U.S. GEOLOGICAL SURVEY PROGRAMS AND INVESTIGATIONS RELATED TO SOIL AND WATER CONSERVATION

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ABSTRACT

The U.S. Geological Survey has a rich tradition of collecting hydrologic data, especially for fluxes of water and suspended sediment, that provide a foundation for studies of soil and water conservation. Applied and basic research has included investigations of the effects of land use on rangelands, croplands, and forests; hazards mapping; derivation of flood and drought frequency, and other statistics related to streamflow and reservoir storage; development and application of models of rainfall-runoff relations, chemical quality, and sediment movement; and studies of the interactive processes of overland and channel flow with vegetation. Networks of streamgaging stations and (or) sampling sites within numerous drainage basins are yielding information that extends databases and enhances the ability to use those data for interpretive studies.

Key Words: Soil, Water, Sediment, Erosion, Conservation, U. S. Geological Survey

1 BACKGROUND

The U. S. Geological Survey (USGS) was established in 1879 to inventory and develop an understanding of the Nation's mineral and water resources. That mandate expanded through the 20th century and now includes responsibility for critical geologic, cartographic, and hydrologic information needs. Today, about 400 field offices of the USGS provide maps, databases, and reports containing analyses and interpretations of water, energy, mineral, and biological resources, land-surface form and composition, marine environments, geologic structures, natural hazards, and the dynamic processes of the Earth information needed to enhance and protect quality of life in the United States and elsewhere.

Within these broad obligations are specific duties to examine:

- the availability, quantity, and quality of water suitable for all biota,
- the effects of land use and population increases on soil and water resources,
- the effects of urbanization on rock, mineral, and water resources,
- the optimal use of interacting ground-water and surface-water resources.
- waste isolation and remediation of contaminated soil and water,
- hydrologic hazards, and
- the effects of climate on water-resources management.

The need for conservation of soil and water resources is implicit in all seven of the above obligations, especially the first four. With fluvial sediment identified as the single most prevalent cause of impairment of streams, lakes and ponds, reservoirs, and estuaries of the United States (U.S. Environmental Protection Agency, 1998), these obligations have become particularly important. In total, this list reflects the strategic directions that the Water Resources Discipline (WRD; formerly the "Water Resources Division") of the USGS will emphasize during much of this decade, and it can be summarized as the WRD's core activities of data collection, applied research, basic research, and ancillary programs.

2 HYDROLOGIC DATA

Effective conservation of soil and water requires knowledge of the quantity and quality of the resources to be conserved. The USGS has a mandate to collect, archive, and disseminate water-resources information for the United States, its territories, and Puerto Rico, and to coordinate water-data acquisition activities through the Federal Government as part of Office of Management and Budget Memorandum 92.01 (Glysson and Gray, 1997). Much of the responsibility for the collection and dissemination of these

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data is given to the WRD, USGS. Various WRD programs have been established for the compilation of a range of hydrologic data, the most well known being the systematic measurement of streamflows and sampling of those discharges to determine fluvial-sediment loads and chemical quality of the water.

Water discharges, as daily values of mean flow, are measured at about 7000 streamflow gage sites throughout the United States, almost 5000 of which provide near-real time data to the World Wide Web (U.S. Geological Survey, 2001a). These data, with related data on water quality, fluvial sediment, and ground-water resources, represent the fundamental database for evaluating the water resources – and changes through time of those resources – of the United States.

Records of water discharge and stage may be complete or partial. Complete records of discharge are usually obtained by using a continuous stage-recording device and a stage-discharge relation through which either instantaneous or mean daily discharges can be computed for any time or any period of time during the period of record. In contrast, partial records – those of specified parts of the year or selected periods – may be obtained through discrete measurements without using a continuous stage-recording device, and pertain only to a few flow characteristics or perhaps only one.

In response to a general decline in the number of streamgaging stations operated in the U.S., coupled with a disproportionate loss of those stations with a long period of record and a declining ability of USGS to continue operating high-priority stations when partners discontinue funding, the USGS developed a conceptual plan for a new approach to the acquisition and delivery of streamflow information (U.S. Geological Survey, 1999a; 1999b). The National Streamflow Monitoring Program (NSIP) provides a plan for a stable, modernized streamgaging network that addresses core Federal and cooperator needs. It also provides for:

- Collection of critical information during floods and droughts,
- Updating streamflow characteristics to assess the impacts of climate and land-use change,
- Developing a reliable system for delivering data to users, and
- Implementing a program of research and development to improve data collection, delivery, and interpretation capabilities for the future.

The NSIP plan includes a web-based application that allows users to select any location on any stream shown in a geographic information system mapping interface and to obtain estimates of streamflow characteristics for the location. Already implemented in the State of Massachusetts (U.S. Geological Survey, 2001b), the point-and-click application promises to reduce substantially the time required by engineers and resource management and regulatory agencies to make determinations of streamflow statistics required for design of structures, water-resources planning and management, permit processing, flood-plain delineation, and other applications.

Information for suspended-sediment and, less frequently, bedload transport is most commonly collected at or near stream gage sites. Daily concentrations of suspended sediment are determined from samples collected by standard techniques using depth-integrating samplers (Edwards and Glysson, 1999). Sediment laboratories operated by the USGS use American Society for Testing and Material Method D 3977-97 (ASTM, 2000; Gray and others, 2000) to produce sediment-concentration data, and the National Sediment Laboratory Quality Assurance Program provides an assessment of the accuracy of those data (Gordon and others, 2001; Gray and others, 2001). Daily sediment discharges from these data, using established methods of combining concentrations with water discharge, are applied to compute sediment discharge (Porterfield, 1972; McKallip and others, 2001).

Samples usually are collected at several verticals in a cross section to obtain a representative suspended-sediment concentration value (Edwards and Glysson, 1999). Alternatively, a single sample may be obtained at a fixed point and a coefficient is applied to compute the mean concentration in the cross section (Porterfield, 1972). During periods of rapid changes in flow or concentrations, samples may be collected at intervals of hours or even minutes. Bedload-transport rates generally are measured at a stream cross section on a less-frequent basis. Results usually are used to develop bedload-transport curves from which bedload transport rates can be estimated for unsampled periods in a manner similar to that used for estimating suspended-sediment transport (Glysson, 1987). Turcios and Gray (2001) provide summary statistics for sediment and ancillary data stored on the USGS National Water Information System Web (NWISWeb) database as of January, 2000. Fluvial sediment, water-quality, and ancillary data may be retrieved from the periodically refreshed NWISWeb database as described by the U.S. Geological Survey (2001c).

Records of surface-water quality ordinarily are obtained at or near streamgaging stations because interpretation of records of surface-water quality almost always requires corresponding discharge data. The frequency of water-quality sampling is variable depending on the purpose of the information. Typically samples are collected either quarterly or monthly, although some water-quality programs now require collection of additional samples during high flows regardless of the timing of their occurrence. The parameters measured also vary with objectives of the monitoring effort. In many cases, the analyses are limited to common dissolved constituents and hardness, but more detailed studies may include analyses for trace elements, dissolved oxygen, nutrients, heavy metals, radionuclides, pesticides and other biochemical compounds, and organic contaminants such as fecal coliform and fecal streptococci.

Hydrologic records for WRD districts (generally conforming to State boundaries) are published annually by the USGS as "Water Resources Data" for the water year and district in which the records were collected. Recent (provisional) near-real time streamflow data are available on the World Wide Web (U.S. Geological Survey, 2001a), as are historical streamflow, sediment, water-quality, and ground-water data collected and compiled by the USGS and other agencies. These data are now available through the National Water Information System (NWIS), a distributed network of computers and file servers for storing and retrieving water data collected at about 1.5 million sites of the United States (U.S. Geological Survey, 2001c). The structure of the NWIS is shown in Fig. 1.

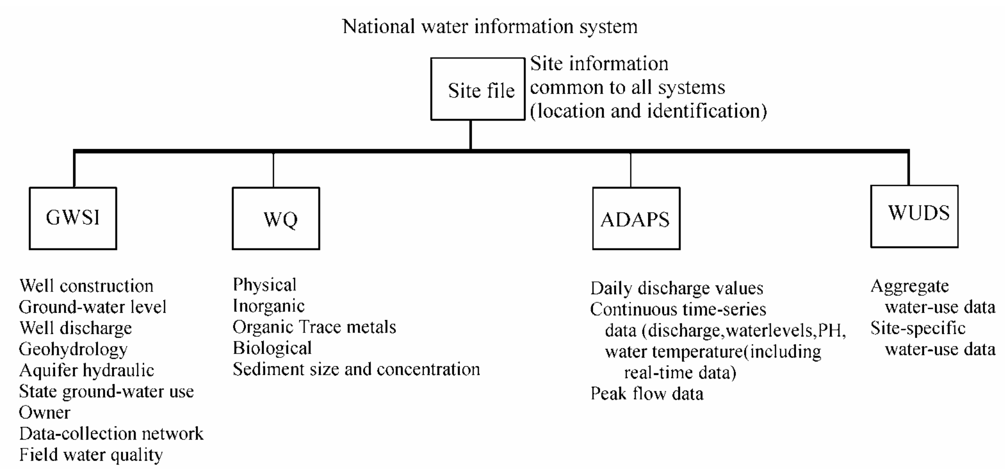

Fig. 1 NWIS structure and types of stored hydrologic data

Many types of data are stored on the NWIS' distributed, local databases, including:

- Site File: The site file includes information for about 440,000 sites throughout the United States and its territories where the USGS has collected or currently collects data.
- Ground-Water Site Inventory (GWSI) Database: The GWSI database has inventory data for about 900,000 wells, springs, and other sources of ground water. The data include site, geohydrologic-characteristics, well-construction history, and one-time field measurements, such as water temperatures.
- Water-Quality File (WQ): The WQ file is a computer database that contains chemical analyses from ground-water and surface-water collection sites. The WQ file contains results of more than 3.5-million analyses of water samples that describe the chemical, physical, biological, and radiochemical characteristics of surface water and ground water.
- Automated Data Processing System (ADAPS): ADAPS is a computer database that contains most surface-water data except for site descriptions and chemical analyses. ADAPS includes time-series data, including about 220 million daily values of streamflows, stages, reservoir contents, water temperatures, specific conductances, suspended-sediment discharges and concentrations, ground-

water levels, and precipitation. ADAPS contains about 500,000 maximum (peak) streamflow and gage-height values at surface-water sites.

- Water-Use Data System (WUDS): WUDS stores aggregate and site-specific water-use data from across the Nation.

3 APPLIED RESEARCH

The application of scientific principles to solve practical natural-resource problems continues to be a WRD responsibility. Emphases of the mid-20th century, as examples, were to determine the availability of ground-water resources in agricultural areas, to supply hydrologic information in support of large-dam and reservoir construction, and to provide technical guidance for the development and conservation of surface- and ground-water supplies in rangelands of the western United States. Some of these responsibilities continue, but now the emphasis of applied research focuses more on resource management in disturbed watersheds, resource conservation on agricultural lands and rangelands, and hazards mitigation, including the conservation of soil and water that could be lost due to extreme events such as floods, mass movements, and hurricanes. A summary of the status of USGS research capabilities and proposals to expand on those capabilities is provided by Gray and others (1997).

Efforts to minimize loss of soil and water resources following a broad range of disturbances are being conducted by USGS personnel. Methods to conserve soil and water in areas altered by urbanization are being developed in and around various cities of the United States and Puerto Rico. Particularly in the western United States, generally small dams and reservoirs that are of questionable utility have lost storage capacity and (or) are obstacles to migration of desirable biota are being considered for removal. Numerical models are being employed to anticipate effective approaches to prevent soil loss or damage to downstream water users. The effects of water and sediment storage on fluvial-geomorphic features and biota upstream and downstream from large impoundments are being investigated along rivers including the Colorado and Bill Williams Rivers in the American Southwest, the Snake River in the northwestern United States, the Gunnison River in the Rocky Mountains, and the Missouri River in the mid-continent area. Destabilization of soils in forests and other areas vulnerable to erosion following surface mining, road building, intense periods of rain or runoff from snowmelt, and rapid movements of soil or rock is a major cause of soil loss in the United States, and appropriate methods to minimize the effects of such disturbances are being investigated. Existing algorithms of erosion-prediction technology are being applied to areas that are especially susceptible to erosion by upland runoff owing to recent denudation by forest or range fires.

Continuing programs in the WRD to conserve soil and water resources of agricultural areas and rangelands, generally in cooperation with other agencies of the United States government, began 60 years ago (Peterson and Melin, 1979). Among these programs are studies of best-management practices to minimize storm runoff and sediment discharges, reseeding of rangelands following sagebrush and pinon-juniper eradication to optimize grazing potential, the effects of grazing on rainfall-runoff relations, construction methods for small earthen reservoirs, and land-treatment practices in semiarid areas to increase infiltration of rainfall and thus replenish soil moisture. Significant results have included the findings that runoff and sediment discharge from grazed and ungrazed watersheds of the western United States show about a 40-percent average increase in runoff due to soil compaction by livestock and a 50-percent average increase in sediment yield due to reduced vegetation cover. Related research has centered on the hydrologic and sediment-discharge effects of sediment-detention dams and irrigation diversions. Of special relevance to rangeland management is the finding that excessive grazing typically is accompanied by conversion of grassland to shrubland, and the finding that sediment yield may increase 10-fold or more due to the conversion and to soil disturbance from grazing.

Programs to mitigate the effects of extreme disturbances include research into the occurrence of high-magnitude floods and of debris flows, especially those related to volcanic eruptions. Starting in the 1970's, WRD systematically mapped many flood-prone bottomlands of medium- and large-size U.S. rivers to determine the extent of lands inundated by floods with a 100-year recurrence interval. Since then, numerous more detailed studies describing flood hazard and the potential for mitigation of the hazard have been conducted locally at the request of and in cooperation with city and county authorities. Where, owing to unstable soil conditions in high-relief areas (such as volcanic terrains and mountains of the humid tropics), there is a potential for mass-movement hazard by debris flow or slope failure, procedures of hydrologic-mapping have been extended to consider hazard by geomorphic processes.

4 BASIC RESEARCH

A wide array of basic-research studies that address issues of soil and water conservation is conducted by USGS scientists, principally within the WRD (U.S. Geological Survey, 2001d). Among these research activities are investigations to understand and model field-scale controls on rainfall-runoff relations, to develop physically based models describing the mechanics of the entrainment, transport, and storage of sediment as suspended load, bedload, and total load, and to determine the manner by which vegetation affects the movement and storage of fluvial sediment.

Investigations into rainfall-runoff relations include model development and studies of response to climatic change, the effect on upland runoff and recharge by variable conditions of soil and vegetation, and loss of streamflow in arid and semiarid regions due to transmission loss. Modeling efforts address watershed response (runoff and sediment yield) to normal and extreme climatic conditions or to changes in physical watershed conditions. Required is the simulation of a variety of hydrologic processes and interactions of those processes to meet objectives of (1) improving the understanding of dynamic watershed systems, (2) developing computer code to describe and evaluate the effects of combinations of precipitation, climate, and land use on yields of water and sediment from watershed surfaces, and (3) proposing procedures to estimate model parameters using measurable watershed and climatic characteristics. Related research considers the effect of climate variability on runoff volume, the development of water resources, mitigation of flood hazard, and interpretation of geomorphic surfaces.

Runoff and sediment discharge from water-deficient areas are affected strongly by the potential for rainfall to infiltrate a soil surface and the ability of vegetation to attenuate runoff and thereby enhance infiltration and evapotranspiration of precipitation. Cooperative studies with faculty and students at the University of Arizona, Tucson, are being conducted to evaluate the accuracy and applicability of the widely used USDA curve-number model, an empirical indicator of runoff potential for specified conditions of rainfall, in water-balance computations for all parts of the United States, but especially arid and semiarid areas. Current work focuses on determining curve-number values for rainfall and runoff data pairs from small drainage basins to update traditional tables. Closely related are studies that rely on the curve-number concept to examine initial ephemeral-streamflow abstraction. This research is being conducted in cooperation with the USDA Agricultural Research Service to determine the relative importance of various watershed and channel characteristics that control the rate of water loss (transmission loss) that occurs when rainfall is sufficient to cause streamflow in ephemeral-stream channels of arid areas.

Models to describe the entrainment, transport, and storage of sediment by water apply (1) fluid and sediment mechanics to basin- and regional-scale hydrologic and geomorphic problems, (2) concepts of environmental dynamics, (3) mathematical representations of hydrologic systems, and (4) river mechanics to channel geometry and pattern. These modeling efforts include broad ranges of areal and temporal scale and are designed to increase the understanding of the processes by which alluvial landforms occur and change, why and where sediment storage occurs, and the mechanisms by which fluvial processes contribute to sediment-related environmental pollution.

Vegetation is a fundamental control of the ability of rainfall to effect erosion on upland surfaces, provides stability and resistance to erosion in stream channels and along channel banks, and promotes deposition of sediment where it reduces the velocity of streamflow. Principal objectives of studies being conducted by USGS scientists to discover the controls that vegetation exerts on water and sediment fluxes are to assess existing research techniques and to develop new ones based on geomorphic principles, to continue the development of the combined use of botanical evidence and maximum-likelihood indicators in flood-frequency prediction, to analyze and interpret the role of vegetation in natural and disturbed fluvial systems, to discover the interacting roles of climate, fluvial geomorphology, and plant ecology in determining water and sediment discharges, and to employ tree-ring chemistry as an indicator of ground- and surface-water quality.

5 ANCILLARY PROGRAMS

Activities related to USGS programs for collecting water- and sediment-discharge data, applied research, and basic research include the operation of special data networks, assistance in the development of erosion and transport models, and the characterization of hydrologic conditions in large drainage basins and reservoirs of the United States. Numerous other programs ancillary to major USGS obligations involving soil and water conservation and the effects of regulation by dams and reservoirs emphasize local concerns and are described elsewhere.

Special data networks include the National Stream-Quality Accounting Network (NASQAN), the Hydrologic Benchmark (HBN) program, the National Water Quality Assessment (NAWQA), the Water, Energy, Biochemical Budgets (WEBB) program, and the Vigil Network. NASQAN is a group of 39 stations for the monitoring of water quality in four of the largest rivers of the United States – the Mississippi, Columbia, Colorado, and Rio Grande (U.S. Geological Survey, 2001e). Samples are collected to provide estimates of the fluxes of a wide range of constituents. The objective of NASQAN is to characterize the water quality of the four large rivers by measuring concentrations and mass transport of dissolved and suspended constituents including nutrients, major ions, dissolved and sediment-bound trace elements, suspended sediment, pesticides, and inorganic and organic forms of carbon.

The HBN program (U.S. Geological Survey, 2001f) is a network of 50 sites in relatively small drainage basins around the United States whose purpose is to provide consistent data on the hydrology, including water quality, and related factors in representative undeveloped watersheds, and to provide analyses on a continuing basis to compare and contrast conditions observed in basins more obviously affected by human activities.

The principal USGS-WRD activity for the characterization of water quality in medium-size drainage basins at scales between those of the NASQAN and the HBN is the National Water-Quality Assessment (NAWQA) program (U.S. Geological Survey, 2001g). NAWQA is a long-term monitoring program to (1) describe the status and trends of water-quality conditions for a large, diverse, and geographically distributed part of the Unites States' ground-water and surface-water resources, (2) provide an improved understanding of the primary natural and human factors affecting these observed conditions and trends, and (3) provide information that supports development and evaluation of management, regulatory, and monitoring decisions of other agencies of the United States government.

The WEBB research program (U.S. Geological Survey, 2001h) focuses on a small network of watersheds that are studied to (1) improve understanding of processes controlling terrestrial water, energy, and biochemical fluxes, their interactions, and their relations to climate variables, and (2) improve the ability to predict continental water, energy, and biochemical budgets over a range of spatial and temporal scales.

A similar monitoring program is the Vigil Network, which is an open-ended group of global sites and small drainage basins for which Internet-accessible geomorphic, hydrologic, and biological data are periodically collected or updated (Orr and Osterkamp, 1999). Observation periods are intended to be greater than the life span of an individual, and data are intended to be archived in a readily retrievable format to allow study by future generations of natural scientists.

The interdisciplinary nature and increasing complexity of environmental and water-resource problems require the use of modeling approaches that can incorporate knowledge from a broad range of scientific disciplines. During the last two decades, WRD scientists of USGS have provided technical support to colleagues of the USDA Agricultural Research Service in their efforts to develop erosion models describing soil loss from croplands and other disturbed areas. Collaboration has occurred for the Water Erosion Prediction Project (WEPP) models, which, as an improvement from the Universal Soil Loss Equation (USLE), are designed to provide the best available erosion prediction technology, for both disturbed and undisturbed watersheds, based on modern hydrologic and erosion science (Foster, 1987).

The Revised Universal Soil Loss Equation (RUSLE; Renard and others, 1997) is another ARS model on which USGS has provided collaboration; RUSLE too is intended to update the USLE and to yield soil-loss estimates from disturbed and undisturbed watersheds. Currently, in cooperation with ARS and faculty from the University of Salta, Argentina, USGS is conducting research to apply the latest version of the RUSLE model to disturbed forest areas, particularly those that have had recent fire.

For watershed- and basin-scale modeling, WRD scientists have developed a set of modular modeling tools, termed the Modular Modeling System (MMS) (U.S. Geological Survey, 2001i), as part of the

USGS Precipitation-Runoff Modeling Project. MMS enables a user to couple selectively the most appropriate process algorithms from applicable models to create an "optimal" model for the desired application. Where existing algorithms are not appropriate, new algorithms can be developed and easily added to the system. This modular approach to model development and application provides a flexible method for identifying appropriate modeling approaches for specific user needs and constraints.

The conceptual framework for MMS has three major components: Pre-process, model, and post-process (Figure 2). A system supervisor provides user access to all components and features of MMS. The framework has been developed for UNIX-based workstations and Linux-based PC's/workstations and uses X-windows and Motif for a Graphical User Interface (GUI). The GUI provides an interactive environment for users to access model-component features, applies selected options, and graphically displays simulation and analysis results. The current GUI is being modifed and enhanced into the full system supervisor, incorporating the linkages needed to access features in all the system components and for application on Windows-based PC's.

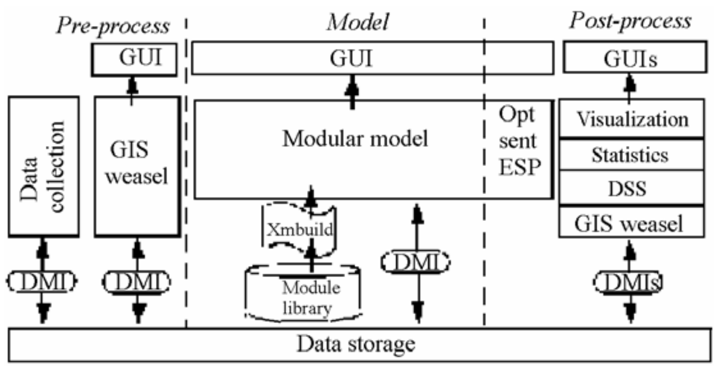

Fig. 2 A schematic diagram of the Modular Modeling System's (MMS) conceptual components.

The Spatially Referenced Model (SPARROW) (Smith and others, 1997) uses statistical methods to calibrate a simple, structural model of riverine water quality. In the context of a mass-balance approach, the model uses numerous spatial databases available at the national level – including those describing hydroclimatic variables, soils, surficial rock types, land cover and topography, erosion rates, and reservoir sedimentation rates – to explain long-term water-quality conditions in selected rivers throughout the U.S. SPARROW was first used to estimate the distribution of nutrients in U.S. rivers and to describe land and stream processes affecting the delivery of nutrients. Schwarz and others (2001) are applying the model to characterize sediment fate and transport on a national scale.

The importance of maintaining a database of sediment deposition in U.S. reservoirs was recognized several decades ago. Reservoir data for nearly 6000 surveys at about 1,800 reservoirs across the conterminous U.S. populate the Reservoir Survey Information System (RESIS) (Stefan, 1996). Although the database contains about 80 years of reservoir records, there are few post-1975 entries owing to inadequate procedures for adding data. An upgraded version of the database, termed RESIS-II (Stallard and others, 2001), is in development. Unlike RESIS, RESIS-II will:

1. be error checked,
2. include an easy procedure for adding new data,
3. operate on desktop computers, and
4. link to other databases, such as the National Inventory of Dams and a geographical information system.

RESIS-II has been used to study reservoir sedimentation in the Mississippi River Basin, in which soil erodibility was determined through stepwise regression to have a dominant influence on sedimentation rates. RESIS-II may provide a means to link land-use history and associated chemical loadings to the sedimentation history of reservoirs.

REFERENCES

American Society for Testing and Materials (ASTM) 2000, Standard Test Methods for Determining Sediment Concentration in Water Samples. D 3977-97, Vol. 11.02, Water (II), pp. 395-400.

Edwards, T. E., and Glysson, G. D. 1999, Field Methods for Measurement of Fluvial Sediment. U. S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chapter C2, 89 pp.

Foster, G. R. 1987, User requirements, USDA Water Erosion Prediction Project (WEPP): USDA Agricultural Research Service, 44 pp.

Glysson, G. D. 1987, Sediment-transport curves: U.S. Geological Survey Open-File Report 87-218, 47 pp.

Glysson, G. D., and Gray, J. R. 1997, Coordination and standardization of Federal sedimentation activities: Accessed March 13, 2001, at http://water.usgs.gov/osw/techniques/workshop/glysson.html

Gordon, J. D., Newland, C. A., GRAY, J. R. 2001, Sediment laboratory quality-assurance project: Studies on methods and materials: Proceedings of the 7th Federal Interagency Sedimentation Conference, Reno, Nevada, March 25-29, 2001, Vol. II, pp. VI-41 to VI-48.

Gray, J. R., Glysson, G. D., Turcios, L. M., and Schwarz, G. E. 2000, Comparability of suspended-sediment concentration and total suspended solids data: U.S. Geological Survey Water-Resources Investigations Report 00-4191, 14 pp.

Gray, J. R., Gordon, J. D., Newland, C. A., and Shroder, L. J. 2001, National quality-assurance program for sediment laboratories operated or used by the U.S. Geological Survey: Proceedings of the 7th Federal Interagency Sedimentation Conference, Reno, Nevada, March 25-29, 2001, Vol. I, Poster No. 37.

Gray, J. R., Williams, S. J., Finger, S. E., and Jones, J. W. 1997, Expanding sediment research capabilities in today's USGS: Accessed March 14, 2001, at http://water.usgs.gov/osw/techniques/workshop/

Mckallip, T. E., Koltun, G. F., Gray, J. R., and Glysson, G. D. 2001, GCLAS: A graphical constituent loading analysis system: Proceedings of the 7th Federal Interagency Sedimentation Conference, Reno, Nevada, March 25-29, 2001, Vol. II, pp. VI-49 to VI-52.

Orr, Tade, and Osterkamp, W. R. 1999, Vigil Network data now online: Eos, Transactions, American Geophysical Union, Vol.. 80, No. 31, p. 346.

Peterson, H. V., and Melin, K. R. 1979, Investigations by the U. S. Geological Survey of soil and moisture conservation on public-domain lands, 1941-1964: U. S. Geological Survey Open-File Report 79-987, 271 pp.

Porterfield, George 1972, Computation of fluvial-sediment discharge: U.S. Geological Survey Techniques of Water Resources Investigations Book 3, Chapter C3, 66 p.

Renard, K. G., Foster, G.R., Weesies, G. A., Mccool, D. K., and Yoder, D. C. 1997, Predicting Soil Erosion by Water: A guide to conservation planning with the revised universal soil loss equation (RUSLE): U.S. Department of Agriculture, Agriculture Handbook No. 703, 404 pp.

Schwarz, G.E., Smith, R.A., Alexander, R.B., and Gray, J.R., 2001, A spatially referenced regression model (SPARROW) for suspended sediment in streams of the conterminous U.S.: Proceedings of the 7th Federal Interagency Sedimentation Conference, Reno, Nevada, March 25-29, 2001, Vol. II, VII-80 to VII-87.

Smith, R.A., Schwarz, G.E., and Alexander, R.B., 1997, Regional interpretation of water-quality monitoring data: Water Resources Research, Vol 33, No. 12, pp. 2781-2798.

Stallard, R.F., Mixon, David, Kinner, D.A., and Worstell, Bruce, 2001, RESIS-II: Making the Reservoir Survey Information System Complete and User Friendly: Proceedings of the 7th Federal Interagency Sedimentation Conference, Reno, Nevada, March 25-29, 2001, Vol. II, IX-9 to IX-11.

Stefan, L.J., 1996, A Reservoir Survey Information system – RESIS: Proceedings of the 6th Federal Interagency Sedimentation Conference, Las Vegas, Nevada, March 10-14, 1996, , Vol. I, I-29 to I-36.

Turcios, L. M., and Gray, J. R. 2001, U. S. Geological Survey sediment and ancillary data on the World Wide Web: Proceedings, 7th Federal Interagency Sedimentation Conference, May 25-29, 2001, Reno, Nevada, Vol. I, Poster 31-35.

U. S. Environmental Protection Agency. 1998, Report of the Federal Advisory Committee on the total maximum daily (TMDL) load program: The National Advisory Council for Environmental Policy and Technology, EPA 100-R-98-006, 97 p., 7 appendixes.

U. S. Geoligical Survey. 1999a, Streamflow information for the next century: U. S. Geological Survey Open-File Report 99-456, 13 pp.

U. S. Geological Survey. 1999b, National streamflow information program: Accessed March 16, 2001, at http://water.usgs.gov/nsip/.

U. S. Geological Survey. 2001a, Real-time water data: Accessed March 13, 2001, at http://water.usgs.gov/realtime.html.

U. S. Geolgogical Survey. 2001b, Streamflow statistics for Massachusetts: Accessed May 16, 2001. at http://ma.water.usgs.gov/streamstats.

U. S. Geological Survey. 2001c, Water resources data for USA: Accessed September 15, 2000, at URL http://water.usgs.gov/nwis/.

U. S. Geological Survey. 2001d, U.S. Geological Survey, Water Resources Discipline, National Research Program (NRP): Accessed March 14, 2001, at http://water.usgs.gov/nrp/

U. S. Geological Survey. 2001e, National Streamflow Quality Accounting Network (NASQAN): Accessed March 14, 2001, at http://water.usgs.gov/nasqan/.

U. S. Geological Survey. 2001f, Hydrologic Benchmark Network: Accessed March 14, 2001, at http://water.usgs.gov/hbn/.

U. S. Geolgogical Survey. 2001g, National Water Quality Assessment Program (NAWQA): Accessed March 14, 2001, at http://water.usgs.gov/nawqa.

U. S. Geological Survey. 2001h, Water, Energy, and Biogeochemical Budget (WEBB) Program: Accessed March 14, 2001, at http://water.usgs.gov/nrp/webb/about.html

U. S. Geological Survey. 2001i, The Modular Modeling System (MMS) - A Modeling Framework for Multi-disciplinary Research and Operational Applications: Accessed May 16, 2001, at http://www.brr.cr.usgs.gov/mms/html/mms_paper.html