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Surface Hydrology, Sediment Transport Dynamics, and Remote Sensing of Disturbed Watersheds in a Humid Temperature Region

Final Report

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ENVIRONMENTAL RESOURCES RESEARCH INSTITUTE

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SURFACE HYDROLOGY, SEDIMENT TRANSPORT DYNAMICS, AND REMOTE SENSING OF DISTURBED WATERSHEDS IN A HUMID TEMPERATURE REGION

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Final Report
for Period August 1, 1987 - July 31, 1991

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DISCLAIMER

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

GRANT SUMMARY

This final report describes research conducted under Department of Energy Agreement No. DE-FG02-87ER60594 (including Amendment A001-M003) for the project period August 1, 1987 to July 31, 1991. Specifics of the agreement are summarized in Table 1.

Table 1. Breakdown of Agreement No. DE-FG02-87ER60594

Grant No.	Award Amount	Budget Period
87-ER60594 A000	$69,494.00	8/1/87 - 7/21/88
87-ER60594 A001	$49,995.00	8/1/88 - 7/31/89
87-ER60594 A002	$65,000.00	8/1/89 - 7/31/90
87-ER60594 M003	0	8/1/90 - 7/31/91
Award total	$184,489.00	

REFLEX BACKGROUND

Research was initiated within and conducted under the auspices of the Remote Fluvial Experiment (REFLEX) Series Program in the Office of Energy Research, Office of Health and Environmental Research, Ecological Research Division of the Department of Energy. As stated in the REFLEX Program dated October 1986, the goals of REFLEX are to:

- apply new and developing aerial and satellite remote sensing technologies--including both advanced sensor systems and digital/optical processing--to interdisciplinary scientific experiments in hydrology and to hydrologic/ecologic interactions;

- develop new concepts for processing and analyzing remote sensing data for general scientific application;

- demonstrate innovative analytical technologies that advance the state of the art in applying information from remote sensing systems, for example, supercomputer processing and analysis.

The REFLEX program was organized around the concept of the universal watershed (Figure 1) with priority given to interdisciplinary research on the hydrologic cycle. Experiments were conducted to evaluate hydrologic interactions between terrestrial landscapes and ecosystems for which historical data bases already exist or where research is in progress.

"The need for information on terrestrial systems to meet environmental health and safety requirements is increasing each year. Information concerning contaminant transport along surface and groundwater pathways is essential to anticipating and to mitigating effects on terrestrial ecosystems and on humans. The advanced technologies of REFLEX can potentially help solve environmental safety problems faced by DOE" (REFLEX Program Document, 1986). The underlying

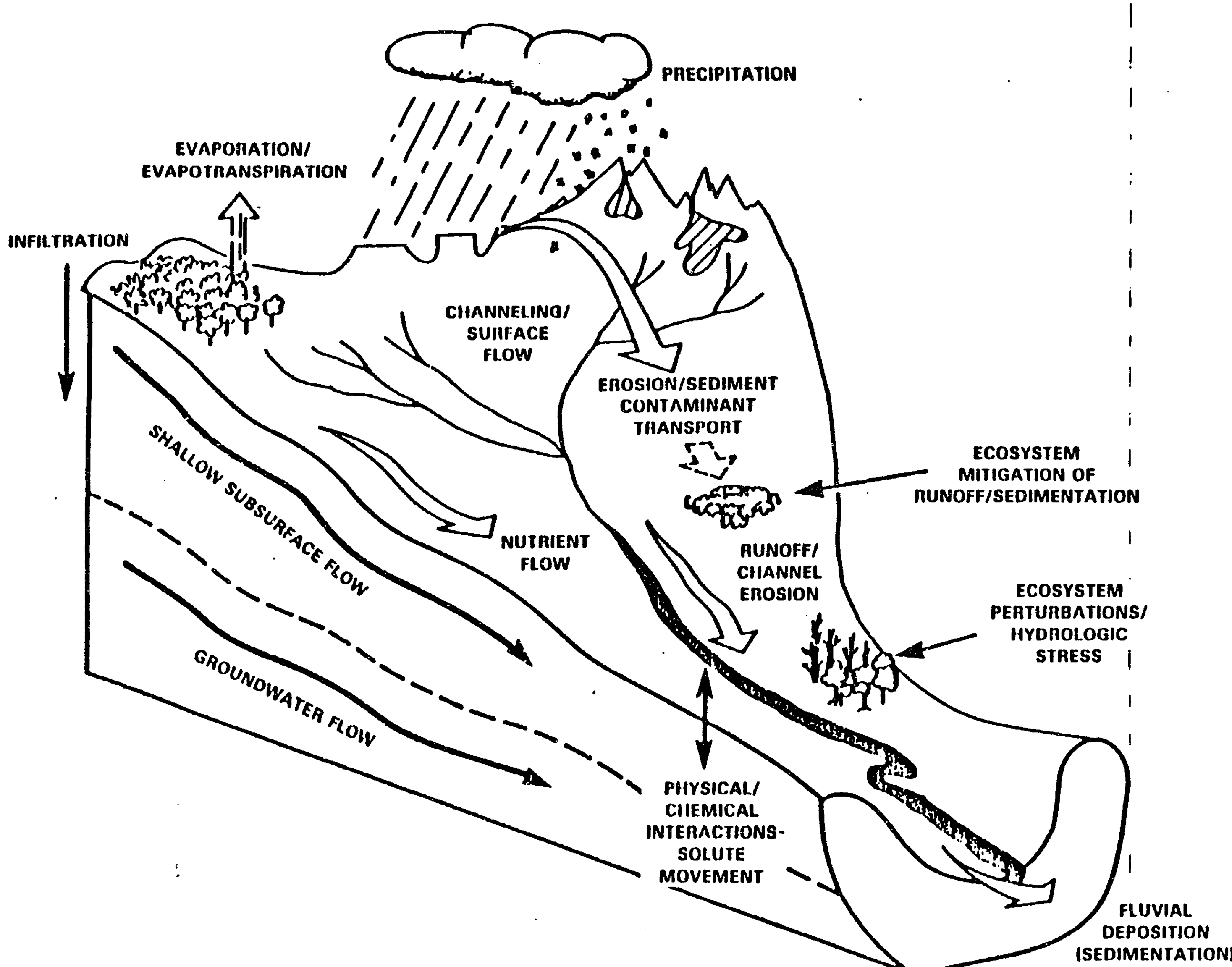

Figure 1 Universal Watershed with Principal Processes and Hydrologic-Ecologic Interactions (from REFLEX Program Document, October 1986).

REFLEX strategy was to study uncertain or unproven scientific concepts using advanced remote sensing technologies.

To achieve the REFLEX goals, experiments were conducted under phase I of the REFLEX program. Phase I (1984-1990) which encompasses the project period of this grant emphasizes identification, exploration, and hypothesis testing of scientific questions related to the hydrologic cycle and to hydrologic/ecologic interactions. Clearly, perturbations caused by energy development or waste disposal in the long term are a general motivation for this research. In addition, the REFLEX experiments are being conducted within different climatic/ecological zones (Figure 2, Table 2) in an effort to explore the limits and benefits of advanced remote sensing technologies and analyses.

RESEARCH OBJECTIVES

To further achieve these REFLEX goals, phase I research activity for this project was initiated in a humid temperate climate in watersheds disturbed by surface coal mining (Figure 3).

The research watersheds are located within the Allegheny Plateau physiographic province of west-central Pennsylvania (Figure 3). The watersheds are characterized by mixed coniferous and deciduous forests with disturbances from bituminous coal mining. Landscapes on the disturbed watersheds are extremely variable. Ungraded surfaces have irregular, hummocky topography on the order of meters to tens of meters. Topographically low areas are often closed depressions with internal drainage that serve as groundwater recharge areas (Figure 4). Regraded surfaces have a wide range of lithologies, soil textures, roughnesses and vegetation densities (Figure 4) which together with the topography determine both the surface and near-surface hydrology as well as sediment erosion and deposition.

The hydrologic system on disturbed watersheds (Figure 5) determines the nature and degree of landscape instability as well as the short- and long-term geomorphic evolution. Initially, rainfall is apportioned between surface runoff, interflow, and groundwater recharge by the infiltration characteristics of the disturbed surface. The initial value of, and subsequent change in, the infiltration capacity determine, to a large degree, the geomorphic evolution of the disturbed watersheds.

In humid, temperature regions, solid and dissolved contaminant loads from disturbed watersheds are transferred to and through the surrounding environment by fluvial erosion and deposition as well as the near-surface groundwater system. Furthermore, contaminants in the form of dissolved load, sediment load, or drastic changes in stream discharge emanate from and are conditioned to a large degree by the surface and near-surface properties of the disturbed watershed. The goal of this research is to describe the geomorphic system and predict the hydrologic response on disturbed watersheds through the use of quantitative relationships and numeric models that predict landscape evolution, contaminant loadings and thus ecological impacts, using both field derived and remotely sensed data.

Table 2. Description of Existing and Proposed REFLEX Sites

Sites	Nevada	Arizona	Alaska	Washington	Pennsylvania	Tennessee	Puerto Rico
Location	Plutonium Valley	Walnut Gulch	Toolik Lake	Hanford Site-NERP	Central Pennsylvania	Oak Ridge Reservation	*
Physiographic Province	Basin and Range	Basin and Range	Arctic Lowland and Brooks Range	Columbia Plateau	Allegheny Plateau	Ridge and Valley	*
Elevation	1225-1690 m	1290-1785 m	750-1000 m	120-1100 m	300-520 m	*	*
Lithologies	basalt, limestone, dolomite, alluvium, densely welded to nonwelded tuffs, and quarzite	clay to conglom-eratic alluvium conglomerate, granodiorite, limestone, granite, rhyolite, basalt tuff, andesite, quartz monzonite	glacial till	basalt, alluvial and eolian material	shales, siltstone, sandstone, conglomerate, limestone, clay, and coal	*	limestone
Climate	semiarid	semiarid	tundra	arid	humid temperature	humid temperature	tropical to semihumid
Vegetation	low and high desert shrub	rangeland grasses and *shrub*	tussock tundra shrubs, *forbs, sedges,* and mosses	shrub-steppe	mixed coniferous-deciduous forest to barren on disturbed lands	*	deciduous
Areal Extent	33 km^2	150 km^2	18 km^2	600 km^2	500 km^2	*	

* Data not available as of January 31, 1988.

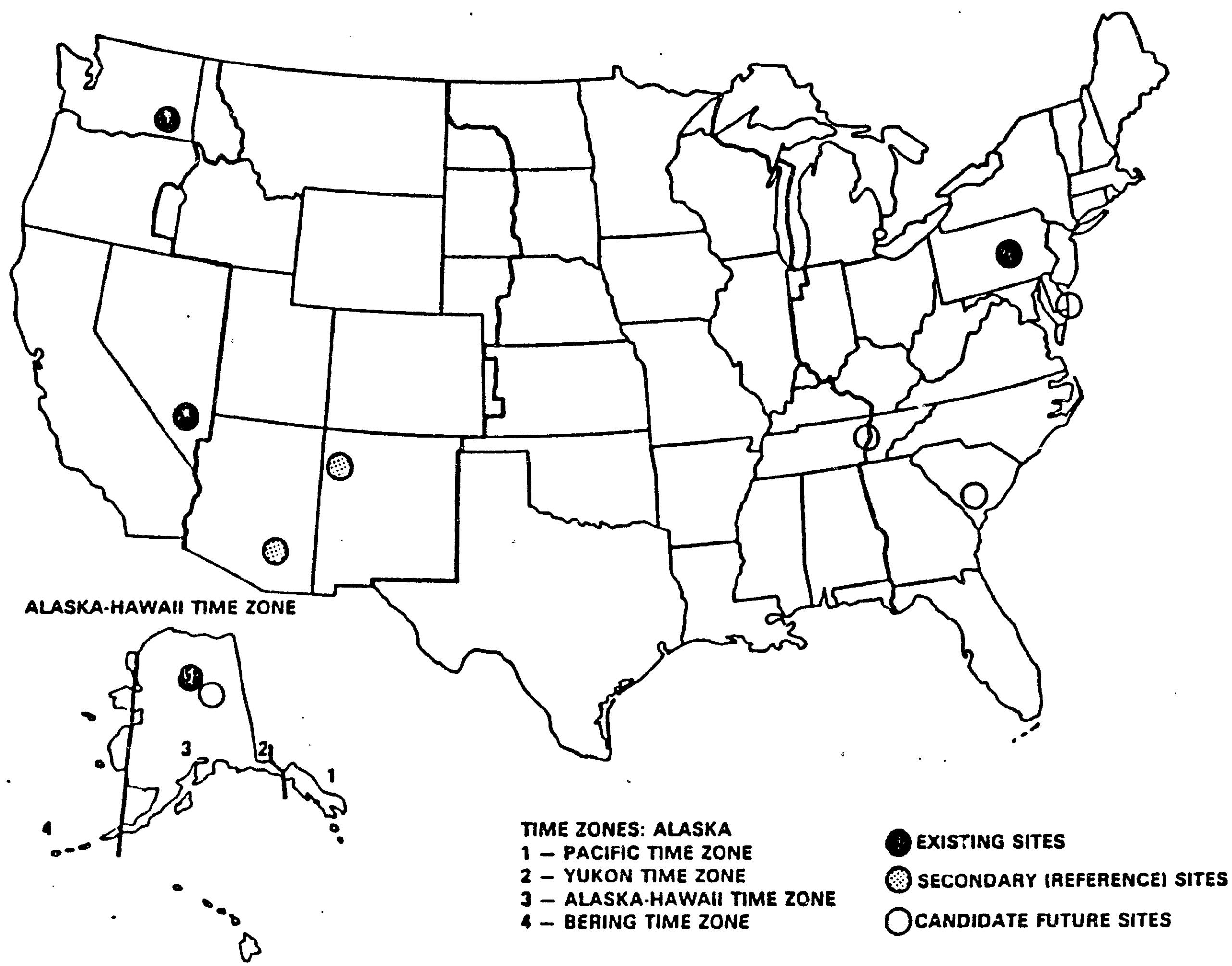

Figure 2 Existing and Proposed REFLEX Site Locations. See Table 2 for Site Descriptions.

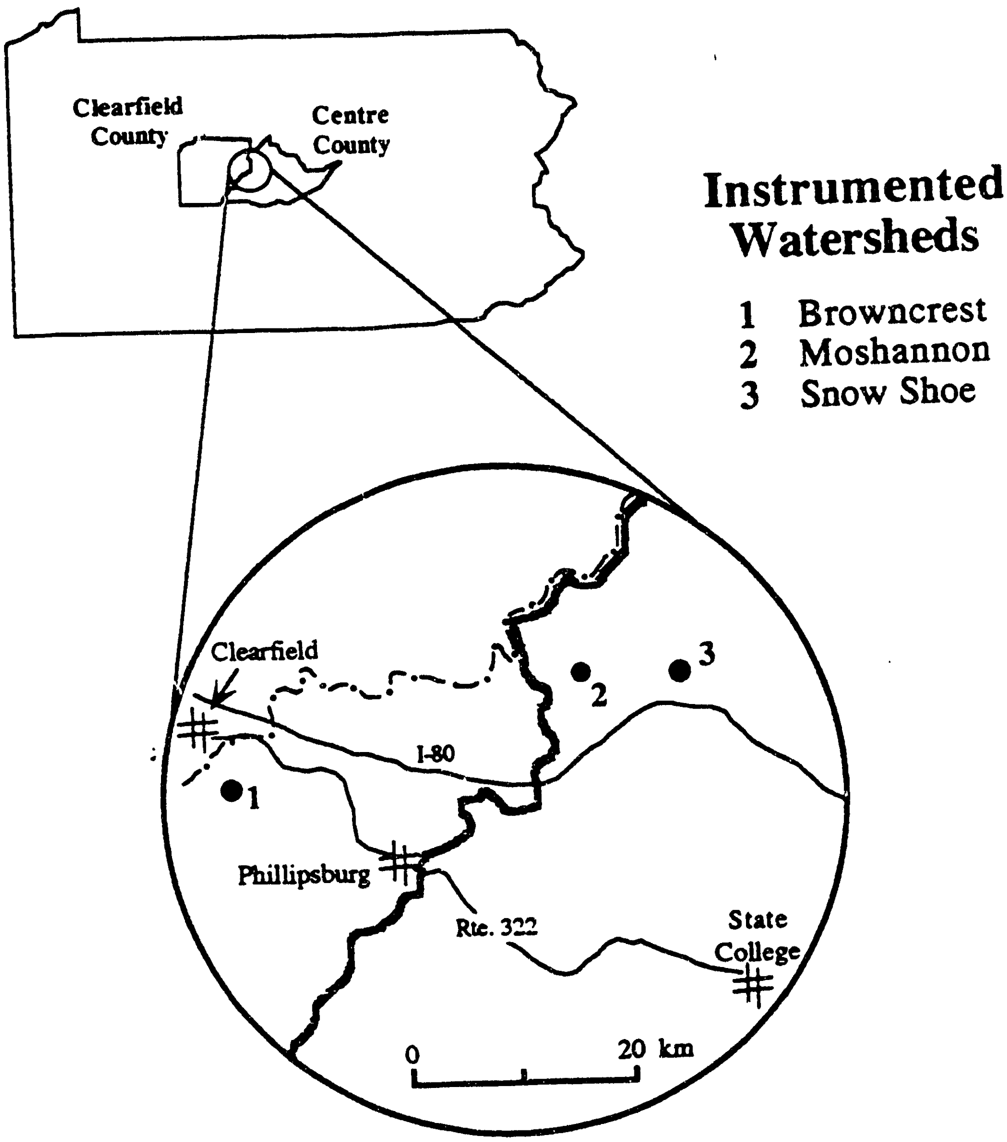

Figure 3. Location of the study watershed.

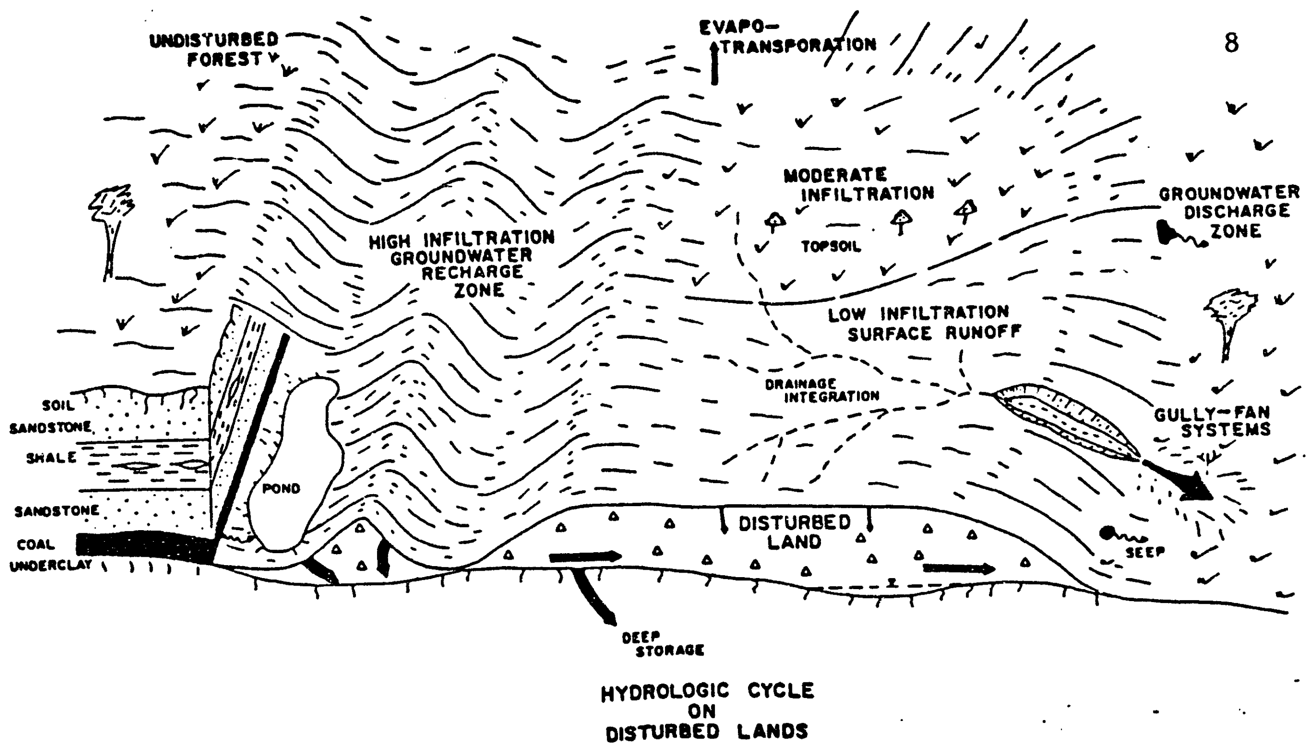

Figure 4. Three-dimensional diagram illustrating the dominant components of the hydrologic cycle on disturbed watersheds which are the focus of this research.

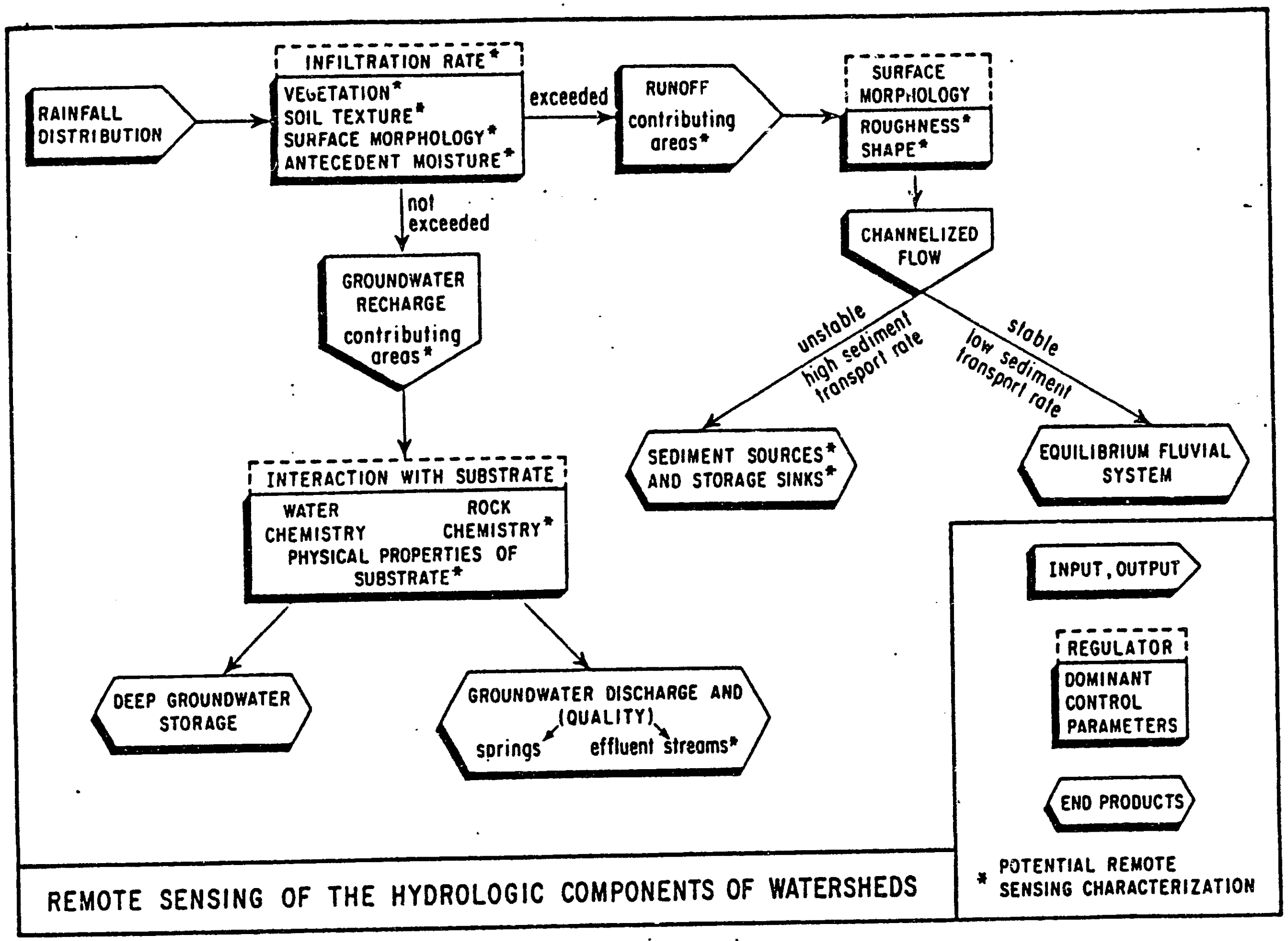

Figure 5. Flow diagram illustrating the hydrologic components, fluid pathways, and independent variables that control the hydrology of disturbed watersheds. The evapotranspiration component can be neglected for the short-duration, high-intensity storms that tend to drive this particular geomorphic system.

To accomplish this goal several disturbed watersheds in the bituminous coal fields of west-central Pennsylvania have been selected for detailed analysis for several reasons. First, because of the potentially rapid rates of landscape modification in disturbed watersheds where high rates of water and sediment discharge per unit area are manifestations of landscape instability, it is possible to investigate the nature of landscape response as disturbed watersheds move rapidly toward an equilibrium state. Second, given the relatively small size of the disturbed subbasins (10^4 to 10^6 m^2) it is possible to quantify mass balance equations for water and sediment movement, and to investigate the sources, allocations, and residence times of sediment in sinks (depositional sites). Third, a large field database exists for the watersheds. Fourth, the magnitude and scale of the hydrologic processes can be characterized with the latest generation of high spatial/spectral resolution remote sensing systems. Finally, data from these studies can be used to evaluate laboratory-scale, experimental geomorphic models of landscape dynamics and evolution which provide the basis for much of our knowledge of landscape evolution.

SUMMARY OF PRIMARY RESULTS

Significant scientific milestones accomplished during the research period are summarized below. Publications that elaborate upon these fundamental accomplishments are itemized in the next section, "List of Publications." All relevant journal articles are included in appendix A to allow the reader to explore and expand upon the scientific milestones outlined below.

The basic hypothesis of this study is that post-reclamation increases in infiltration capacity caused by the development of macropore networks are sufficient to cause changes in the dominant runoff processes and that these differences in infiltrating capacity are detectable with spectral satellite data. As greater volumes of rainfall are infiltrated, the dominant runoff process is expected to shift from infiltration excess overland flow to saturation overland flow (Figure 6a). Furthermore, because the type of runoff process controls the spatial extent and rate of runoff, channel erosion, and basin discharge characteristics (Figure 6b) should respond to changes in the dominant runoff process. Changes in the timing and volume of water discharge should also fundamentally control sediment discharge. While the threshold for sediment entrainment will remain constant for a given sediment size distribution, the probability of sediment transport and total sediment discharge (contaminant loading) are expected to vary directly with observed trends in water discharge.

The specific objectives of this research are to (1) quantify relationships between surface spectral properties and infiltration capacity (2) explore the interaction between surface hydrology and basin morphology, specifically drainage network morphology, and (3) develop a comprehensive process-response model for drainage basin evolution. Hillslope hydrology (runoff process, volume, and rate) and drainage network morphology are two of the most dynamic drainage basin variables and both variables influence drainage basin water and sediment

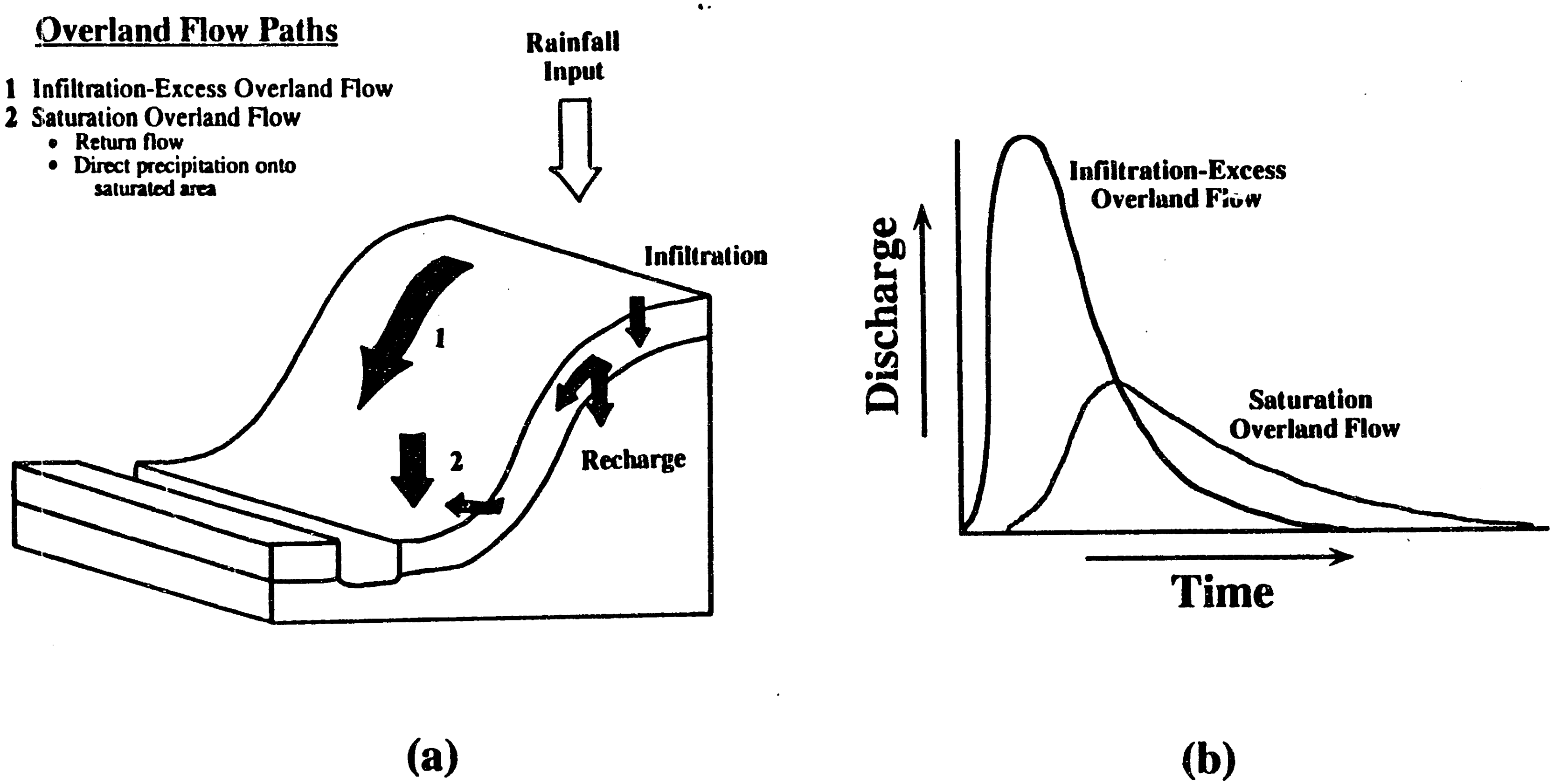

Figure 6. Definition diagram of (a) infiltration-excess and saturation overland flow paths and (b) characteristic storm hydrographs.

discharge. This research examines the response of the drainage network and drainage basin water discharge to changes in the dominant processes that control infiltration and runoff namely macropore network development (Guebert and Gardner, in preparation). Infiltration, the primary regulator of runoff, is analyzed with respect to surface spectral characteristics (Guebert and Gardner, 1989a,b) and drainage basin water discharge. Changes in basin discharge measured on a storm event basis in the field are supplemented with simulated discharge events using a distributed hydrologic model. The hydrologic model is evaluated and parameterized by means of a detailed sensitivity analysis (Ritter, submitted). The response of drainage basin water discharge to changes in infiltration properties of minesoils, and the inferred runoff process, and drainage network morphology is examined in (Ritter and Gardner, submitted). The threshold discharge, or stream power, for sediment entrainment and the implications for changes in sediment discharge through time is also discussed. Ritter and Gardner (submitted) conclude with a process-response model for drainage basin evolution, with implications for natural drainage basin response to climate change. Finally, in Ritter and Gardner (1991, in press) basic rainfall-runoff relationships developed (Ritter and Gardner, submitted) will be applied to an empirical method for predicting discharge on reclaimed surface mines and compared to standard relationships presently used for discharge prediction

LIST OF PUBLICATIONS

Theses, research publications, and abstracts partially or completely funded by Agreement No. DE-FG02-87ER60594 are itemized below. Complete reproduction of all publications are included in Appendix A.

Theses:

Guebert, M.D., 1988, Relationship of Remotely Sensed SPOT Data to Infiltration Capacity on Surface Mined Land in Central Pennsylvania, unpub. MS thesis. The Pennsylvania State University, University Park, PA. 37 pp.

Guebert, M.D., 1991, Macropore Flow on a Reclaimed Surface Mined Watershed: Control on Hillslope and Surface Hydrology, unpub. PhD thesis. The Pennsylvania State University, University Park, PA. 100 pp.

Mazid, M., 1988, Flood Forecasting Using Remote Sensed Information. PhD thesis. The Pennsylvania State University, University Park, PA. 177 pp.

Ritter, J.B., 1990, Surface Hydrology of Drainage Basins Disturbed by Surface Mining and Reclamation, Central Pennsylvania, unpub. PhD thesis. The Pennsylvania State University, University Park, PA. 182 pp.

Publications:

Guebert, M. and T.W. Gardner, 1989a, SPOT classification of infiltration characteristics on disturbed watersheds, central Pennsylvania, Technical Papers, 1989 American Society of Photogrammetry and Remote Sensing Annual Convention, Baltimore MD, v.3, pp. 389-398.

Guebert, M.D., and T.W. Gardner, 1989b, Unsupervised SPOT classification and infiltration rates on surface mined watersheds, central Pennsylvania, Photogrammetric Engineering and Remote Sensing, v. 55, pp. 1479-1486.

Gardner, T.W., K.C. Sasowsky, and R.L. Day, 1990, Automated extraction of geomorphometric properties from digital elevation models, Zeit. fur, Geom., Supplemental Band 80, pp. 57-68.

Miller, A.C., Cieslak, J.A., The Effects of Disturbing the Hydric Soils in the White Deer Creek Watershed (in preparation for submittal).

Ritter, J.B., and T.W. Gardner, 1991, Runoff curve numbers for reclaimed surface mine watersheds in central Pennsylvania, Journal of the Irrigation and Drainage Division, American Society of Civil Engineers, v. 117, p. 1-11.

Ritter, John B. (in press, 1992), The application of field infiltration data to hydrologic model parameterization: an example from drainage basins disturbed by surface mining (Journal of Hydrology).

Ritter, J.B. and T.W. Gardner, Hydrologic evolution of drainage basins disturbed by surface mining, central Pennsylvania: Implications for a drainage basin hydrologic process-response model (submitted to the Geological Society of America Bulletin, August 1991).

Guebert, M.D. and T.W. Gardner, Macropore flow as a control of the hillslope and surface hydrology on reclaimed mine land (in preparation for submittal).

Abstracts:

Guebert, M.D., and T.W. Gardner, 1989, SPOT Classification of infiltration characteristics on disturbed land central Pennsylvania, American Society of Photogrammetry and Remote Sensing, annual meeting.

Gardner, T.W., R.L. Day, and K.F. Connors, 1989, Automated characterization of watershed parameters from digital terrain data sets, 2nd International Conference on Geomorphology, Geooko, v. 1, p. 101.

Gardner, T.W., R.L. Day, and K.F. Connors, 1989, Uniformly gridded digital elevation data as input to distributed-type hydrologic models, American Geophysical Union, EOS, v. 70, p. 1091. (Invited).

Ritter, J.B. and T.W. Gardner, 1990, Hydrologic Evolution of Disturbed Watersheds with Implications for Long-term Basin Evolution, EOS, v. 71, p. 513.

Guebert, M.D. and T.W. Gardner, 1991, Macropore flow on a reclaimed strip-mine hillslope: contribution to the surface discharge hydrograph, EOS v. 72, p. 137.

APPENDIX A
RESEARCH PUBLICATIONS

7 reprints + reprints removed and cycled separately.

END

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