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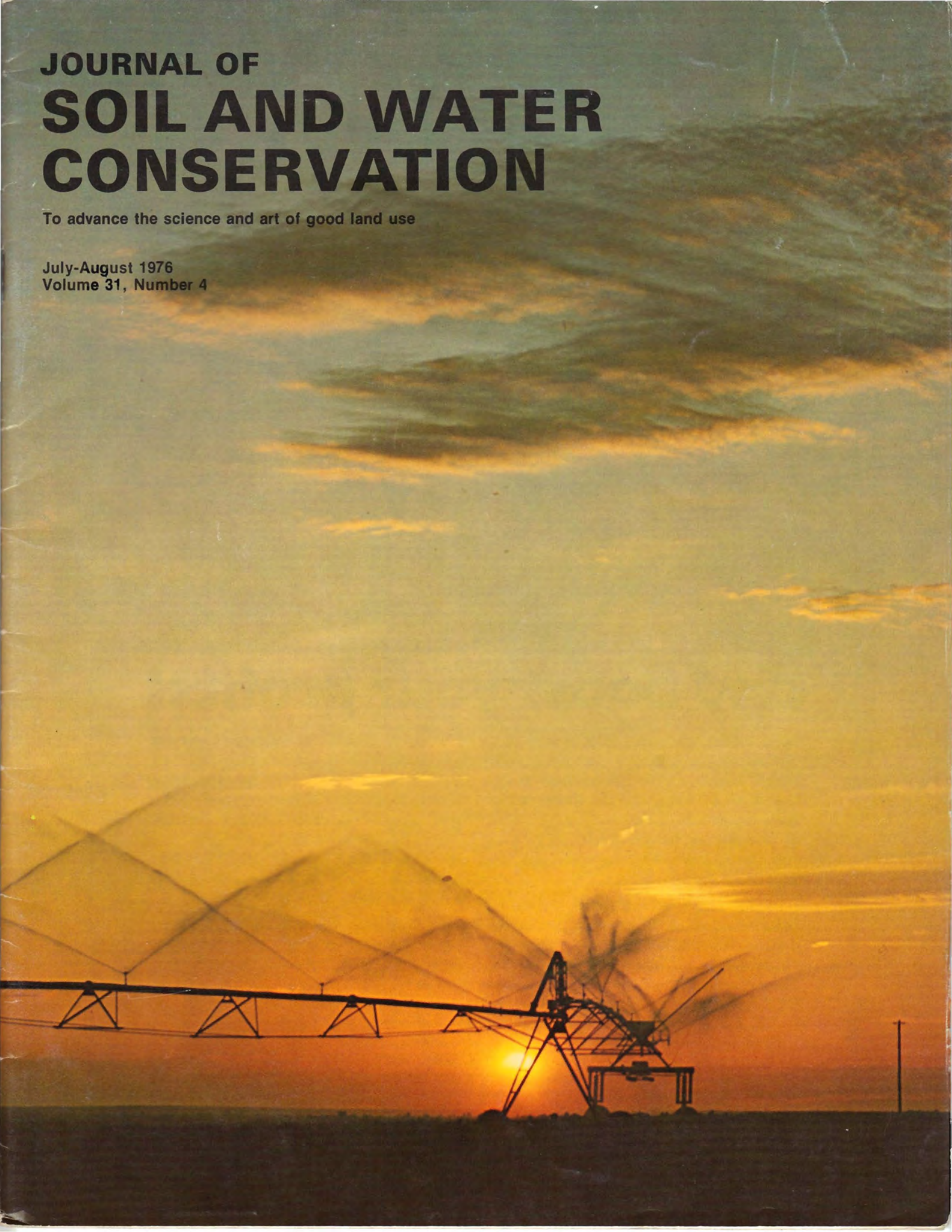

titudes about water, political interests are also an important factor. The right to decide is a highly esteemed privilege. In many communities, power struggles among various groups, such as the planning board, selectmen or councilmen, economic development commission, water department, and citizens groups, are not uncommon. The use of water supply facilities to control land use would in effect elevate the objectives of the planning board above the objectives of the other groups. Planners thus would become decision-makers. It is unlikely that such a procedure would be well received or easily implemented. Someone no doubt would have to apply strong arguments or coercive forces.

The political question of who makes the decisions can also have regional implications. Just as a developer desires assurance that no one else will develop the land he is leaving alone for the sake of land use planning, so too communities may not wish to withhold water for fear of losing desirable development, unless they are assured that neighboring communities will act in similar fashion.

Such a situation implies that decision-making should be made by an agency with a regional outlook and regional powers. Local water supply agencies could be united in some way but remain subordinate to the planning group.

Legal Issues

There may also be legal issues to consider. Will the courts view the withholding of water and water facilities as a taking of the lands denied development rights due to a lack of municipal water? A discussion of this issue is beyond the scope of this article, but a number of authors have examined the question (*2, 3, 11*). Briefly, they indicate that since 1970 a number of techniques have been proposed and tried to control the problems associated with poor land use patterns. Generally, the courts have looked favorably upon these techniques so long as a technique is designed to achieve a comprehensive planning goal and racial or socioeconomic discrimination is not a prime factor behind the decision process. For example, courts have upheld the Ramapo, New York, decision to control (not prohibit) development based upon the availability of municipal services and facilities (*11*).

Water supply facilities can and do play an important role in community development. As a result, they can be used to control development. Such use, however, must recognize the problems associated with people's attitudes about water, political realities and legal niceties.

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Mapping runoff-producing zones in humid regions

T. R. MOORE, T. DUNNE, and C. H. TAYLOR

SINCE the 1930s, the Horton infiltration approach to runoff production has dominated hydrology and its applications in the prediction of river discharges and land management (*13, 14, 22*). Field observations have confirmed the Horton model of overland flow, a form of runoff common in semi-arid regions and on agricultural lands, such as those in the midwestern United States. On these lands, infiltration capacities are usually less than the major rainfall intensities.

Because the infiltration capacity of soils within a catchment is rarely uni-

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form, the production of Horton overland flow varies spatially. This is the basis of Betson's (*1*) partial-area model of storm runoff. It is based on the original Horton analysis of overland flow, but suggests that only a small portion of some catchments contribute storm runoff.

In humid regions, a soil's infiltration capacity remains high unless vegetative cover is disturbed. Hence, Horton overland flow is confined to such locations as roads and parking lots, skid trails in forests, some fields, and artificial fills. In humid regions without severe disturbance, Horton overland flow does not occur, and at least three other processes generate storm runoff: subsurface storm flow, return flow, and direct precipitation onto saturated areas (Figure 1). Their relative importance varies with topography, antecedent soil wetness, and storm size. For example, where soils are well drained, deep, and permeable and where steep hillsides border on a narrow valley floor, subsurface storm flow dominates the hydrograph, but emerges from the ground surface over only limited zones of the catchment (*26*). Ragan (*20*) described catchments of this type in Vermont, as did Hewlett and Nutter (*12*) in the Southern Appalachians. Where soils are thinner, the footslopes gentler, and the saturated and near-saturated valley bottoms more extensive, saturation overland flow is much more important, and its importance increases with storm size (*4*, *6*, *7*).

The saturated area that produces most storm runoff in humid regions varies with time, both during and between rainstorms. The water table rises to the soil surface over an expanding area as rainfall progresses, extending from the river channels into tributaries and footslopes occupied by poorly drained soils. Conceptual models of this expanding and contracting saturated area have been developed by the U. S. Forest Service (the variable source concept) (*11*, *25*) and the Tennessee Valley Authority (the dynamic watershed concept) (*23*). The models have been tested in catchments in New England (*4*, *20*) and North Carolina (*12*).

Need for a Prediction Technique

Routine techniques have been developed to quantify the pattern of infiltration capacities, hence the prediction of areas producing Horton overland flow. These techniques are frequently used in resource assessment and land management when decisions must be made about the suitability of land for various purposes and the probable environmental impact of land use changes. It would be helpful to make the recognition and prediction of saturated areas in humid regions equally routine. The size and location of these variable contributing areas are of interest for predicting rates or volumes of runoff in humid regions. Use of the simplest techniques may require only an estimate of the total area saturated at the beginning and end of a storm, while others will require estimates of the width of the saturated area or the travel time of saturation overland flow.

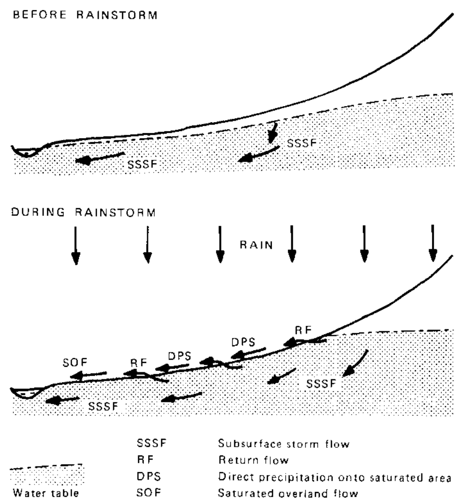

Figure 1. Runoff-producing processes in a humid-region catchment during a rainstorm.

There are other reasons for knowing which areas of a watershed yield saturation overland flow. The source of runoff in relation to sources of contaminants, such as phosphates or bacteria, is an important control on water quality (*5*, *16*). Knowing what areas in a catchment produce saturation overland flow would allow major sources of various contaminants to be delineated. Then, perhaps, steps could be taken to minimize such inputs. Better methods of predicting the location, magnitude, and frequency of ground saturation at various times of the year would also improve the analyses of land suitability for plowing, planting, and harvesting. Houses are still built where saturation overland flow occurs also. The routine recognition of variable source areas would help in zoning to eliminate problems with septic tanks and other housing needs.

Thus, it would be useful to develop some simple field techniques that would make the recognition and prediction of these saturated areas routine. Here, we make some suggestions of methods that are being used for that purpose. The methods are not perfected. We offer them to stimulate further discussion and trial in the hope that the delineation of areas producing saturation overland flow will become as routine as the mapping of infiltration capacity in regions experiencing Horton overland flow. The prediction tools we use are routinely available: information on hydrology and soils from the Soil Conservation Service, Agricultural Research Service, and other resource assessment agencies.

Delineating Saturated Areas

The best method of evaluating the size, location, and variation of saturated areas is by repeated field mapping. Ishaq and Hutt (*15*) developed a method to identify source areas using color infrared and visible wavelength photography. Since ground mapping can only be done for small catchments and aerial photography can be carried out only rarely, field measurements must be correlated with some other easily observable characteristic of the basin to allow mapping over larger areas. The basin characteristics we have found to be most useful are topography, soils, vegetation, antecedent moisture index, and hydrologic budgeting.

To illustrate some of these techniques we selected a small drainage basin in northeastern Vermont. The basin is developed in glacial till. Sandy loams cover the upper parts of its hillslopes with moderately to poorly drained silt loams on the concave footslopes.

Field mapping shows that the extent of the saturated area varies seasonally from 15 to 51 percent (Figure 2). Expansion of the saturated area at snowmelt and after heavy rainstorms takes place by headward extension of the channels into swales and also by lateral expansion up the basin's hillslopes. A nearby catchment with steeper valley sides, better drained sandy soils, and a narrower valley floor section has a seasonal saturated area variation of 4 to 15 percent. Thus, for catchment areas up to 1 square mile, it is possible to define the seasonal or inter-storm variation of the saturated area by repeated field mapping. The variation is large.

Topography obviously has a major influence on the distribution of the saturated area. These areas occur mainly in the valley bottoms and the lower parts of swales. They extend up the swales and footslopes during wet periods. They also occur in areas where bedrock is close to the surface, promoting the emergence of groundwater. An example of this occurs in the northern part of the drainage basin, which is not low-lying but becomes saturated after snowmelt because the soils are shallow. Soils with shallow hard pans may also be easily saturated. It is difficult, however, to use topography solely as an indicator of saturated areas.

Soil morphology is a more useful criterion. When soils become saturated, free oxygen is consumed, iron and manganese are reduced and mobilized, and gley morphology occurs as grey and brown mottling. Although there is a general correlation between gley morphology and period of saturation in the surface horizon of the soil, most saturated-area soils will waterlog for only a short period and may not produce well-defined gley morphology (*18*). The surface horizon is also liable to disruption by changes in vegetation and land use.

Subsoil gley morphology may be a more successful indicator of the distribution of saturated areas. Several studies have shown a reasonably good correlation between subsoil gley morphology and soil water regime, and morphological criteria have been employed in drainage class definitions (*17*, *21*). From the distribution and type of gley morphology within a soil profile, the soil water regime and water table depth can be estimated. However, the soil morphology-water regime relationships in subsoils are affected by the color of the parent material, the availability of organic matter, the presence of fossil gley morphology, and the occurrence of aerated water tables.

Comparisons of the map showing soil drainage classes (mapped at 1: 8,000) and the distribution of the saturation area in the Vermont basin (Figures 2 and 3) reveal a good spatial correlation between the saturated area and the moderately well, poorly, and very poorly drained soils. After snowmelt, the saturated zone occupies the very poorly and poorly drained soils, plus some soils classed as moderately well or well drained. These soils are usually shallow phases or those with a hardpan in the profile. In summer, the saturated areas are confined to the very poorly drained soils with some extension into the poorly drained soils. In the county soil survey reports the Soil Conservation Service describes soil series according to drainage class and tabulates the depth to the seasonal high water table.

In some regions, it is possible to use plants as indicators of soil drainage in outlining runoff-producing areas. Hack and Goodlett (*10*) described the method of physiographic ecology for humid areas. In Vermont, for example, northern white cedar, white spruce, and balsam fir that are not located in old-field sites outline approximately the maximum extent of the saturated area in most years. During very wet years, and at the base of long slopes, the saturated area may extend into a hardwood cover that includes butternut, yellow birch, and basswood. Sedges and occasional willows and elms outline the minimum extent of the saturated area in late summer (*27*).

The use of plants as indicators of soil wetness should be approached with care because plants reflect only broad regimes of soil water rather than specific seasonal characteristics. Plants are also affected by nutrients, light, and land use variations.

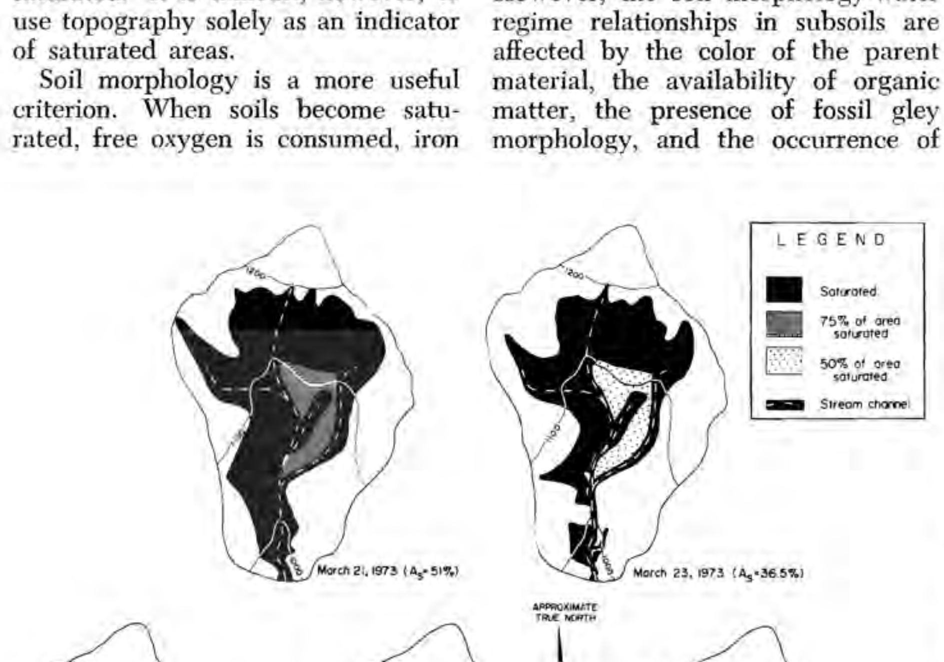

Figure 2. Seasonal extent of the saturated area before summer storms, autumn storms, and immediately after snowmelt in a Vermont catchment with steep, well-drained slopes and a narrow valley bottom.

A Day-to-Day Accounting

The techniques described above can be used to predict seasonal maximums and minimums of saturated areas within catchments, but for a day-to-day accounting of the extent of a saturated area, some hydrologic technique involving a routinely measured parameter is necessary.

Often there is a correlation between a stream's base flow and the extent of the saturated area within a drainage basin. Two Vermont catchments illustrate this correlation (Figure 4). The nature of this relationship varies with a catchment's topography and soils, but it can be evaluated with only a few measurements. In addition, it seems to remain stable from year to year.

Other hydrologic prediction techniques we have found useful include correlating the saturated area and antecedent precipitation indexes or water table levels. Dickinson and Whiteley (3) found the soil moisture measurements could be related to an estimate of the saturated area's coverage. We obtained a similar correlation for one of the Vermont catchments (Figure 5). Water table fluctuations can be predicted from budgeting using water budgets or meteorological variables, thus generating a long-term record of the saturated area.

Design calculations of the saturated zone and the runoff produced by subsurface stormflow and saturation overland flow can be made from simplifications of the soil-water system (*8, 9, 24, 25*). Soil survey reports contain information on soil depths, textures, and seasonal water tables. From this information, the amount of water required to raise the water table to the soil surface can be calculated if the unsaturated part of the profile is at field capacity, which is common during the seasons when the saturated area is most extensive. Comparison of this calculation with precipitation data will yield an estimate of the probability of complete saturation (exhaustion of storage capacity) occurring in representative soil profiles within the drainage basin. This method, however, does not allow for the rate at which return flow emerges from the soil over the lower saturated areas.

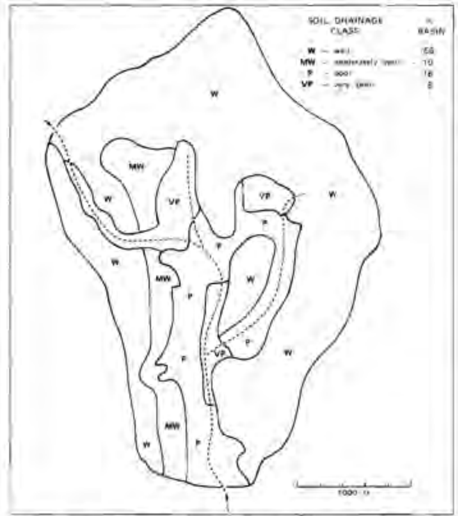

Figure 3. Soil drainage class map of the Vermont catchment (Figure 2).

Summary

In undisturbed humid regions the saturated areas of a catchment play an important role in determining storm runoff through subsurface storm flow, return flow, and direct precipitation onto saturated areas. The saturated areas also serve an important function in determining stream water quality and land capability. For these reasons there is a need to be able to predict routinely the distribution of these saturated areas in drainage basins, both spatially, seasonally, and through individual storms.

A number of relatively simple observations indicate fairly well the distribution of saturated areas in catchments. These are field mapping, remote sensing, soil morphology, topography, and vegetation. In addition, estimates can be derived from soil moisture budgets of typical soil types and hydrograph analysis. Each method will have different applicability in different types of catchments, however.

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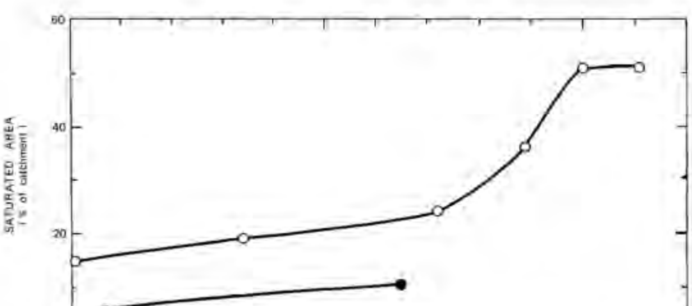

Figure 4. Relation between baseflow and the extent of the saturated area in two Vermont catchments.

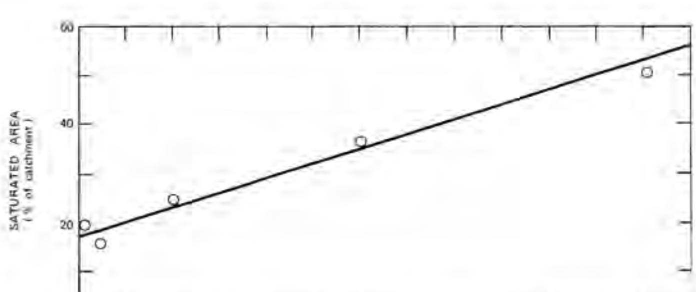

Figure 5. Relation between antecedent precipitation index and the extent of the saturated area in the Vermont catchment (Figure 2).

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Geomorphological mapping applied to soil erosion evaluation

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AERIAL photographs provide a base for mapping soil erosion and evaluating soil erosion hazards. This is because most erosion features are visible in direct stereoscopic image, and those that are not can be readily inferred from tonal variations (*2*). Compared with ground surveys, use of aerial photographs minimizes the time required to produce maps and lowers the cost of surveys (*20*). Yet, in spite of the work by a number of researchers (*15, 11, 3*), no standard technique exists for mapping soil erosion.

Derivation of Mapping System

The rate of soil erosion by water is governed principally by rainfall erosivity and soil erodibility. It is influenced locally by relief, slope, and plant cover. These factors also provide the basis for geomorphological studies of fluvial erosion both on hillsides (*4*) and in drainage basins (*10*). Because of the similarity between studies of soil erosion and fluvial geomorphology and because the techniques of geomorphological mapping are reasonably well established, it seems logical to examine these techniques from the standpoint of their suitability for mapping soil erosion.

Different countries have developed their own systems of geomorphological survey (*9, 12, 18*), although at least two attempts have been made recently to produce a more unified system (*6, 19*). Some common features emerge from the profusion of techniques and symbolization that exists. Most maps portray four categories of information. These are morphographic (concerned with the identification of land forms), morphogenetic (describing the origin of landforms), morphometric (giving measurements such as height, distance, and steepness), and morphochronologic (concerned with the age of landforms). In practice, the age and genesis of particular features are often difficult to determine, and the morphographic and morphometric elements dominate.

Most geomorphological maps possess two disadvantages for showing information on soil erosion. First, the maps are cluttered with extraneous material making it difficult to extract relevant information. Second, they generally include insufficient detail on the factors influencing erosion. This second deficiency means that the maps must be considered static in concept. As such, they provide a poor base for assessing spatial and temporal variations in erosion intensity. By carefully selecting parameters and appropriate symbols, however, a special-purpose map can be produced that is dynamic in concept and can enhance the understanding of the relationship between erosion incidence and its controlling variables in the area being studied. The value of special-purpose maps is increasingly being recognized in the field of applied geomorphology because of their simplicity and flexibility (*6, 19*).

In addition to showing the type, intensity, and location of erosion, the aim of our mapping system is to portray information on the spatial distribution of erosivity, runoff, slope length, slope steepness, slope curvature in profile and plan, relief, soil type, and plant cover. As many features as possible are shown on a single basic map, using linear and areal symbols derived largely from the work of Verstappen and van Zuidam (*19*) and Gerlach and Niemirowski (*8*). Additional features are shown on a series of overlays, for example, erosivity (using isoerodents), soil type, and slope steepness (using area shading).

The most suitable base for the main map is a detailed topographic contour map. A large amount of data can be extracted from the contour patterns, such as relief, altitude, slope length, slope steepness, and slope curvature. Furthermore, a topographic map shows settlements and communications from which a surveyor can re-

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