HYDROLOGIC SOIL GROUP ASSIGNMENT

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Abstract

Assignment of soils to hydrologic soil groups has been based on published criteria subjectively interpreted and applied by soil scientists. As a result hydrologic soil group placement for any given soil lacks consistency of method and correlation to the respective soil's physical properties. A method of placing soil into hydrologic soil groups was developed using fuzzy systems techniques. This method consists of a set of fuzzy system rules and evaluations that establish a consistency in the interpretation of hydrologic soil group criteria. The fuzzy system placement of soil into a hydrologic soil group correlates well with previously established placements. This approach also identified those soils that may have been improperly placed in a given hydrologic soil group and those that have insufficient data to make a proper group placement.

Introduction

Soil Hydrologic Groups (HSG) along with land use, management practices, and hydrologic conditions, determine soil cover complexes and their associated runoff curve numbers. Soil Hydrologic Groups are assigned to soil series and phase of series using the criteria found in either the NRCS National Engineering Handbook or National Soil Survey Handbook. Soil scientists rely on their interpretation of the published criteria to place soils into the appropriate hydrologic groups. The soil scientist's interpretation of the published criteria has varied through time and across states and regions. Thus, hydrologic group criteria are not uniformly applied across the United States which causes inconsistent placement of soils into their respective hydrologic groups. This is most evident in the comparison of soils with similar hydrologic and physical properties but dissimilar hydrologic group placement.

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Our goal has been to develop an automated system that would place a soil into its appropriate hydrologic group. This automated approach to Hydrologic Soil Group assignment would replace the subjective interpretation of the soil scientist and provide a national, standardization of the hydrologic group criteria. This system applies the soil physical and hydrologic properties to the published criteria and produces the appropriate group assignment for the soil. Further, it reduces the error associated with soil scientists' interpretation of the hydrologic group criteria. Such a system would also bring a consistency to the assignment of hydrologic groups between states and regions of the United States.

Background

Soils in the United States, Puerto Rico, and its territories have been assigned to Hydrologic Soil Groups. The assigned groups are listed in Natural Resources Conservation Service Field Office Technical Guides, published soil surveys, and local, state, and national soil databases. The Hydrologic Soil Groups, as defined by ARS and NRCS engineers, are A, B, C, D, and dual groups A/D, B/D and C/D. (Engineering Staff, 1993)

Soils in hydrologic group **A** have low runoff potential. These soils have a high rate of infiltration when thoroughly wet. The depth to any restrictive layer is greater than 100 cm (40 inches) and to a permanent water table is deeper than 150cm (6 feet). (Engineering Staff, 1986)

Soils that have a moderate rate of infiltration when thoroughly wet are in hydrologic group **B**. Water movement through these soils is moderately rapid. The depth to any restrictive layer is greater than 50 cm (20 inches) and to a permanent water table is deeper than 60 cm (2 feet). (Engineering Staff, 1986)

Hydrologic group **C** soils have a slow rate of infiltration rate when thoroughly wet. Water movement through these soils is moderate or moderately slow and they generally have a restrictive layer that impedes the downward movement of water. The depth to the restrictive layer is greater than 50 cm (20 inches) and to a permanent water table is deeper than 60 cm (2 feet). (Engineering Staff, 1986)

Soils in hydrologic group **D** have a high runoff potential. These soils have a very slow infiltration rate when thoroughly wet. Water movement through the soil is slow or very slow. A restrictive layer of nearly impervious material may be within 50 cm (20 inches) of the soil surface and the depth to a permanent water table is shallower than 60 cm (2 feet). (Engineering Staff, 1986)

Dual Hydrologic Soil Groups (A/D, B/D, and C/D) are given for certain wet soils that could be adequately drained. The first letter applies to the drained and the second to the undrained condition. Soils are assigned to dual groups if the depth to a permanent water table is the sole criteria for assigning a soil to hydrologic group D. (Engineering Staff, 1993)

Soils were originally assigned to Hydrologic Soil Groups within selected small watersheds, and assignments were based on rainfall-runoff data and infiltrometer plots in those watersheds. (Musgrave, 1995). Since those initial groupings, assignment of soils to Hydrologic Soil Groups has been based on the judgment of soil scientists. They assign soils to the hydrologic groups, that contain soils with similar hydrologic and physical properties. Thus, these groupings reflect the premise that saturated soils with similar depth, permeability, and texture will have similar response during an intense rainstorm. (Soil Survey Staff, 1993).

Purpose

The purpose of this activity was to develop a model or rule-based, automated system that provides objective placement of soils into Hydrologic Soil Groups. The essential objectives are:

1. The system had to maintain the conceptual relationship between a soil's physical and hydrologic properties and its placement in a Hydrologic Soil Group.
2. It had to assign soils with similar physical and hydrologic properties into the same hydrologic group.
3. The Hydrologic Soil Group criteria used by the system model is that published in the USDA-NRCS National Engineering Handbook, 1993.
4. The placement of a soil into a hydrologic group had to correlate relatively closely to that soil's current Hydrologic Soil Group assignment.

Previous attempts to develop an automated system have met with varying degrees of success. These attempts included a stochastic model, neural net modeling, and cluster analysis modeling. Although these modeling procedures assigned a soil to a hydrologic soil group, the results did not have the degree of consistency and accuracy desired. Nor, did the model results correlate well with the expected assignment of a soil into its respective hydrologic group.

Method

We applied fuzzy system modeling techniques to assignment of soils to hydrologic groups. The fuzzy system model design is based on the published hydrologic group assumptions and criteria. The assumptions are that the soil surface is bare and the soil is not permanently frozen. The soil physical and hydrologic characteristics that make up the hydrologic group criteria are the depth to permanent water, depth to a restrictive layer, minimum K_{sat} in the soil's upper 100 cm (40 inches), and soil texture. (Soil Survey Staff, 1993).

The fuzzy system hydrologic grouping model was developed using the National Soil Information System (NASIS) soil interpretation subsystem. The NASIS subsystem is an automated, fuzzy logic based analytical tool that allows the user to build and test models relevant to the application of soils data to interpret or group soil for various uses and applications. There are three components to any NASIS fuzzy systems model -- the Property, the Evaluation, and the Rule. (NASIS Development Team, 1997). For this discussion, these model components are specific to the grouping of soils into their corresponding hydrologic groups.

The Property is an SQL (Standard Query Language) statement that retrieves the specified soil attribute data from the soil survey database. An example of a property is the depth to a restrictive layer. The Evaluation's function is to apply the output received from the SQL statement to a statement of the property's relevance to the soil's hydrologic grouping. In the case of the depth to a restrictive layer, the evaluation determines the fit or truthfulness of the statement "Soil runoff potential increases as the soil's depth to a restrictive layer becomes more shallow." At some threshold, the restrictive layer depth has a maximum contribution to runoff and the evaluation is "true". The restrictive layer depth threshold for Hydrologic Soil Groups is 50 cm (20 inches). (Engineering Staff, 1993)

Using the fuzzy analytical tools in NASIS, an evaluation for each soil property that contributes to the hydrologic grouping of soils was created. The output from an evaluation is a number between 0 and 1. This number represents the truthfulness of the statement being evaluated. The closer the number is to 1 the greater the soil's property contribution to the grouping criterion. (Cox, 1994). Conversely, the closer the number is to 0 the less the soil property contributes to the hydrologic grouping. In the restrictive layer example, an evaluation output of 1 would mean the soil's restrictive layer is shallower than 50 cm (20 inches). Any output less than 1 means that the depth to any soil restrictive layer is greater than 50 cm (20 inches). The numeric output from the evaluation is passed to the rule.

The Rule serves two functions. The first is to provide tools that bring the various hydrologic group criterion evaluations together into a single Hydrologic Soil Group model. The second is to convert the model's numeric output into a Hydrologic Soil Group. For this study, the published Hydrologic Soil Group criteria and criteria relationships were translated into a set of rules that were used to develop the Hydrologic Soil Group Model. This model was applied to NASIS soil data from Kansas, South Dakota, Missouri, Iowa, Wyoming, and Colorado. The results of this application were evaluated by comparing a soil's system generated Hydrologic Soil Group to its stored NASIS Hydrologic Soil Group.

Results

The Hydrologic Soil Group fuzzy model was applied to 1,828 unique soil phases and the correlation between these soils' assigned and modeled hydrologic grouping was analyzed. Table 1 gives the correlation between the current assigned HSG and the modeled HSG. The correlation analysis proved to be relatively close and the overall HSG frequency coincidence between the assigned and the modeled hydrologic grouping exceeded 54%. Comparison by HSG showed some groups having a better correlation than others. The correlation frequency between the assigned and modeled

HSG A and HSG D soils is higher than that between the assigned and modeled HSG B and HSG C soils.

Table one: Correlation Frequency Between Soils' Assigned and Fuzzy Modeled HSG

		FUZZY HSG ASSIGNMENT FREQUENCY						
CURRENT HSG	NUMBER OF SOILS	A	B	C	D	A/D	B/D	C/D
A	155	0.90	0.08	0.00	0.01	0.01	0.00	0.00
B	821	0.25	0.54	0.17	0.02	0.01	0.00	0.00
C	405	0.04	0.25	0.34	0.31	0.00	0.03	0.04
D	404	0.02	0.05	0.05	0.64	0.06	0.10	0.08
A/D	1	0.00	0.00	0.00	0.00	0.00	1.00	0.00
B/D	29	0.10	0.07	0.07	0.00	0.10	0.55	0.10
C/D	13	0.00	0.08	0.08	0.39	0.00	0.31	0.15

There are several reasons for the poor correlation between the assigned and modeled groups B and C. The first is the boundary condition. This occurs when a soil has properties that do not fit entirely into a single hydrologic group. In this case, the soil scientist may have placed the soil into one HSG while the model placed the soil into an adjacent group. Groups B and C are the most prone to this error because they are bounded by two groups whereas HSG A and D are only bounded by one group. No analysis is possible to isolate this error, but it does indicate that for those soils assigned B and C groups their grouping may need to be reevaluated to ensure correct placement. Another source of poor correlation frequency is that the assigned HSG may be relatively correct but data errors in the database may not support the corresponding HSG determination by the model. Finally, some correlation inconsistencies can be attributed to the fuzzy modeling of the subjective Hydrologic Soil Group criteria.

The dual HSG correlation contains the same potential sources of mismatching between the assigned and modeled HSG as do the single groups. The difference here is that the dual groups are dependent on the presence of drainable water within 60 cm (2 feet) of the soil surface. The interpretation of drainable water is highly subjective and depends on the soil scientist's perception of drainable. The fuzzy HSG model assumes that any permanent water within 60 cm (2 feet) of the soil surface is drainable. Further, several of the soils assigned to HSG A, B, and C have permanent water within 60 cm (2 feet) of the soil surface and should have been assigned to either HSG D or to their respective dual HSG.

Conclusion

The fuzzy model of Hydrologic Soil Groups has proven successful. Its outputs have a relatively high degree of correlation to current Hydrologic Soil Group placement. Moreover, the conceptual relationship between the hydrologic group criteria and the soil hydrologic and physical properties has been maintained. The model also provides the soil scientist with information about the compatibility of the subject soil's data and it's HSG assignment. In this case, if the soil scientist HSG assignment and the model's HSG output is not the same, then the soil scientist has an indication that either the model's soil data inputs need to be reviewed and updated or they need to reassess their HSG assigned.

The fuzzy system approach to HSG assignment makes additional information available to the watershed hydrologist. Not only does the model output provide a HSG assignment, it also produces (as output) a "fuzzy number" (a number between 0 and 1). This additional output provides information that could be used to redefine hydrologic groups, split hydrologic groups into subgroups, or to develop new hydrologic groups. The intent of this analysis is not to split or add new HSGs to the system. It does however point out that the capability does exist to provide a specific number to represent a soil's runoff potential. Whether this is proper in the context of "Runoff Curve Number" technology remains to be debated but the capability does exist to test and further develop this concept.

References

Cox, E. 1994. The Fuzzy Systems Handbook: a practitioner's guide to building, using, and maintaining fuzzy systems. Academic Press, Inc. Chestnut Hill, MA. Chapter 3.

Engineering Staff. 1986. Urban Hydrology for Small Watersheds, Technical Release 55. USDA-NRCS, Engineering Division. U.S. Gov. Print. Office, Washington, DC. Part 630, Section 4, Chapter 7.

Engineering Staff. 1993. National Engineering Handbook. USDA-NRCS, Engineering Division. U.S. Gov. Print. Office, Washington, DC. Part 630, Section 4, Chapter 7.

Musgrave, G. W. 1955. "How much of the rain enters the soil?" Water Yearbook of Agriculture. U.S. Department of Agriculture. Washington, DC. pp. 151-159.

NASIS Development Team. June 1997. National Soil Information System, Getting Started 3.1. USDA-NRCS, Information Resource Management Division. Washington, DC. Chapters 13 to 15.

Soil Survey Staff. 1993. National Soil Survey Handbook. USDA-SCS, Soil Survey Division. U.S. Gov. Print. Office, Washington, DC. Section 618.