stream flow (Q), so the suspended sediment concentration (SSC) is highly variable. Suspended sediment reduces water clarity, which can be measured in nephelometric turbidity units (NTUs) using light-scattering instruments. Although SSC and NTU are highly correlated, the relationship between the two can vary from site to site. Still another difficulty is that many streams in the Piedmont of Georgia received large historic inputs of sediment during the 19^{th} and early 20^{th} centuries. In these streams, often it is difficult to determine if the impairment is due to historic or current sediment inputs.

The recommendations, summarized below and discussed in detail in section III of the white paper, were the result of a consensus-building process and represent the opinion of the majority of the TAG members. Most of these recommendations concern the first five-year cycle of the TMDL process (Phase I) when all listed streams are scheduled for TMDL development. Due to court orders, Phase I TMDLs will have to be developed under time constraints and with limited resources and data. In the second five-year cycle (Phase

II), these TMDLs will be revised. The Phase II TMDLs should benefit from the experience and additional resources and data gathered during the Phase I process.

We recommend, as a preliminary step, that the problem causing biologic impairment be carefully identified. Sediment can carry a variety of organic and inorganic pollutants that may affect biota, and this should be considered. A carefully crafted inventory of the potential sediment sources and the pathways by which sediments enter the waterbody should be developed. A priority system should be used to direct immediate attention to waterbodies that are clearly impaired by sediment and have a high potential for recovery. If a waterbody is listed based on a very limited number of samples or surveys, such waters should be placed on a preliminary list. These waterbodies should be targeted for additional monitoring and analysis. If the requisite data analysis has not been compiled within five years after placement on the preliminary list or if the detailed assessment indicates that the waterbodies are, in fact, impaired, then the waterbodies should be placed on the final list of impaired waters.

To develop a TMDL for a stream that is clearly impaired, the sediment load that the stream can assimilate must be specified. Load is usually given in units of tons of sediment per year or day and is a product of the SSC and Q (with appropriate unit conversions and the use of a rating curve bias factor). We recommend the use of a reference stream wherever possible to determine the acceptable sediment load for impaired stream. Reference streams are streams that are representative of the characteristics of the region and subject to minimal human disturbance. In the case where an appropriate reference stream is not available, we propose using a target long-term mean suspended sediment concentration (SSC_0) of 20-30 mg/L and the mean discharge (Q_0) for the impaired stream (this can be estimated if it is not available).

Our target SSC_0 is based primarily on research conducted in the Piedmont region of the Etowah River basin that showed that the index of biologic integrity declined when baseflow turbidity exceeded 10 NTU or when baseflow SSC exceeded 10 mg/L (Fig. 1). Three other studies on streams in the Blue Ridge region found a similar threshold turbidity level. Baseflow SSC or turbidity may be a good indicator of overall water quality, especially in streams with historic sediment. Clay-size particles settle out slowly so that a stream with a high storm flow sediment load is likely to remain turbid for some time after a storm. In streams where historic sediment is the only source, baseflow SSC and turbidity are likely to be low because the clay-size particles have been carried downstream in the intervening decades. In effect, baseflow SSC is a surrogate for the overall sediment load. Our target SSC_0 is higher than 10 mg/L because the long-term mean concentration can be expected to be slightly higher than the baseflow SSC and because of the uncertainty in extrapolating from measures of turbidity (the more likely parameter to be monitored in impaired streams) to SSC. Because of the lack of research regarding SSC_0 in other ecoregions across the state of Georgia, this recommendation should only apply to streams in the Piedmont and Blue Ridge ecoregions.

The TMDL should be expressed as an annual sediment load and a daily sediment load. The daily load will depend on Q. If an average Q is used for daily load, then this would represent an upper limit for baseflow or chronic conditions. If a sediment rating curve slope is available, a Q and SSC for stormflow conditions can be used to calculate a daily-load upper limit that would represent acute conditions (see Appendix A of the white paper).

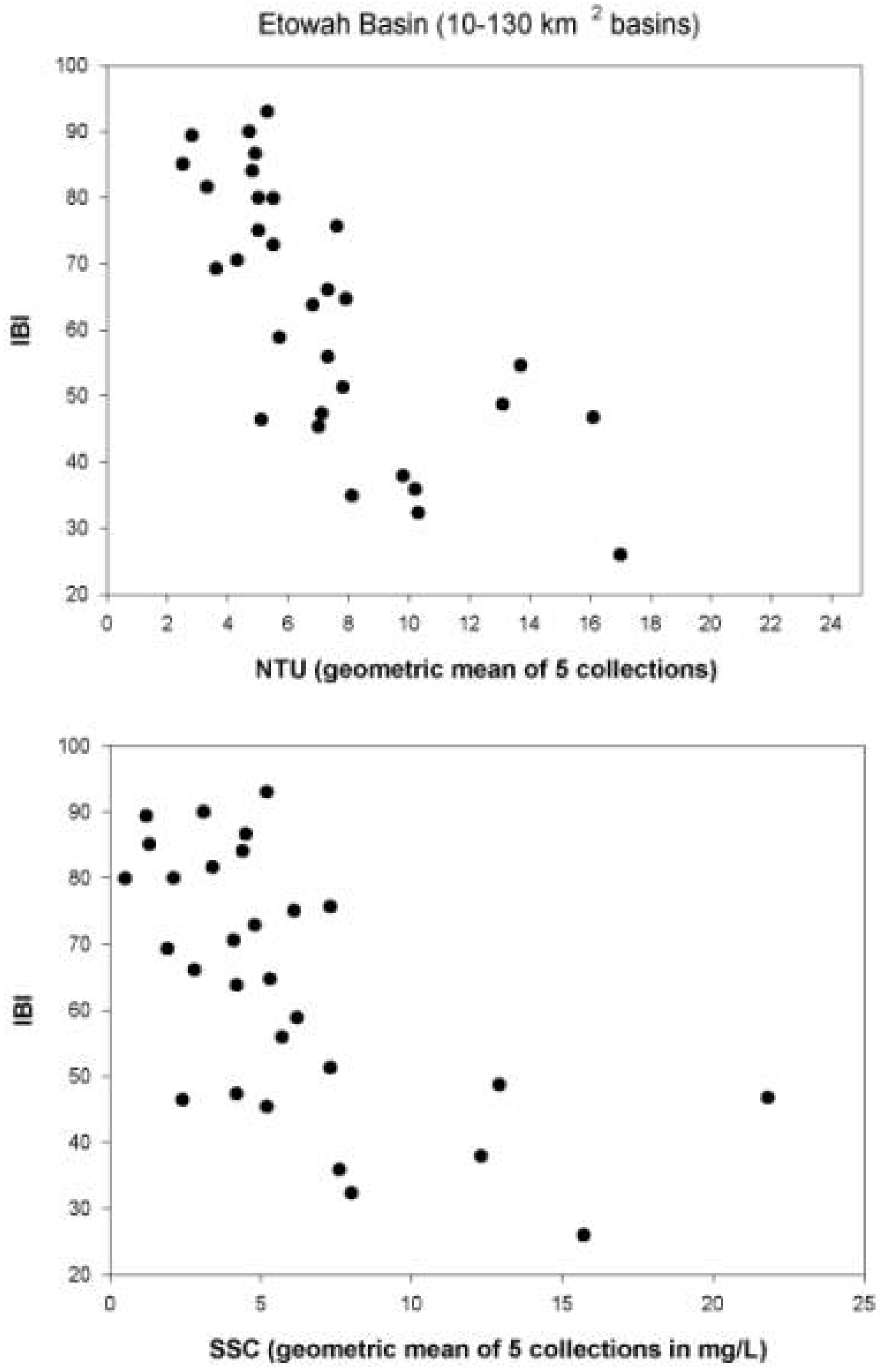

Figure 1. IBI as a function of NTU (top figure) and SSC (bottom figure) at 31 wadeable stream segments whose basin sizes range from 10-130 km^2 (Walters et al., 2001).

The TMDL for an impaired stream must be allocated between point source loads and nonpoint source loads and must include a margin of safety and may consider an allowance for future growth. Construction activities on sites above five acres should be required to obtain a specific, rather than a general, National Pollutant Discharge Elimination System (NPDES) permit. The permit should specify the load allocated to the site. The sum of all permitted loads in a listed watershed should not exceed the total point source load allocation.

Follow-up monitoring is a key component of the TMDL process and should be emphasized in the Phase I TMDLs because of the uncertainty surrounding their development. This information will be critical in developing more accurate TMDLs during Phase II. Implementing TMDLs is critical to the success of the TMDL program. TMDL implementation should be the subject of a separate white paper developed with more stakeholder input. TMDL development and implementation need to be closely linked. Our discussions made it apparent that there are a number of research questions that need to be answered. These include:

- the relationship between biotic indices, SSC, and other physical parameters (sediment loads, watershed surveys, etc.,) in reference streams identified by WRD and EPA in each hydrological and ecological region in Georgia
- standards for acute (storm driven) sediment loads
- reference conditions based on bed characteristics
- estimation techniques to measure various components of sediment budgets (bedloads, streambank recession, construction sites, dirt roads, etc.)
- development of methods to derive the margin of safety from model uncertainty

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Implementation of the Narrative Sediment Standard: The Colorado Experience

Robert McConnell
Colorado Department of Public Health and Environment
Water Quality Control Division

Colorado's water quality standards include narrative standards that apply to all surface waters statewide. One of these narrative standards states that: "…state surface waters shall be free from substances attributable to human-caused point source or nonpoint source discharge in amounts concentrations or combinations which … can settle to form bottom deposits detrimental to the beneficial uses. Depositions are stream bottom buildup of materials which include but are not limited to anaerobic sludges, mine slurry or tailings, silt, or mud." This standard is referred to as the narrative sediment standard.

The Water Quality Control Division, in conjunction with an external work group, developed guidance for implementing the sediment standard. This guidance, entitled "Implementation Guidance for the Determination of Impacts to Aquatic life in Streams and Rivers Caused by the Deposition of Sediment," was adopted as interim guidance by the Colorado Water Quality Control Commission. The goal of this guidance is to provide a consistent approach which allows many different agencies, individuals or stakeholders to come to similar conclusions when assessing rivers and streams potentially affected by deposited sediments. The guidance is intended to apply only to stream and river environments and to be limited to the aquatic life beneficial use. It applies to substances such as sediment resulting from human–induced erosion which create a physical impediment to the health of aquatic systems through their deposition on stream bottoms. The guidance does address toxics in sediment nor is it intended to provide a complete analysis of use attainment or guidance for development of sediment TMDLs.

The site-specific assessment approach described in the guidance is based on the concept of comparing the actual conditions of a specific stream segment with the reference conditions of the same stream to determine attainment of the narrative standard. The key element of this approach is the concept of reference condition or <u>expected condition</u> of streams. The guidance sets forth a recommended approach for selecting expected conditions and defining the conditions at reference sites. It then provides guidance for measuring the sediment deposition and biological condition at reference sites and study or impacted sites.

In the Colorado approach, in order to determine attainment of the narrative standard, there must be a concurrent demonstration of sediment deposition and biological impact. This demonstration is accomplished with a sequential two-part assessment. First, the stream bottom substrate must be assessed to determine whether there has been sediment deposition. Second, the macroinvertebrate community and/or fish community must be assessed to determine if there has been an impact to the beneficial use. The degree of departure from expected condition for both sediment and biological condition is then compared in the narrative sediment standard matrix (shown below) and the determination is made if the standard has been attained, is threatened or is exceeded.

Experience gained by the Water Quality Control Division and by other stakeholders that have used the guidance, has shown that although the guidance is a good starting point from a conceptual standpoint, there are still a number of technical and policy aspects that need further development. For example, determining the reference or expected condition has been especially difficult. Techniques, such as pebble counts, for measuring sediment deposition for high and moderate gradient streams are available but have not been adapted adequately for low gradient and fine substrate streams. Better techniques for assessing biological condition or impact, such as biocriteria, and relating that impact to sediment deposition also need to be developed. Finally, the Water Quality Control Division and some other agencies that have used this guidance have observed that having only one cell in the sediment standard matrix that corresponds to "exceeded" may be too conservative in that it fails to identify stream segments or portions of segments as exceeding based on expectations from field observations, professional judgment, and experience in evaluating sediment impacts to streams. As this guidance is applied in Colorado, and data from various sites continues to be collected, it may be necessary to adjust the percentages and the number of categories used in the standard attainment matrix in order to improve our ability to determine attainment of the sediment standard.

Narrative Sediment Standard Attainment Matrix

Biological % of Expected *Substrate % of Expected*	**0–17**	**18–50**	**51–79**	**80–100**
0–58	Exceeded	Threatened	Attained	Attained
59–73	Threatened	Threatened	Attained	Attained
74–100	Attained	Attained	Attained	Attained

Some Future Directions by the USGS and Others in Support of USEPA's "Clean" Sediment TMDL Program?

John R. Gray
Office of Surface Water, Water Resources Discipline
jrgray@usgs.gov; http://water.usgs.gov/osw/techniques/sediment

The following represents one vision of future endeavors related to fluvial sediment assessments. This list is neither comprehensive nor exhaustive, and the order of the entries does not imply the author's priority.

***A Vision for Future Federal Sediment-Data Production*:** According to Osterkamp and others (1992; 1998) and Trimble and Crosson (2000), the Nation needs a permanent, base-funded, national sediment monitoring and research network for the traditional and emerging needs described previously, and to provide reliable values of sediment fluxes at an adequate number of properly distributed streamgages. The short-term benefits would include relevant and readily available data describing ambient sedimentary conditions and loads, and the requisite data to calibrate models for simulating fluvial sedimentary processes. The long-term benefits would include identification of trends in sedimentary conditions, and a more complete data set with which to calibrate and verify simulation models. Fundamental requirements for an effective national sediment monitoring and research program would include:

$ A CORE NETWORK OF SEDIMENT STATIONS that is equipped to continuously monitor a basic set of flow, sediment, and ancillary characteristics based on a consistent set of protocols and equipment at perhaps hundreds of sites representing a broad range of drainage basins in terms of geography, areal extent, hydrology, and geomorphology. The focus of these sites would be measurement of fluvial-sediment yields. It would be most beneficial to collect these data at sites where other water-quality parameters are monitored.

$ A SUBSET OF THE SEDIMENT STATION NETWORK FOR SEDIMENT RESEARCH at which testing on emerging sediment-surrogate technologies and new methodologies can take place at a minimum of additional expense. A major focus of this effort would be to identify technologies that provide a reliable sediment-concentration time series that can be used as the basis for computing daily suspended-sediment discharges. A secondary focus would be to identify surrogate technologies for measuring characteristics of bedload, bed material, and bed topography.

$ AN EQUIPMENT AND METHODS ANALYTICAL COMPONENT that addresses development of equipment and techniques for collecting, processing, and laboratory analysis of sediment samples.

$ A DATA-SYNTHESIS RESEARCH COMPONENT that focuses on identifying or developing more efficient methods of measuring and estimating selected fluvial sediment characteristics; developing a means to estimate the uncertainty associated in these measurements and estimates; and on performing syntheses on historical and new sediment and ancillary data to learn more about the sedimentary characteristics of our Nation's rivers.

$ A COMMON DATABASE that can accept all types of instantaneous and time series sediment and ancillary data collected by approved protocols, including specific information on the instruments and methods used to acquire the data.

***A First Step: Development and Verification of Sediment Surrogate Technologies for the 21st Century*:** Traditional techniques for collecting and analyzing sediment data do not meet all of the above-stated requirements of a national sediment monitoring and research network. Before such a program can become operational, new cost-effective and safe approaches for continuous monitoring that include uncertainty analyses are needed.

An ideal suspended-sediment surrogate technology would automatically monitor and record a signal that varies as a direct function of suspended-sediment concentration and (or) particle-size distribution representative of the entire stream cross-section for any river in any flow regime with an acceptable and quantifiable accuracy. Although there is no evidence that such a technology is even on the drawing board, let alone verified and ready for deployment, the literature is rife with descriptions of emerging technologies for measuring selected characteristics of fluvial sediment (Wren, 2000; Gray and Schmidt, 1998). Considerable progress is being made to devise or improve upon available new technologies to measure selected characteristics of fluvial sediment. Instruments have been developed that operate on acoustic, differential density, pump, focused-beam reflectance, laser diffraction, nuclear, optical backscatter, optical transmission, and spectral reflectance principles (Wren et al., 2000). Although some surrogate technologies show promise, none is commonly accepted or extensively used.

Formal adoption of any sediment-surrogate technology for use in large-scale sediment-monitoring programs by the Subcommittee on Sedimentation must be predicated on performance testing. Isokinetic samplers— primarily those developed by the Federal Interagency Sedimentation Project (FISP) and described by Edwards and Glysson (1999)—generally are considered the standard against which the performance of other types of samplers are compared. Ideally, a controlled setting such as a laboratory flume would provide flow and sedimentary conditions enabling direct assessments of the efficacy of the new technology. Even in that case, direct comparisons between an adequate amount of comparative data from the surrogate technology and isokinetic samplers collected for a sufficient time period over a broad range of flow and sedimentary conditions, would be needed to determine if any bias, or change in bias, would result from implementation of the new technology (Gray and Schmidt, 2001).

***Collection of Selected Geomorphic Parameters at Gaging Stations*:** Channel cross-section morphology, channel slope, bed-material size distributions, and benchmarked photography should be standard parameters to be collected at index gaging stations, if not all gaging stations. Sediment-transport data (suspended and bedload where appropriate/feasible) and rainfall depths and intensity representative of the drainage area of interest are also desirable in concert with flow data.

***Geomorphology Database*:** A national database
(RCMAP? http://co.water.usgs.gov/projects/rcmap/rcmap.html), should be developed/expanded to capture data, successes, and failures from TMDL and stream restoration projects.

Empirical, Geographically-Based Thresholds of Effect (Criteria) Determined with Conditional Probabilities—A Proposed Approach

John F. Paul
National Health and Environmental Effects Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

How can you use field data to develop geographically-based aquatic criteria? Typical methods to develop criteria using data collected at sites across a geographic area include: (1) characterizing reference sites and using best professional judgment; (2) using the 75th percentile of reference sites; (3) using the 5th to 25th percentile of all sites; and (4) relying on previously developed predictive relationships. One common issue with these typical methods is how to extrapolate from sites with data to the entire geographic area. Another issue is a possible bias in results due to the way sites were selected. A conditional probability approach using survey data overcomes these issues. This approach is consistent with the expression of numeric water quality criteria as likelihood of impairment by exceeding a value of a pollution metric. In drinking water programs, this is often referred to as an "exceedance probability."

Data on Mid-Atlantic wadable streams were collected by USEPA's Environmental Monitoring and Assessment Program (EMAP) in 1993–94 and are used to illustrate the approach. This sampling was implemented with a suite of biological indicators at sites selected with a probability-based design, and have been reported in the Mid-Atlantic Highlands Assessment State-of-the-Streams report (EPA-903-R-00-015). For illustration, a stream sedimentation criteria was determined from a channel sedimentation index (CSI). The CSI expresses the deviation in the actual amount of substrate fines from that which would be normally expected to occur. EMAP streams benthic invertebrate survey data were used to determine the likelihood of impaired benthic conditions as a function of the CSI. The use of survey data permits an unbiased extrapolation of results to the statistical population from which the probability sample was drawn (e.g., the results would be applicable to all of the wadable streams in a state if the sample was drawn from a sampling frame of all wadable streams in the state).

This approach requires that the ability to identify an impaired biological community has already been established (e.g., benthic IBI values < 60 on a 0B100 scale). The implementation of the proposed approach has two steps: (1) identify a subset of the sampled resource that exceeds a specific pollution value, and (2) determine the fraction of that subset which exhibits impaired biological conditions. This two-step process is repeated for all observed values of the pollution metric. Since the sites were selected with a probability design, the fraction of the resource that is impaired is the probability of observing impaired biological conditions when a pollution value is exceeded.

Final development of criteria levels for the pollution metric based upon biological impairment must be a management decision. However, a scientifically defensible approach to establishing a benchmark criteria by determining significant differences for biological community condition from geographic background levels are put forward.

Reference Sediment-Transport Rates for Level III Ecoregions and Preliminary Links with Aquatic Indices

Andrew Simon, Roger Kuhnle and Wendy Dickerson
USDA-ARS National Sedimentation Laboratory
Oxford, MS 38655
asimon@ars.usda.gov

Introduction

Suspended sediment is listed as one of the principal pollutants of surface waters in the United States. To identify those sediment-transport conditions that represent impacted conditions, it is critical to first be able to define the non-disturbed, stable, or "reference" condition for the particular waterbody. A process-based six-stage model of channel evolution (Simon and Hupp, 1986; Simon, 1989a) that differentiates between stable (reference), equilibrium conditions and various states of channel instability was found to be related to rates of suspended-sediment and bed-material transport. Stages of channel evolution have been found to be related to rates of bed-material and suspended sediment transport with peak transport rates occurring during stages IV and V (Simon, 1989b). "Pre-disturbed" Stage I conditions and/or "Restabilization" Stage VI conditions are used as the "reference" condition by which targets of sediment-transport rates can be established for a given Level III ecoregion.

Analysis of Suspended-Sediment Data

Analysis of suspended-sediment transport data involves establishing a relation between flow and sediment concentration or load. Instantaneous-concentration data combined with either an instantaneous flow value or flow data representing the value obtained from the stage-discharge relation at 15-minute intervals are best. Mean-daily values of both flow and sediment loads, which are readily available from the USGS tend to be biased towards lower flows, particularly in flashy basins. For establishing sediment-transport rating relations, instantaneous concentration and 15-minute flow data were used from USGS and ARS gauging station records.

Because the "effective discharge" is that discharge or range of discharges that shape channels and perform the most geomorphic work (transport the most sediment) over the long term it can serve as a useful indicator of regional suspended-sediment transport conditions for "reference" and impacted sites. In many parts of the United States, the effective discharge is approximately equal to the peak flow that occurs on average, about every 1.5 years ($Q_{1.5}$; for example, Andrews, 1980; Andrews and Nankervis, 1995) and may be analogous to the bankfull discharge in stable streams. The recurrence interval for the effective discharge in this study was calculated for 10 streams located in two different Ecoregions in Mississippi. Using the annual-maximum peak-flow series for each of the sites with available data, the effective discharge ($Q_{1.5}$) was then calculated from the log-Pearson Type III distribution. Where peak-flow data were not available, the $Q_{1.5}$ was calculated from regional relations based on drainage area obtained from the U.S. Geological Survey (1993) and calculated in this study.

The effective discharge ($Q_{1.5}$) was determined at all sites and applied to the sediment-transport relation that was derived for the site to obtain the sediment load at the effective discharge (Figure 1). To normalize the data for differences in basin size, the sediment load was divided by drainage area to obtain sediment yield (in $T/D/km^2$). All rating relations were checked to be sure that the $Q_{1.5}$ was within the measured bounds of the data set. If the $Q_{1.5}$ was more than 50% greater than the maximum sampled discharge, the calculated sediment yield was not included. Finally, the data were sorted by ecoregion to establish the range and distribution of sediment yields that could be used as a relative measure of sediment production, transport, and degree of impact. Suspended-sediment yield values at $Q_{1.5}$ ranged over about six orders of magnitude, from 0.01 T/D/km^2 in the Northern Rockies (#15) to about 6,400 T/D/km^2 in Mississippi Valley Loess Plains (MVLP; #74). The MVLP ecoregion produces the greatest amount of sediment per unit drainage area in the nation. The nationwide distribution of median suspended-sediment concentrations and yields are shown in Figure 2.

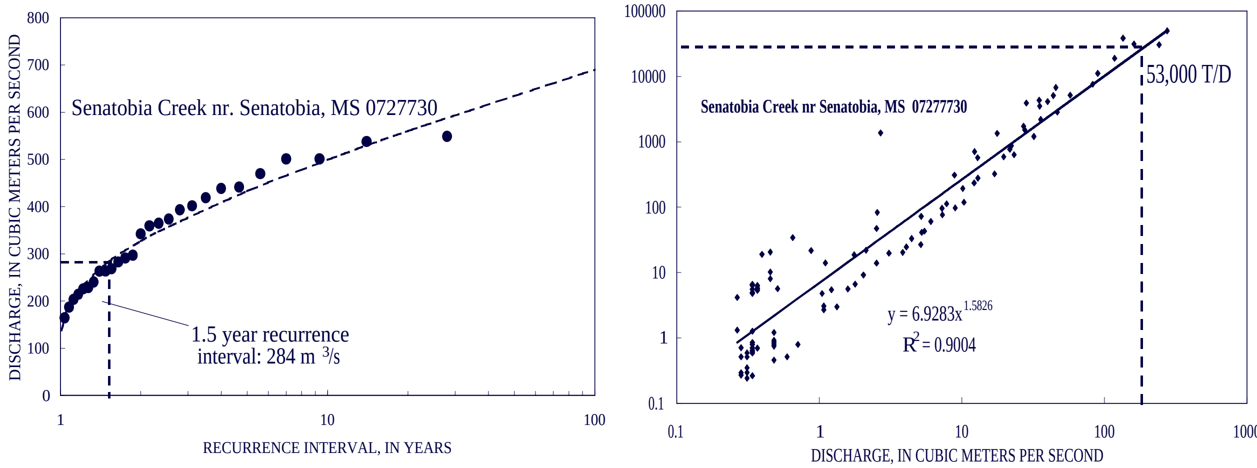

Figure 1. (A) Obtaining the Q1.5 (effective discharge) from the log-Pearson Type III distribution, and (B) suspended-sediment load at the effective discharge.

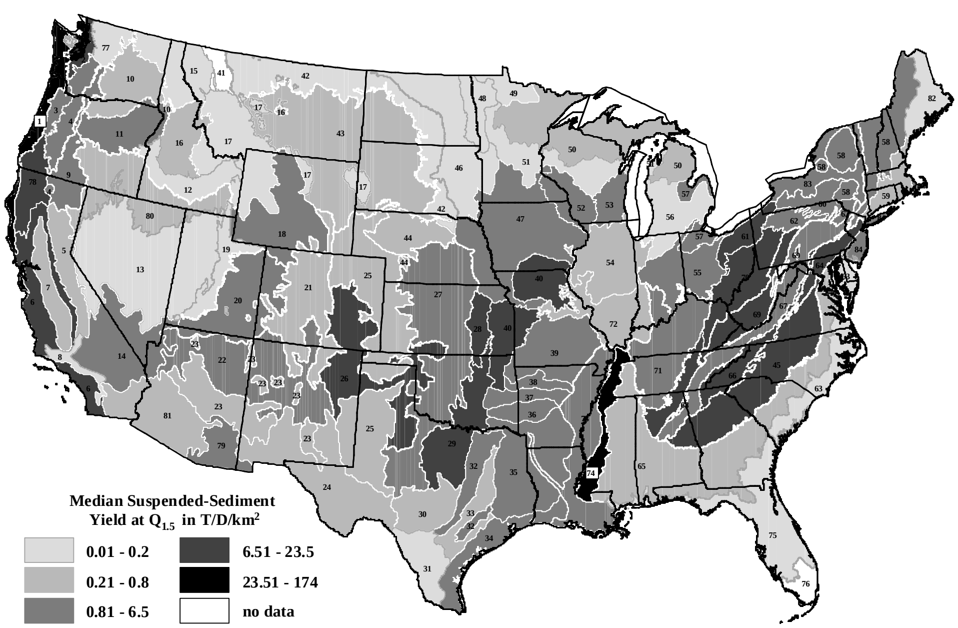

Figure 2. Median suspended-sediment concentrations (A) and yields (B) at the $Q_{1.5}$ for Level III ecoregions of the conterminous United States.

Table 1. Examples of preliminary reference values for suspended sediment, expressed as yield at the $Q_{1.5}$

Ecoregion No.	**Ecoregion Name**	**States Included**	**Preliminary "Reference" Transport Rate in T/D/km^2**
1	Coast Range	CA, OR, WA	30.5
15	Northern Rockies	ID, MT, WA	0.05
22	Arizona/New Mexico Plateau	AZ, CO, NM	2.24
28	Flint Hills	KS, OK	5.79
40	Central Irregular Plains	KS, IA, MO, OK	2.07
54	Central Cornbelt Plains	IL, IN	0.34
63	Mid-Atlantic Coastal Plain	DE, MD, NC, SC, VA	0.03
65	Southeastern Plains	AL, GA, MD, MS, NC, SC, TN, VA	0.41
72	Interior River Lowland	KY, IA, IL, IN, MO	0.19
74	Mississippi Valley Loess Plains	KY, MS, TN	37.1

"Reference" or "Target" Sediment Yields

The working hypothesis for determining "reference" and "target" values for suspended sediment in this study is that stable channel conditions can be represented by channel evolution Stages I and VI. It follows, therefore, that effective-discharge sediment yields for Stages I and VI in a given ecoregion represent background or "natural" transport rates. Quartile measures for Stage I and VI conditions occurring at the study sites are shown overlaying data from all other sites in those ecoregions in Figure 3. As expected, Stage VI sediment-yield values are considerably lower for each quartile measure in each of the ecoregions. Preliminary values are shown on individual sub-plots assuming the median Stage VI value (2nd quartile) is used as an estimate of the stable, "reference" suspended-sediment yield for an ecoregion (Figure 3). Note the range of median "reference" values, further supporting the premise that water-quality targets for sediment need to be done at least at the Level III ecoregion scale, if not smaller. These results should be considered preliminary as more sites in each of the ecoregions are evaluated for stage of channel evolution, additional Stage VI sites are identified in other states, and the data set is further differentiated by dominant bed-material size class.

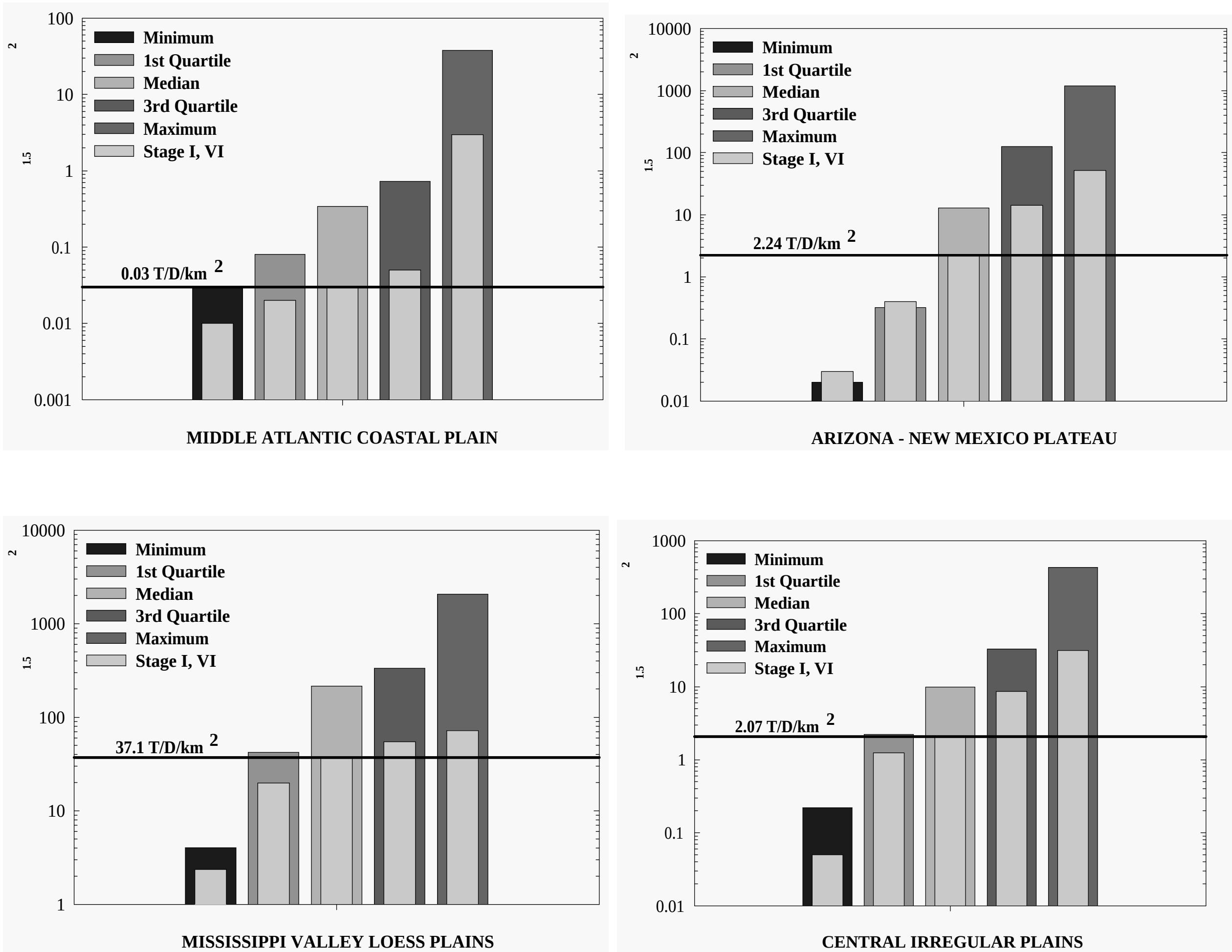

Figure 3- Examples of quartile measures of suspended-sediment yields at the $Q_{1.5}$ for reference/stable (Stage I and VI) sites, and all other sites in eight ecoregions. Yield values shown are preliminary "reference" values.

Links with Aquatic Indices

Sediment data were also analyzed at several stations to ascertain the relative magnitudes, durations, and frequencies of given concentrations. It is these types of data that may prove crucial in linking suspended-sediment concentrations and bed-material movement to biologic integrity of aquatic habitat. Preliminary results for the Mississippi Valley Loess Plains (Ecoregion 74) show decreasing total numbers of benthic macro-inverterbrates and numbers of species for increasing durations of a given concentration of suspended sediment (Figure 4). Additional analysis of these types of data will be performed in other ecoregions where biologic data are available to determine threshold conditions for biologic health and stream impairment.

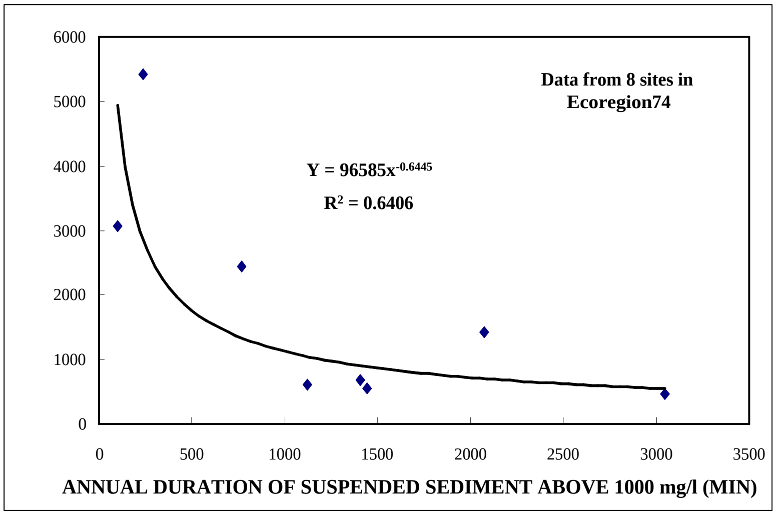

Figure 4 – Inverse relation between the annual duration of concentrations of 1,000 mg/l and total numbers of benthic-macro inverterbrates.

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GSTARS 3.0: A Numerical Model for Reservoir and River Sedimentation

Chih Ted Yang
Sedimentation and River Hydraulics Group, Technical Service Center
U.S. Bureau of Reclamation, Mail Code D-8540
P.O. Box 25007
Denver, CO 80225

Francisco J. M. Simões
U.S. Geological Survey
P.O. Box 25046, MS 413
Denver, CO 80225

The US Bureau of Reclamation has been developing a series of models with the generic denomination of GSTARS for simulating alluvial rivers with movable boundaries. In this paper the GSTARS 3.0 model (Generalized Sediment Transport model for Alluvial River Simulation version 3.0) is presented. Previous versions of the model (GSTARS 2.0 and 2.1) were developed for the simulation of large (wide) alluvial rivers. In addition to solving river sedimentation problems, GSTARS 3.0 has been developed to address several specific issues in reservoir sedimentation. The GSTARS 3.0 is a quasi-steady state model based on a one-dimensional backwater algorithm that can compute flow transitions (e.g., hydraulic jumps) and mixed regime flows (subcritical, supercritical, or any combination of the two). Sediment is routed using the stream tube concept. Bed changes are computed independently for each stream tube. GSTARS 3.0 sediment transport capabilities cover a wide range of conditions, such as fractional transport, bed sorting and armoring, over 16 sediment transport functions for sizes ranging from clay to gravel, and non-equilibrium sediment transport. It has the capability of dealing with flows carrying high concentration of silt and clay. Other special capabilities include bank stability criteria and the computation of channel width changes based on the theory of total stream power minimization. This paper provides a general description of the concepts and approaches used in GSTARS 3.0. Examples are given to illustrate the potential application of GSTARS 3.0 for solutions of engineering problems in reservoir sedimentation.

Sediment Transport Modeling —Tools for TMDL Analysis

Earl J. Hayter
U.S. Environmental Protection Agency
National Exposure Research Laboratory (NERL)
Ecosystems Research Division (ERD)
Athens, GA

It is estimated that Total Maximum Daily Loads (TMDLs) for a majority of the sediment-impaired waters listed on state 303d lists can be achieved by implementation of Best Management Practices (BMPs), and thus will not require the use of sediment transport models. For those waterways where modeling is deemed necessary, states have the choice of several modeling tools that can be used to calculate the maximum allowable load of instream sediment without exceeding the specified water quality target. Several EPA supported mathematical models are described herein.

Two types of models are described: instream sediment transport and fate models, and watershed loading models. The latter are included since sediment loads from the source watershed have to be estimated and added as nonpoint source loads to the sediment transport model.

Instream Sediment Transport Models

EFDC—The EFDC (Environmental Fluid Dynamics Code) model solves the three-dimensional (3-D), vertically hydrostatic, free surface, turbulent-averaged equations of motions for a variable density fluid using a stretched or sigma vertical coordinate and Cartesian or curvilinear, orthogonal horizontal coordinates (Hamrick 1992; Hamrick 1996). The model also solves the dynamically coupled equations for turbulent kinetic energy and length scale, salinity and temperature. The turbulent kinetic energy and length scale equations are solved using the Mellor-Yamada level 2.5 turbulence closure scheme (Mellor and Yamada 1982) as modified by Galperin et al. (1988). The EFDC model also simultaneously solves the Eulerian transport-transformation equations for dissolved and suspended materials, e.g., sediment, toxic contaminants, and water quality state variables. The sediment module can represent the transport and fate of multiple size classes of both cohesive and noncohesive sediments. EFDC is scheduled to be released on the CEAM website (www.epa.gov/ceampubl/) in January 2003.

EFDC1D—is a one-dimensional (1-D) version of the three-dimensional (3-D) version of EFDC that can simulate hydrodynamics and sediment transport in low-order stream networks (Hamrick 2001; Hayter et al. 2001). EFDC1D can simulate bi-directional unsteady flows and has the ability to accommodate unsteady inflows and outflows associated with upstream inflows, lateral inflows and withdrawals, groundwater-surface water interaction, evaporation and direct rainfall. EFDC1D also includes representation of hydraulic structures such as dams and culverts. For sediment transport, the model simulates settling, deposition and resuspension of multiple size classes of cohesive and noncohesive sediments. The sediment bed can be represented by multiple layers of mixed sediment classes. A bed consolidation module is included to predict time variations of bed depth, void ratio, bulk density and shear strength. The sediment bed representation is dynamically coupled to the cross-sectional area representation to account for area changes due to deposition and resuspension. EFDC1D is scheduled to be released on the CEAM in November 2002.

GSTARS—The **G**eneralized **S**tream **T**ube model for **A**lluvial **R**iver **S**imulation model simulates the flow of water and sediment transport in alluvial rivers (Yang and Simtes 2000). This model consists of the following four components. 1) Water surface profiles are determined using both the energy and momentum equations to perform backwater computations. 2) The stream tube concept is used in routing sediment. Bed sorting and armoring are accounted for in each stream tube, and the sediment transport rate is calculated using one of 11 methods included in the code. 3) The concept of minimum total stream power is used to compute changes in channel widths and depths. 4) The fourth component is a bank stability criteria based on the angle of repose of the bank material and conservation of sediment mass.

HSCTM2D— The Hydrodynamic, Sediment, and Contaminant Transport Model (HSCTM2D) is a finite element modeling system for simulating two-dimensional, vertically-integrated, surface water flow (typically riverine or estuarine hydrodynamics), sediment transport, and contaminant transport (Hayter *et al*. 1999). The modeling system consists of two modules, one for hydrodynamic modeling (HYDRO2D) and the other for sediment and contaminant transport modeling (CS2D). The HSCTM2D modeling system may be used to simulate both short term (less than 1 year) and long term scour and/or sedimentation rates and contaminant transport and fate in vertically well-mixed bodies of water. HSCTM2D is currently on the CEAM web site (www.epa.gov/ceampubl/swater/hsctm2d/index.htm).

Watershed Loading Models

TMDL USLE–The U.S. EPA's TMDL Universal Soil Loss Equation (USLE) model is a Windows-based software application for estimating diffuse (i.e., nonpoint) average annual sediment source loads within a watershed using the Revised Universal Soil Loss Equation (RUSLE) (www.epa.gov/ceampubl/swater/usle/index.htm). Applications of this software can vary from a simple computation of the annual edge-of-field sediment loading from a single parcel of land to more extensive applications designed to estimate grouped sediment sources throughout a watershed. Estimates of sediment loadings for grouped sources are particularly useful for TMDL analysis, since similar control measures can be considered for similar sources throughout the watershed. The strength of the RUSLE methodology is in estimating sediment loadings generated by erosion on agricultural lands. However, the RUSLE has also been applied to rangeland, forestlands, landfills, construction sites, mining sites, reclaimed lands, military training lands, parks, and other land uses where mineral soil material is exposed to the erosive forces of raindrop impact and overland flow.

HSPF—Hydrological Simulation Program - FORTRAN (HSPF) is a modeling system of watershed hydrology and water quality for both conventional and toxic organic pollutants that enables the integrated simulation of land runoff processes with instream hydraulics and fate and transport, including sediment-chemical interactions, in one-dimensional stream channels (Bicknell et al. 1997). HSPF uses the lumped-parameter approach for representing variations in land-uses, soil types, etc., throughout the modeled watershed. HSPF can simulate the transport and fate of up to three types of sediment (clay, silt, and sand) and the transport and transformation of a single organic chemical. HSPF is currently on the CEAM website (www.epa.gov/ceampubl/swater/hspf/index.htm).

TOPLATS—is a spatially-distributed, physically-based, continuous simulation hydrologic model (Peters-Lidard and Keel 2002a). It consists of two components: TOPMODEL, which computes the lateral redistribution of subsurface water in the saturated zone (variable contributing area concept) as a function of both soil type and topography (Beven and Kirkly 1979; Sivapalan et al. 1987), and a water and energy balance model which computers fluxes across the surface-atmosphere interface (Peters-Lidard et al. 1997, 1998). TOPLATS has recently been applied to the Middle Swamp watershed in North Carolina (Peters-Lidard and Keel 2002b). TOPLATS is scheduled to be released on the CEAM website in September 2003.

Modeling Framework Application

As an example of a tool that can be used to determine sediment TMDLs, a modeling framework that can be used to evaluate sedimentation in waterways, e.g., low-order stream networks, is described. The framework also accounts for instream sediment processes such as aggregation and degradation of the sediment beds in the modeled waterways. The framework consists of coupled models that simulate both watershed and instream physical processes. Watershed sediment loads are represented as nonpoint source loadings in the sediment transport model, and can be calculated in units of tons of sediment per acre per year (for performing baseflow analysis) or tons of sediment per acre per day or hour (for performing rain-event analysis). The watershed portion of the framework consists of: a) the U.S. EPA's TMDL USLE model for baseflow simulations, or b) the U.S. EPA's HSPF model (Imhoff et al. 1995) for rain-event simulations. The instream portion of the framework consists of the EFDC1D model. This modeling framework is currently being applied to a reach of the Housatonic River in Massachusetts.

Ongoing Research

In addition to the development, testing and support of the above models, NERL/ERD is also developing modeling protocols for use in determining sediment TMDLs. These protocols will supplement the protocols for determining sediment TMDLs published by the EPA's Office of Water (U.S. EPA 1999). The latter do not contain specific recommendations related to the use of sediment transport models, nor guidance in determining when modeling is necessary, both of which will be discussed in detail in the modeling protocols. These protocols will be delivered to the Office of Water in September 2004. NERL/ERD is also involved in the development of a web-based or spreadsheet-based user-friendly version of Rosgen's WARSS methodology.

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NCCHE Sediment Models: Capabilities and Applications

Sam S.Y. Wang
National Center for Computational Hydroscience and Engineering
The University of Mississippi
University, MS 38677

The National Center for Computational Hydroscience and Engineering at The University of Mississippi has been developing, verifying, validating, and refining computational simulation models for studying free-surface flows, sediment transport, morphodynamic processes since 1989. This long term project has been supported by funds provided by the US Congress with a mandate "to develop state of the art of numerical-empirical models in support of the DEC (Demonstration Erosion Control) Project." The DEC project has been conducted by COE Vicksburg District, WES (now renamed ERDC), USGS, USDA-ARS National Sedimentation Laboratory in Mississippi.

A series of numerical-empirical models has been developed for simulating unsteady, free-surface, turbulent flows; sediment/pollutant and solute transport; channel aggradation/degradation, bank erosion and retreat, local scours, channel widening, meandering and migration; run-off of and routing of water and sediment in channel networks of watershed and river basin.

Most of these models have been verified and validated by using analytic methods, laboratory and field measurements following the most rigorous and comprehensive testing procedure under development by the ASCE Environmental and Water Resources Institute's Task Committee on 3-D Free Surface Flow Model Verification and Validation, which is chaired by Dr. Sam Wang of NCCHE. The sediment models have been validated by several laboratory experiments and field measurements.

The most realistic model is of course a time-dependent and three-dimensional model. It is based on unsteady, 3-D Navier-Stokes equation and continuity equation with several turbulence closures at varying level of sophistications, such as the eddy viscosity, mixing length, standard κ-ϵ, nonlinear κ-ϵ, etc. Our models do not have hydrostatic pressure and rigid lid assumptions. It solves the instantaneous surface elevation locally, and the pressure distribution becomes hydrostatic in steady uniform flow as a special case. The advection diffusion equation and non-equilibrium transport equation are used to predict the suspended and the bed loads respectively. The sediment being transported in water is considered to have a non-uniform size distribution. Our models are capable of considering the effects of secondary flows vortices, in stream structures, vegetations, cohesiveness, armoring, etc.

To reduce the computing time, depth-integrated differential equations have been used to develop a set of 2-D flow and sediment transport models to obtain approximate solutions for shallow water flow and sediment transport problems. And a set of cross-sectional area averaged equations have been used to develop the 1-D model. It has been planned to integrate all of our models into a basin or watershed model for the analysis and prediction of flow, sediment transport and morphological changes of channel network of a river basin or a watershed. The primary models to be used are 1-D models. The 2-D and 3-D models are used only if achieving the required accuracy of the results in certain parts of the watershed cannot be obtained without them.

The sediment models developed by NCCHE have been successfully applied to solve the following real world problems: the flow, sediment concentration distribution and discharges in the old river control reach of the Lower Mississippi River; sedimentation problems during the construction and operation of the lock and dam systems along the Red River Waterway in Louisiana; 3-D flow sediment transport, local scour and their effects on ecology around submerged and exposed spur dikes; channel widening, meander initiation and migration; flow and sedimentation processes in the region of a large number of bridge piers of an interstate highway ramp in a swamp; the evaluation of effectiveness of submerged weir systems in the Victoria Bendway of Mississippi River for improving navigatability; the flood stage and sediment transport predictions of several rivers with and without in stream structures as well as with and without tidal effects; the agricultural contaminants effects on the oxbow lakes including fate functions; the environmental effects of absorption and desorption of heavy metals by suspended and bed sediments; the rainfall and sediment routing in channel network of a watershed; the effectiveness evaluation of alternative designs of sediment reduction and control structures in the channel network; and other applications.

Additional models for simulation of pollutant transport and water quality; TMDL prediction; pollutant source identification, optimization of measures for flood, sediment and pollutant controls; decision support system for both preventative and remedial engineering design and for BMP. We anticipate all of NCCHE's modeling capabilities are to be made available to all federal agencies in the near future.

Agricultural BMPs and Modeling for Sediment

James V. Bonta
USDA ARS
North Appalachian Experimental Watershed
Coshocton, OH

Don Wauchope
USDA ARS
Southeast Watershed Research Laboratory
Tifton, GA

Introduction

Sustaining agricultural production for high commodity yields and quality has been a major goal of the agricultural community. One component of agricultural sustainability is the control of erosion and sediment transport on agricultural fields. Erosion degrades the soil resource and can affect nutrient and pesticide application rates and transport through the soil profile and in direct runoff. Soil-erosion research over the last 50+ years began with an understanding of factors affecting erosion, and developed continuously to development of several models to quantify these interacting factors for land-management planning to minimize erosion. Concurrent with these efforts were field evaluations of various best-management practices (BMPs) to control erosion. A major goal of modeling was to mathematically describe these BMPs so the benefits of implementing them in a variety of climates and physiographic regions could be quantified.

The purpose of this paper is to briefly outline many broad classes of agricultural BMPs that have been developed to control erosion, and to list several models developed by the USDA Agricultural Research Service (ARS) that can be used to estimate the impacts of implementing BMPs to control erosion. The scope of the paper is to consider only BMPs that can be implemented on fields and small watersheds— the area size on which BMPs are implemented by agricultural producers and landowners. Models, on the other hand, consider these field-sized areas as well as larger watersheds (up to many square kilometers) so downstream impacts of spatially variable field-scale BMP implementations can be quantified. While historical development of BMPs has focused on agricultural lands, the results are directly applicable to other disturbed areas such as construction sites, urban areas, and mining sites.

Agricultural BMPs

Many of the BMPs commonly used for erosion control were field tested and developed prior to 1980. Table 1 lists 17 broad classes of BMPs that have been developed and their positive and negative highlights. The reports by Stewart et al. (1975a and b) are good references for developing an understanding of BMPs for erosion, nutrients, and pesticides, and fundamental principals of erosion and chemical control. There are implementation variations within each general BMP practice in Table 1, and often more than one practice is used concurrently to solve a particular problem.

Table 1. Principal Types of Cropland Erosion Control Practices and Their Highlights (Stewart et al., 1975a)

ID	Erosion Control Practice	Practice Highlights
E1	No-till plant in prior-crop residues	Most effective in dormant grass or small grain; highly effective in crop residues; minimizes spring sediment surges and provides year-round control; reduces man, machine, and fuel requirements; delays soil warming and drying; requires more pesticides and nitrogen; limits fertilizer- and pesticide-placement options; some climatic and soil restrictions.
E2	Conservation tillage	Includes a variety of no-plow systems that retain some of the residues on the surface; more widely adaptable but somewhat less effective than E 1; advantages and disadvantages generally same as E 1 but to lesser degree.
E3	Sod-based rotations	Good meadows lose virtually no soil and reduce erosion from succeeding crops; total soil loss greatly reduced but loses unequally distributed over rotation cycle; aid in control of some diseases and pests; more fertilizer-placement options; less realized income from hay years; greater potential transport of water soluble P; some climatic restrictions.
E4	Meadow-less rotations	Aid in disease and pest control; may provide more continuous soil protection than one-crop systems; much less effective than E 3.
E5	Winter cover crops	Reduce winter erosion where corn stover has been removed and after low-residue crops; provide good base for slot-planting next crop; usually no advantage over heavy cover of chopped stalks or straw; may reduce leaching of nitrate; water use by winter cover may reduce yield of cash crop.
E6	Improved soil fertility	Can substantially reduce erosion hazards as well as increase crop yields.
E7	Timing of field operations	Fall plowing facilitates more timely planting in wet springs, but it greatly increases winter and early spring erosion hazards; optimum timing of spring operations can reduce erosion and increase yields.
E8	Plow-plant systems	Rough, cloddy surface increases infiltration and reduces erosion; much less effective than E 1 and E 2 when long rain periods occur; seedling stands may be poor when moisture conditions are less than optimum. Mulch effect is lost by plowing.
E9	Contouring	Can reduce average soil loss by 50% on moderate slopes, but less on steep slopes; loses effectiveness if rows break over; must be supported by terraces on long slopes; soil, climatic, and topographic limitations; not compatible with use of large farming equipment on many topographies. Does not affect fertilizer and pesticide rates.
E10	Graded rows	Similar to contouring but less susceptible to row breakovers.

Table 1. Principal Types of Cropland Erosion Control Practices and Their Highlights (Stewart et al., 1975a – Cont'd)

E11	Contour strip cropping	Rowcrop and hay in alternate 50- to 100-foot strips reduce soil loss to about 50% of that with the same rotation contoured only; fall seeded grain in lieu of meadow about half as effective; alternating corn and spring grain not effective; area must be suitable for across-slope farming and establishment of rotation meadows; favorable and unfavorable features similar to E 3 and E 9.
E12	Terraces	Support contouring and agronomic practices by reducing effective slope length and runoff concentration; reduce erosion and conserve soil moisture; facilitate more intensive cropping; conventional gradient terraces often incompatible with use of large equipment, but new designs have alleviated this problem; substantial initial cost and some maintenance costs.
E13	Grassed outlets	Facilitate drainage of graded rows and terrace channels with minimal erosion; involve establishment and maintenance costs and may interfere with use of large implements.
E14	Ridge planting	Earlier warming and drying of row zone; reduces erosion by concentrating runoff flow in mulch-covered furrows; most effective when rows are across slope.
E15	Contour listing	Minimizes row breakover; can reduce annual soil loss by 50%; loses effectiveness with post-emergence corn cultivation; disadvantages same as E 9.
E16	Change in land use	Sometimes the only solution. Well managed permanent grass or woodland effective where other control practices are inadequate; lost acreage can be compensated for by more intensive use of less erodible land.
E17	Other practices	Contour furrows, diversions, subsurface drainage, land forming, closer row spacing, etc.

Since about 1980 BMP erosion-control research within the ARS included the following topics: 1.) gypsum soil amendment; 2.) polyacrylamide (PAM); 3.) grass hedges; and 4.) on-site erosion control. Applying gypsum to soil decreases soil dispersion at the soil surface, increases infiltration, reduces erosion, and is inexpensive. PAM strengthens aggregates, increases infiltration, reduces erosion, is environmentally safe, and is expensive. It is used in rainfed agriculture as well as in irrigation applications. In rainfed areas, it is used in critical areas during vegetation establishment. If disturbed, it will lose its effectiveness (Flanagan et al., 2002). Research has shown that when gypsum and PAM are combined erosion is reduced more than if each practice was used alone (Peterson et al., 2002). Stiff grass hedges reduce surface slopes by ponding water, allowing water flow through the thick vegetation, and forcing deposition of sediment (Ritchie et al, 1997 and Dabney et al, 1995). On-site erosion control by trapping sediment in small depressions on the slope was studied by Bonta et al. (1991) by using bulldozer imprints on surface-mine spoil. Tracking with bulldozer tracks oriented along the contour (bulldozer movement up and down the slope) yielded less sediment than tracks oriented along the slope and backblading (which was the worst case). At least two companies are marketing an imprinting device that mimics bulldozer tracks.

ARS Models of Erosion and Sediment Transport

Early erosion research and development of erosion models led to the Universal Soil Loss Equation (USLE, Wischmeier and Smith, 1978) which is the basis for current erosion modeling. The USLE quantifies the interacting factors of precipitation intensity and energy, soil erodibility, slope length and steepness, cover management, and supporting practices to yield an estimate of soil loss prior to deposition at the base of a slope. BMP effectiveness is generally quantified with these factors, although actual expressions can be complex. Deposition of sediment and channel processes are additional factors that must be considered when computing watershed sediment yield.

Thirteen models that simulate erosion and/or sediment yield, or for which there are plans to incorporate such simulation, are listed in Table 2. Some of these models are not intended to simulate actual erosion, but were developed to compare different scenarios (e.g., GLEAMS). Some are research models (e.g., RZWQM), and some were designed as comprehensive models for farms (e.g., GPFARM). Of special significance is the new OMS modeling effort. This joint ARS, NRCS, and USGS collaboration has as its goal to develop a library of tested model components. When finalized, a user will be able to construct a custom model by choosing which components and model theories will be included in the final model. To date the ARS RZWQM model has been incorporated into the OMS libraries. The CONCEPTS model simulates channel processes and can be incorporated into the AnnAGNPS model. The last three models listed in Table 2 are weather/storm generation models. All models require some type of weather inputs to drive the models. CLIGEN is used in WEPP, and GEM is used in AnnAGNPS and will replace CLIGEN in the future. StormGen is under development and simulates a record of individual storms and will be combined with GEM. Table 2 lists only ARS models, however, many nonARS models are also available to simulate sediment yield.

Table 2. Active USDA-Agricultural Research Service modeling projects related to erosion-modeling science (adapted from Wauchope et al., 2002)

MODEL/DATABASE DESCRIPTION	CONTACT
RUSLE/RUSLE2 (Revised Universal Soil Loss Equation): Field scale model for estimating long-term soil losses from field-sized areas. Used in many larger watershed models.	http://www.sedlab.olemiss.edu/rusle/ Sedimentation Lab, Oxford, MS
AnnAGNPS[†] (Annualized Agricultural NonPoint Source model): watershed-scale, distributed parameter, nonpoint pollution model for chemicals, nutrients and sediments.	Ron Bingner: rbingner@ars.usda.gov http://www.sedlab.olemiss.edu/AGNPS.html National Sedimentation Lab., Oxford, MS
CONCEPTS (Conservation Channel Evolution and Pollutant Transport System): Models open-channel hydraulics, sediment transport, and channel morphology. Can be coupled with AnnAGNPS.	Carlos Alonso: calonso@ars.usda.gov http://www.sedlab.olemiss.edu/agnps/Concepts/concepts.html National Sedimentation Lab., Oxford, MS
EPIC (Erosion-Productivity Impact Calculator): Determines the relationship between erosion and agricultural productivity using modified USLE parameters.	J. R. Williams http://www.brc.tamus.edu/epic/ Grassland, Soil and Water Research Laboratory Temple, TX
WEPP (Water Erosion Prediction Project): Simulates erosion and deposition process on a hillslope.	Dennis Flanagan: flanagan@purdue.edu National Soil Erosion Lab, W. Lafayette, IN

Table 2. Active USDA-Agricultural Research Service modeling projects related to erosion-modeling science (adapted from Wauchope et al., 2002 – Cont'd)

EAHM (Everglades Agro-Hydrology Model): Uses WEPP model hydrology and GLEAMS pesticide algorithms to describe south Florida Agricultural nonpoint pollution	M. R. Savabi: rsavabi@saa.ars.usda.gov Subtropocal Horticultural Research Unit, Miami, FL
GLEAMS† (Groundwater Loading Effects of Agricultural Management Systems): field-scale model of sediment, nutrient, pesticide leaching and runoff	Version 2.1: Daren Harmel, dharmel@brc.tamus.edu http://arsserv0.tamu.edu/nrsu/glmsfact.htm Version 3.0: http://www.cpes.peachnet. edu/sewrl/Gleams/gleams_y2k_update.htm
GPFARM† (Great Plains Framework for Agricultural Resource Management): decision support system for Great Plains farmers	Laj Ahuja: ahuja@gpsr.colostate.edu Great Plains Systems Research, Ft. Collins, CO
OMS (Object Modeling System): a framework for archiving and configuring modular simulation models. Under development, but significant results to date. Allows for flexible watershed modeling using a library of tested modules.	Laj Ahuja: ahuja@gpsr.colostate.edu Great Plains Systems Research, Ft. Collins, CO
REMM† Riparian Ecosystem Management Model Simulation of movement and fate of pollutants in streamside soil/water/plant systems	Richard Lowrance: LORENZ@tifton.cpes.peachnet.edu http://sacs.cpes.peachnet.edu/remm/ Southeast Watershed Res. Lab. Tifton, GA
RZWQM† (Root Zone Water Quality Model): field-scale hydrology and nutrient/pesticide leaching and runoff prediction model (erosion modeling is a future research objective)	Laj Ahuja: ahuja@gpsr.colostate.edu Great Plains Systems Research, Ft. Collins, CO
SWAT† (Soil and Water Assessment Tool): models water, sediment, chemical movement in a large watershed (EPA supports SWAT as part of BASINS)	Jeff Arnold: arnold@brc.tamus.edu http://www.brc.tamus.edu/swat/index.html EPA: http://www.epa.gov/OST/BASINS/ Natural Resources Systems Research Temple, TX
SWRRB (Simulator for Water Resources in Rural Basins): Spatially distributed model for simulating sediment yield from small to large watersheds	Jeff Arnold: arnold@brc.tamus.edu Natural Resources Systems Research Temple, TX
StormGen: generates synthetic storm data including storm occurrence, depth, duration, and within storm intensity - seasonal (monthly) dependence	Jim Bonta: bonta@coshocton.ars.usda.gov North Appalachian Experimental Watershed Research, Coshocton, OH
GEM (Generation of weather Elements for Multiple applications): Synthetic generation of weather elements needed for running some models	Greg Johnson: http://www.wcc.nrcs.usda.gov/water/climate/gem/gem.html Water and Climate Center, Portland, OR
CLIGEN: Synthetic generation of weather elements needed for running some models	Charles Myers: meyerc@ecn.purdue.edu http://horizon.nserl.purdue.edu/Cligen/ National Soil Erosion Lab, W. Lafayette, IN

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Urban BMP Models: Accuracy and Application

Billy J. Barfield
Biosystems and Agricultural Engineering
Oklahoma State University
Stillwater, OK 74078
405-744-8398
bill@okstate.edu

Changing land use as a result of urbanization is a major concern to individuals and organizations charged with maintaining healthy ecosystems. The parameter currently being fairly widely proposed as the prime variable in defining urbanization impact is percent imperviousness (Schuler and Holland, 2000). As land use changes from a less disturbed state such as forest or pasture to the more disturbed state of construction and then to urbanized land use, runoff volume and soil erosion change dramatically. In the change from an undisturbed forest to a fully urbanized area, the peak discharge and runoff volume can change by a factor of five or more. In the change from an undisturbed forest to a construction operation, the sediment yield and sediment concentration can change by a factor of 10,000 or more. These changes in flow and sediment loading (Haan et al., 1994) ultimately translate into changes in channel geomorphology, habitat, and the structure and function of the aquatic ecosystem.

Urban Stormwater BMPS: Problems and Prospects

A variety of storm water and sediment BMPs are used in an attempt to decrease the impact of urbanization. Perhaps the easiest impact to control is peak discharge. Typically, this is controlled by the use of a storm water detention structure which stores water with a slow release rate set to match a pre-disturbed peak. The design of such systems is straightforward and sometimes the goal of peak matching is even accomplished with a structure that occupies only a few percent of the developed area. Control of storm water volume to match a pre-disturbed volume is much more difficult and is seldom accomplished, although infiltration practices such as pervious pavements and infiltration basins are proposed as BMPs (Clar et al., 2002b). Matching pre and post-construction runoff volumes using infiltration basins can take a high percentage of the development area. More recent proposals for matching volumes include the use of bioretention cells and other low-impact development practices. These practices can be shown theoretically to match pre-disturbed volumes (Vogel and Barfield, 2001) but a significant database is not yet available to validate this approach.

Control of sediment concentration and discharge from construction operations is much more difficult. BMPs used to control sediment include sediment ponds; ditch checks, vegetative filter strips, buffer strips, storm sewer inlet traps, silt fence and straw bales. Varying degrees of success have been attained with these controls (Clar et al, 2002a, 2002b).

Urban Sediment BMPS: Problems and Prospects

The most commonly proposed sediment BMP is the sediment pond where outflow rates and surface area are varied to control the overflow rate and thus trapping efficiency. It can be shown that attempting to control total suspended sediment concentrations to pre-disturbed levels in the discharge from a construction site will typically require surface areas that greatly exceed the area under construction. Therefore, in areas that require sediment ponds, either a trapping efficiency standard or a settleable solids standard is used (SCDHEC, 1995). Settleable solids are those solids that will settle in an Imhoff cone in one hour, thus reasonable sized ponds can be designed to meet a settleable solids standard of 0.5 ml/l or a trapping efficiency of 85 percent. These are the values that have been proposed by some regulatory authorities (SCDHEC, 1995, Hayes et al, 2000). Sediment ponds are normally robust structures that reduce sediment loads even when poorly designed and installed. Of course, the trapping efficiency under these conditions can be greatly reduced.

Ditch check BMPs are small rock fill dams used in road ditches and small channels to retard flow and trap sediment. Trapping efficiencies are typically low and storage volume is small. One of the chief benefits is that ditch checks can control the grade and prevent channel degradation. Trapping of sediment results from the small impoundment that occurs upstream and not from the filtering action of the porous ditch check. Operating alone, ditch checks will not normally yield an effluent concentration that meets a trapping efficiency or settleable solids standard. Installation is critical to successful operation and improper installation can result in failure and enhanced erosion. A common practice that leads to failure is neglecting to shape the top of the ditch check so that overtopping always occurs over the center of rock structure and not around the edges where erosion can cause failure.

Vegetative filter strips and buffer strips (VFS) trap sediment by settling within the grass and by infiltration of fines into the soil matrix. They can be effective in trapping sediment until the sediment load is such that the trapped sediment inundates the grass. At that point, the filter strip becomes ineffective. Typical sediment loads from a construction area during a large storm can inundate a VFS unless it is used in conjunction with some other practice, thus VFS are not normally recommended as a stand-alone BMP for sediment control from construction sites. They can be, however, effective in controlling pollutants from post-construction runoff if the infiltration rate is high.

Silt fence (filter fence) is probably the most ubiquitous sediment BMP used in construction, yet is almost universally ineffective. In the process of developing design aids for South Carolina and Louisville, KY, Hayes et al. (1996, 2000) visited numerous construction sites in both states and visually evaluated the performance of many fence installations. In all cases, the fence was ineffective as a result of one or more of the following reasons: 1) undercutting of the fence as a result of erosion of the burial trench from cross contour flow, 2) overtopping resulting from flow accumulation at low points on the fence, 3) excessive stretching of the filter fabric due to ponding, 4) insufficient post stability and/or backing of the fence, 5) damage to the fence from construction, 6) damage due to vandalism, and 7) inadequate maintenance. Problems 5–7 can only be solved by education and appropriate regulatory oversight; however, problems 1–4 can be solved by improved design, materials development, and installation techniques. These are the subjects of ongoing research.

Modeling the Effectiveness of BMPS

Sediment ponds have been modeled by empirical equations, by application of reactor theory, and by using computational fluid dynamic (CDF) models that solve the basic equations of motion. The empirical equations lack the necessary robustness to evaluate the flow and sediment properties that control sedimentation. Reactor models include the DEPOSITS plug flow model (Ward et al., 1979), the CSTRS model based on mixed reactors (Wilson and Barfield, 1984), and the BASIN model (Wilson and Barfield, 1985) based on a combination of diffusion and reactor theory, strike a balance between complexity and simplicity to allow process-based modeling with a minimum of input parameters. The experimental data indicate that the models predict with an accuracy of a few percent when considering trapping efficiency. The CSTRS model and BASIN model predict similar trapping efficiencies and effluent concentrations that more closely match the experimental data than do predictions from the DEPOSIT model. The CSTRS model is used in the SEDIMOT II and SEDIMOT III models as well as the SEDCAD model. An offshoot of the CSTRS model is the impoundment element of the WEPP model, known as WEPPSIE (Lindley et al., 1998). This model, working in a continuous simulation mode, predicts daily sediment trapping during storms and between storms. The CDF models solve the turbulent equations of motion and are considerably more complex than the reactor models.

Tapp et al. (1984) have evaluated use of flocculants in sediment ponds. The results show that flocculation can improve trapping in a natural setting, but problems with controlling injection rates and the required mixing in storms of varying intensity and flow rates make field application difficult.
Vegetative buffer strips have been successfully modeled by the Kentucky GRASFIL model of Hayes and others (Hayes et al., 1984). The GRASFIL model accurately predicted effluent concentrations and trapping efficiencies as controlled by flow rate, slope, size of the VFS, infiltration rate, density and type of grass media, sediment size distribution, and mass of sediment trapped. The resulting models have been incorporated into the SEDIMOT II and III models as well as the SEDCAD model.

Ditch check modeling is limited by the ability to estimate flow rates through the porous media. Haan et al. (1994, chapter 5) present a graphical relationship to predict flow rates based on average diameter and length of flow path through the rock fill. This is based on the model of Herrera and Felton (1991), which uses a calibrated friction factor approach. Using this relationship for predicting flow, the trapping in the impoundment zone can be calculated, an approach utilized in SEDIMOT III and WEPPSIE.

Modeling of filter fence trapping can be accomplished by predicting the flow with a slurry flow rate (Lindley et al., 1997). However, the predicted values will greatly exceed actual values unless the problems discussed previously are solved.

Development of Simplified Relationships

It is possible to use complex models to develop simple relationships that are accurate in a small percentage of cases and conservative in all others. These relationships can be used to develop conservative designs and are better than the rules of thumb often used. Utilizing the SEDIMOT III model, Hayes et al. (1996, 2000) and Barfield et al. (2000) generated a massive database of trapping efficiencies as related to watershed and BMP parameters. These were used to develop simple design aids for ponds and ditch checks. The design aids were developed for South Carolina, Louisville, KY, and for a future generation of TR55 and are currently being used in design. A further refinement of the approach was used to develop the IDEAL spreadsheet model for Coastal South Carolina and Greenville County, SC. This model calculates storm water runoff, sediment yield, nutrient yield and pathogens and routes them through buffer strips and wet or dry detention basins. The output is the yield through the BMP in an average storm, the annual storm, and the total annual value. Algorithms used in the model are based on the more complex relationships in SEDIMOT III, but are simplified to explicit equations using response surface methodologies.

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Assessment and Management of Reservoir Sedimentation

Sean J. Bennett
USDA ARS
National Sedimentation Laboratory
P.O. Box 1157
Oxford, MS 38655
662-232-2926
sjbennett@ars.usda.gov

Aging flood control reservoirs across the U.S. are rapidly filling with sediment via natural watershed processes and those accelerated by human-induced disturbances. Mean annual rates of storage capacity loss for reservoirs typically range from 0.1 to 4% or more. Action agencies such as the U.S. Department of Agriculture-Natural Resources Conservation Service (USDA-NRCS) and the U.S. Army Corps of Engineers (COE) are confronted with the challenge of maintaining this aging infrastructure to provide for adequate flood control while at the same time preserving ecology, maintaining water quality standards, and affording recreational opportunities.

Since 1948, the USDA-NRCS and its cooperators have constructed nearly 11,000 flood control dams in 47 states. More than $8.5 billion (1997 dollars) of federal funds and over $6 billion of local funds have been invested. This $14.5 billion infrastructure provides over $1 billion in benefits annually. The primary purposes for these structures were to prevent flooding and to protect watersheds for a service life of 50 years. Typically, these reservoirs trapped much of the sediment inflow (from 80 to 100%), reduced peak discharges (by as much as 50%), and decreased watershed sediment yields (by as much as 50 to 60%). At present, more than half of these dams are older than 34 years and more than 1,800 will reach their 50-year design life within the next 10 years. A rapid survey conducted in April 1999 by the USDA-NRCS revealed more than 2,200 dams need immediate rehabilitation at an estimated cost of more than $540 million. Before any rehabilitation strategy can be designed and implemented for those reservoirs with excessive sedimentation, the USDA-NRCS needs to determine the volume of sediment deposited within a given reservoir and the quality of the sediment with respect to agrichemicals and contaminants.

While the reservoirs in northern Mississippi have not experienced excessive sedimentation, the COE are particularly interested in maintaining good water quality standards, ecological integrity, and recreational opportunities in reservoirs downstream of major channel improvements and restoration programs. This becomes problematic in unstable watersheds where vast amounts of sediment upstream will be displaced during channel improvements and where agricultural practices have been pervasive for more than 50 years, suggesting that the stored sediment may be of questionable quality.

Research programs have focused on assessing sedimentation issues within flood control reservoirs in Oklahoma and Mississippi utilizing: (1) vibracoring equipment to obtain continuous, undisturbed sediment cores through the entire post-construction deposit, (2) high-resolution geophysical techniques (acoustic and seismic systems) to map the subsurface sediment stratigraphy, (3) stratigraphic analysis and cesium-137 emissions to discriminate post-construction deposition from pre-construction (parent) material, and (4) analytical techniques to determine sediment quality (agrichemicals and contaminants), organic carbon storage, bulk sediment chemistry, and subsurface geochemical conditions. Results from these research programs, as well the environmental impacts of reservoir sedimentation, will be presented and discussed.

Appendix D. Davenport Paper: Landscape Approach to Managing Agricultural Nonpoint Source Sediment

Landscape Approach to Managing Agricultural Nonpoint Source Sediment

Thomas E. Davenport
United States Environmental Protection Agency
Chicago, Illinois

Abstract
States report that about 40 percent of the waters they assessed do not meet water quality goals. About half of the nation's more than 2,000 major water bodies have serious or moderate water quality problems. There are many anthropogenic sources of sediment that are likely to enter and degrade our nation's water resources. Agriculture in its several forms is by far the largest generator of pollutants. The present approach of addressing agricultural pollutant sources on a site-by-site basis has not been totally effective and in a number of cases has resulted in further degradation downstream. Most programs used to control agricultural nonpoint source pollution are modeled after the traditional agricultural stewardship efforts that focus on infield best management practices based on a land manager's interest and operational constraints. An approach that integrates the spatial juxtaposition and dynamic interaction between potential pollutant generation and movement with agricultural management is needed to comprehensively address water quality concerns. This approach must include a combination of activities that promote the prevention, mitigation and treatment of agricultural pollution. To enhance the effectiveness of the landscape approach a new way to prioritize areas within the landscape needs to be adopted that is based upon site-specific conditions and takes in to account the potential for causing off-site impacts. Utilizing the landscape approach and this new prioritization process together, we can focus available resources and implement effective strategies to solve agricultural related problems.

To make the landscape approach effective the existing approach to field level planning must be changed. The present approach of planning on a rotation must be replaced with a potential pollutant generating approach based upon the pollutant of concern. In addition the field level focus must be expended to include more than just the field itself. This paper will present a landscape approach to agricultural management on a watershed basis to implement sediment management goals, and a revised approach to field level planning and implementation for sediment management.

Introduction
The United States is tremendously rich in natural resources. The more than 3.6 million miles of streams (rivers), 41.6 million acres of lakes (reservoirs and ponds), 90,400 miles^2 of estuaries, approximately 274 million acres of wetlands, 72,000 miles of coastal shorelines and abundant groundwater provide great social, cultural, and economic value.

Nationally much progress has been made in cleaning up impaired waters, but there are still many waters in this country that do not support the goals of the Clean Water Act. The 1998 National Water Quality Inventory (USEPA, 2000) reports that about 40 percent of the assessed waters do not meet water quality goals. Impaired waters are not safe for one or more beneficial uses including fishing, swimming, drinking or aquatic life support. About half of the nation's more than 2,000 major water bodies have serious or moderate water quality problems. In addition to the environmental effects, runoff pollution affects our recreation and our health.

Water pollution may be categorized by type of pollutant sources. Point sources discharge effluent directly into water resources through an identifiable pipe, ditch or other conveyance. Industrial and municipal discharges fall into this category. Nonpoint source pollution (NPS), the largest cause of water quality

Table 1. Leading pollutants causing impairments in assessed water bodies (USEPA, 2000)

Rivers & Streams	Lakes, Ponds and Reservoirs	Estuaries
Siltation	Nutrients	Pathogens
Pathogens	Metals	Organic Enrichment
Nutrients	Siltation	Metals

impairments in the United States, enters waters diffusely in the runoff or leachate from rain or melting snow, and is often a function of land cover and management.

Table 1 shows the top three pollutants causing impairments by water body type. Table 2 shows the top three pollutant sources by water body type.

Agricultural Nonpoint Sources of Pollution

Section 303(d) of the Clean Water Act provides that states, territories, and authorized tribes are to list waters where technology-based limits alone do not ensure attainment of water quality standards. Of the top 15 categories of impairment identified on the 1998 303(d) list, 11 are related to point source, nonpoint sources or a combination of sources associated with agricultural operations. Agriculture is the most widespread source of water pollution across the nation.

The over application and underutilization of nutrients, associated with crop production, are the two main causes of nutrient contamination of surface and ground water. Soil loss, resulting in sediment production, removes available nutrients and deteriorates soil structure causing a decrease in the productive capacity of the crop land from which it is eroded. Nationwide approximately half of the total sediment, delivered to lakes and streams, is from cropland. The runoff from agricultural lands, carrying excessive amounts of sediment scours the stream channel, alters the character of the stream, and affects aquatic life impairing functions such as photosynthesis, respiration, growth and reproduction. The primary agricultural pollutants are: sediment, nutrients, pesticides, salts and pathogens. The most severe agricultural related problem is soil erosion resulting in sediment production (USEPA, 2000). Mismanagement of animal wastes can result in discharge of nutrients, pathogens, oxygen-demanding substances and sediments to nearby water bodies. Accumulation of salts reduces irrigated agricultural production and runoff of saline water harms aquatic ecosystems. Pesticide residues reaching surface and ground water may contaminate drinking water supplies, and, for surface water systems, may harm aquatic life. The factors common with all of these pollutants are their availability and a transport mechanism to export them from the field to the water body.

Control of Agricultural NPS Pollution

The traditional management approach to controlling agricultural NPS pollution is by the voluntary implementation of various Best Management Practices (BMPs) that minimize pollutants at the source, retard the transport or remediate pollutants prior to delivery to waterbodies within a watershed. Most NPS programs used to control agricultural pollution are modeled after the traditional USDA agricultural stewardship efforts that focus on in field BMPs based on a landowner/operator's interest and operational constraints. It is important to note the implementation of various BMPs does not eliminate pollutant generation and transport, but only lowers export rates thereby either improving or protecting water quality. Physically and economically, it is impractical to eliminate all pollutants from surface and ground waters.

Table 2. Leading sources* causing impairments in assessed water bodies (USEPA, 2000)

Rivers & Streams	Lakes, Ponds and Reservoirs	Estuaries
Agriculture	Agriculture	Municipal Point Source
Hydromodification	Hydromodification	Urban Runoff/Storm Sewers
Urban Runoff/Storm Sewers	Urban Runoff/Storm Sewers	Atmospheric Deposition

*Excludes unknown, natural and other pollutant source categories

Additionally, the movement of some agricultural “pollutants,” such as sediment and nutrients, from land to surface and ground water is a natural process. These parameters (sediment and nutrients) only become pollutants when they are available in excess quantities.

Resource Management Systems (RMSs) are the combinations of BMPs that are implemented by individual landowner/operator to meet soil, water, air, related plant, animal, and human resource needs and criterion. Any two or more BMPs used together to control a pollutant from the same source constitute a RMS. BMPs are typically applied as systems of practices because one practice rarely solves all the water quality problems at a site, and the same practice will not work for all the sources of a pollutant. A RMS is tailored for a specific pollutant, source, geographic location, as well as to landowner’s economic situation. Systems of RMSs are more effective in controlling NPS pollutants from critical areas than a single BMP would be. All three types (vegetative, managerial and structural) of practices may be needed in a system approach to solve field specific water quality problems.

Field Landscape

Watershed landscapes differ from one another based on the consistent pattern formed by their structured elements, and the predominant land management approach needed. The movement of material and energy between landscape zones is dependent on the movement of water. Landscape analysis considers the spatial juxtaposition and dynamic interaction between potential pollutant generation and runoff processes in the context of resulting water quality from each field within a zone. In some instances, all the water on a field is generated from precipitation on the field. Often the water on a field is a combination of precipitation and runoff from adjoining fields. Analysis at the field level is needed for development of field specific control strategies to meet the goals of that particular zone. Field level analysis is a neccessity to adequately address the identified source and its transport system within the various landscape management zones. The field level analysis focuses on the control of four primary factors: water runoff and soil moisture, erosion potential, nutrient availability, and other contaminant availaility. These factors are dependent and highly interactive.

Watershed areas can be divided into general categories based upon topographic characteristics and potential pollutant generation based upon erosion types. Figure 1 shows a watershed with delinated landscape zones. The upland zone is characterized as relatively flat, less than 2% slope, ideally with permeable, well-drained soils and the absence of sheet erosion and drainage ditches. The relative magnitude of the eroding forces of sheet erosion is usually less than the resistance of the soil. Raindrop splash erosion does occur in the upland zone. The transition zone has slopes greater than 2%, ideally with well-drained soils. Soils in this zone, in addition to raindrop splash, gravity and overland runoff causing erosion, can be impacted by a combination of sheet, rill, mega-rill and gully erosion. Water management practices are usually necessary to address overland flow in this zone. Riparian Zone cropland has a slope

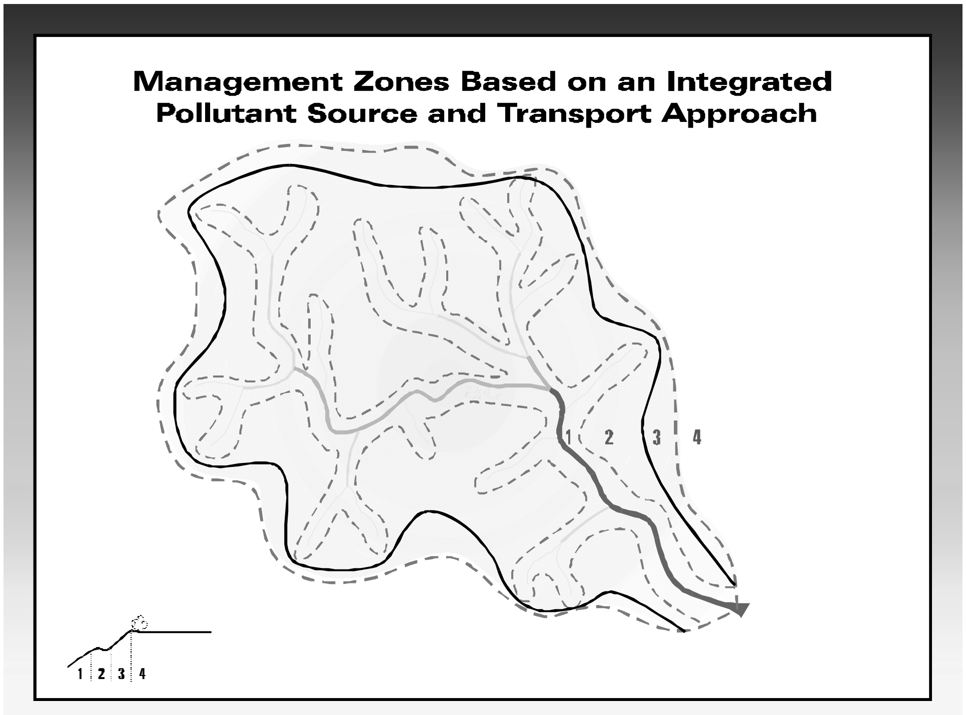

Figure 1. Watershed Landscape Management Approach

of 2% or less and is adjacent to a watercourse or drainage network. Soils generally are poorly drained to hydric and are characterized by being inundated by floodwaters at some interval and/or low permeability. The upland and riparian zones are typically the most productive for row crop production.

Using site-specific farming, the basic principles of the erosion process and landscape zone characteristics, a landscape approach to addressing NPS pollution problems can be implemented (figure 1). The issue that needs to be addressed at two scales (watershed and field) is the level of treatment needed to adequately control pollutant loadings. The landscape approach lends itself to establishing variable management objectives based upon the pollutant of concern and which zone the field is in. For each landscape zone a pollution management approach is established (Table 3).

Table 3. General Management Approach by Landscape Zone (Davenport and Kirschner, 2002)*.

Landscape Zone	Management Approach
Upland	Source reduction control
Transitional	Source reduction control and manage/retard pollutant transport
Riparian	Source reduction control, manage/retard pollutant transport and treatment

*These are viewed as minimum levels of management.

Based upon field level analysis management goal(s) are set for individual fields, taking into account the watershed management plan reduction goal, landscape zone management approach, and land owner's objectives and operational constraints. This level of management becomes the minimum that is acceptable for cropland within that zone. Table 3 shows the concept of differential management approaches by landscape zone. Within each zone RMSs need to be designed so that they alter water runoff, provide cover for soil, and change the water absorption capacity of soil, rain splash energy, and soil structure.

Source control focuses on reducing the detachment of pollutants by rainfall and overland runoff. The overall goal of an RMS designed for this purpose would be to limit the amount of bare soil exposed to rainfall and runoff. Residue cover is the single most important factor to influence soil loss (MWPS, 2000). In addition, residue effects not only soil detachment but also the hydrologic cycle (Table 4). Reviewing Table 4 indicates that in terms of soil erosion, the source reduction practice "no-till" provides the greatest annual reduction (93%) in comparison to the existing moldboard plow system or the alternative ridge-till system. The annual reduction of ridge till in comparison to the moldboard system is 57%. The goals of the watershed implementation plan would be the determining factor for promoting either ridge till or no-till systems. Residue management reduces pollutant (sediment & phosphorous) generation and reduces pollutant export by reducing overland flow and encouraging particle deposition.

The concept of manage/retard pollutant transport focuses on reducing and managing overland runoff and associated pollutants. The overall goal of an RMS designed for this purpose would be to reduce the runoff energy, quantity and length of overland runoff. These RMSs either alter the runoff through increased infiltration and/or slowing the flow of water to reduce the velocity. Due to its ability to affect runoff, residue management should be a key component in these types of RMSs. Table 4 also shows the total amounts of water runoff with varying tillage systems in a natural runoff study of a small watershed in Iowa.

Treatment focuses on the removal or remediation of NPS pollutants. Planning and implementation of RMSs for this purpose focus on creating sinks for sediment, such as constructed wetlands, thereby reducing export off agricultural fields. These sinks must be capable of intercepting sediment and must support one or more of the processes that removes sediment and associated pollutants. The two key factors that must be considered are: (1) the capability of a particular area to intercept runoff and (2) its ability to provide different pollutant removal processes. These RMSs are usually considered off-field control techniques. The most commonly used off-field control practices are vegetative filter strips, riparian buffer zones, WASCOBs and constructed wetlands.

Table 4. Range of Runoff and Erosion Rates for various tillage systems over 3 years (Davenport and Kirschner, 2002).

Tillage	**Soil Erosion, Tons/Acre (Range)**	**Water Runoff, Gallons/Acre (Range)**
Moldboard Plow	7.3–23.1	43,700–87,600
Ridge Till	1.4–10.1	21,400–58,000
No-Till	0.5–1.6	23,500–40,000

Planning Time Frame
Traditionally RMSs are designed for predominate field condition and for the expected crop rotation. The various landscape zones address the predominate field conditions, however different design criteria for the crop rotation aspects are needed in the landscape approach for water quality purposes. The new design criteria need to focus on designing RMSs that are zone specific and address the maximum pollution production period of an individual rotation rather than the average condition for the rotation and focus on meeting off-site environmental goals "T_{wq}" rather than “T” values associated with productivity. For example; Iowa field data (Table 4) shows the maximum soil erosion during the rotation managed with no-till was 1.6 tons per acre. This part of the rotation becomes the design phase (T_{wq}) for the practices to be implemented as part of a no-till system and this would ensure that the worst case scenarios are addressed and an environmental margin of safety is applied. This does not mean the same tillage system is required for the entire rotation. Tables 5A and B shows the effectivienss of various tillage systems in reducing water erosion in relationship to a moldboard plow system. For example a corn, soybean rotation (based upon the information in Tables 5A &5B), the soybean portion becomes the design phase. Since source reduction (no-till) alone will not address the excessive soil loss, a retard/management (waterway) management component needs to be designed and implemented in conjunction with the “no-till” to address sediment runoff regardless of its landscape location.

Edge of Field Planning
In addition to the design period aspect, the scope of the existing parcel or site-specific planning of pollutant management systems for the riparian zone fields needs to be modified . Presently the focus is on the actively cropped areas. The Sycamore Creek (MI) Project documented that existing land treatment approach must expand the focus on off-field practices to improve water quality. The project documented a 60% reduction in sediment loading in the Willow Creek subwatershed. There was a direct correlation between the extent of no-till cropland management and sediment reduction. However, in Marshall Drain where there was greater percentage of cropland treated with no-till management there was not a significant reduction in sediment loading. The effort to control soil erosion from cropland was supplemented by streambank stabilization in Willow Creek and not in Marshall Drain (Lomard, et al, 2000). This indicates that land management factors affecting the riparian zone may have an equal or

Table 5A. Measured corn residue cover and soil loss by various tillage systems used on a 10% slope and silt loam soil (modified from MWPS, 2000)

Tillage System	Residue Cover	Cumulative soil loss tons/acre	Water erosion reduction compared to moldboard plow (%)
Moldboard plow, disk, disk, plant	7	7.8	--
Disk, Disk, plant	21	2.2	72
Chisel plow, disk, plant	35	2.1	74
Rotary-till, plant	27	1.9	76
Till-plant	34	1.1	86
N0-till plant	39	0.7	92

Table 5B. Measured soybean residue cover and soil loss by various tillage systems used on a 5% slope and silty clay loam soil (modified from MWPS, 2000)

Moldboard plow, disk, disk, plant	2	14.3	--
Disk, plant	8	10.6	26
Chisel plow, disk, plant	7	9.6	32
Field cultivate, plant	18	7.6	46
No-till, plant	27	5.1	64

greater effect on suspended solids loads in these Grand River tributaries than cropland management such as "no-till". The importance of the streambank stabilization as part of a holistic or comprehenive approach to whole planning has been documented previously in a number of studies by the Agricultural Research Service (Dale Bucks personal comunication) and the Illinois State Water Survey in Court Creek-Knox County, Illinois (Roseboon and White, 1990). The landscape approach promotes the expansion in planning focus in the riparian zone.

Conclusions

With the advances in precision farming and an increased ability to provide site-specific management, a landscape approach to NPS pollution control and management is possible. In order to increase our ability to manage and reduce off-site impacts, technical and financial assistance must be targeted to specific areas as defined in a watershed management plan within the landscape context. In addition to targeting assistance on a landscape basis, field planning should be revised to focus on the maximum pollutant production periods of a rotation rather the entire rotation. This will ensure that the worst case scenarios are addressed and an environmental margin of safety is applied. The inclusion of the adajacent riparian areas (i.e, streambanks) in the field specific planning in the riparian zone will promote more complete management of sediment sources on a watershed basis.

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