DSat8 and Seasonal High Water Tables in Indiana Soils

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ABSTRACT

The phrase "seasonal high water table" (SHWT) is used frequently in regulations that deal with permits for onsite sewage treatment systems and in design of the systems. Different soil scientists evaluating the same soil might place the depth of the SHWT at different depths, however. We propose that two quantitatively defined terms, DSat8 and DRD, replace the more ambiguous SHWT in regulating and designing onsite systems. DSat8 is the depth below which a soil layer is saturated >8% of the time. DRD is the depth to reduction depletions (gray colors) in the soil profile. DRD can be used to estimate DSat8 for many soils. We identify the kinds of soils for which soil color (DRD) is a reliable indicator of water table depth (DSat8), and we propose guidelines based on soil and landscape properties to estimate DSat8 for soils in which color is not a reliable indicator of water table depth.

INTRODUCTION

Saturation of soil with water and chemical reduction of iron (Fe) in soils are two separate processes, but often the two processes are not differentiated. Soil saturation occurs when all soil pores are filled with water. The upper surface of saturated soil defines the water table. Reduction occurs when an atom gains electrons. Conversely, oxidation occurs when an atom loses electrons. Electrons responsible for reduction are produced mainly by the microbial oxidation of carbon (e.g., respiration). A number of atoms in soil can gain and lose electrons, e.g., oxygen, nitrogen, manganese, iron, and carbon. Because many elements are involved, reduction in soils is a continuum with no sharp breaks. For soils, however, reduction of *iron* has become accepted as a key marker of reduced soils because the presence or absence iron oxides can be inferred from soil color. Soils are composed mainly of grayish silicate minerals, but small amounts of iron oxides impart brownish or reddish colors to the more oxidized soils. If the soil becomes anaerobic, however, iron oxides are generally reduced and dissolved and one sees the underlying grayish silicate minerals. Thus, reddish and brownish soils reflect oxidizing conditions, gray colors reflect reducing conditions, and a mixture of the two colors (mottling) reflects alternating oxidizing and reducing conditions. The definition of reduction depletions, below, is based on these principles.

Saturation and reduction are often related. When soil is not saturated with water, air (with oxygen) diffuses readily in the soil, and the electrons produced by microorganisms are absorbed by oxygen. When the soil becomes saturated and soil water is stagnant, oxygen is excluded from soil pore space. Then, electrons are absorbed by nitrogen, manganese, and eventually by iron, and the soil becomes gray because of depletion of Fe. In many soils, soil color is a reliable indicator of saturation.

In other soils, however, saturation and reduction are poorly related because the water that saturates the soil might contain small amounts of oxygen, evidence of Fe reduction is masked by other soil components, or other reasons. For these soils, not distinguishing between saturation and reduction could lead to problems in using the soil.

One example is using the seasonal high water table (SHWT) for issuing permits for onsite sewage disposal systems and for designing the systems. In a proposed rule that deals with onsite systems, SHWT is defined as the "upper limit of soil saturated with water for periods long enough for anaerobic conditions to affect soil color. In some cases, a dry zone may underlie the seasonal high water table" (Indiana State Department of Health, Jan. 8, 2003). This definition appears to assume that the relation between soil saturation and anaerobic conditions (and presumable Fe reduction) is similar for all soils, but this is not the case, as will be shown here. Thus different people have different interpretaions of what SHWT means. To illustrate the problem, we recently asked a group of soil scientists how they recognized SHWT in the field. Some said that it was the highest level of the water table when measured for a few years, some said that it was the depth to uppermost gray soil colors, and others said that it was the depth to which the water table usually rises. Each answer has merit. The first is similar to the *Soil Taxonomy* (Soil Survey Staff, 1999) definition of aquic moisture regime, which requires "at least a few days" of saturation. The second answer is used by most soil scientists in the field, but it is based on reduction, not saturation. The third answer is probably closest to what is proposed here, but it is not known what "usually rises" means. The various interpretations of the phrase has practical implications. For example, a county health official reported that for identical descriptions of a soil with 18 inches of dark surface horizon over a dominantly gray subsoil, some soil scientist place the SHWT at 18 inches and others place it at the surface. Also, some soils are known to have seeps, but this condition is not reflected by Fe depletion features (gray colors) in the soil. In this paper we define two terms and suggest they be used instead of the more ambiguous SHWT.

The objective of this paper is to 1) identify soils in which reduction is a reliable indicator of saturation 2) characterize the relationship between saturation and reduction for these soils 3) extrapolate this relationship to soils in which reduction is a less reliable indicator of saturation. This paper is an elaboration of the discussion on pages 49 to 52 of *Indiana Soil and Landscape Evaluation Manual* (Franzmeier, et al, 2004). Also, see that manual for definitions of soil and landscape terms used herein.

METHODS and RESULTS

The degree of reduction in soils is measured by the redox potential (Eh) which varies over a wide range of values with no natural breaks to form natural classes of Eh. Along this continuum, we need to establish criteria to separate soils that show significant reduction features from those that do not. The criteria below are arbitrary, but are similar to criteria used to make separations in *Soil Taxonomy*.

Reduction depletions are soil features that show evidence of significant loss of iron as recognized by gray colors in >2% of the matrix,or dominantly gray clay films, or both. For most soils, gray colors have value $\geq$4 and chroma $\leq$2, but for sandy soils chroma may be $\leq$3. ***Depth to reduction features (DRD)*** *is the depth below which reduction depletions occur.*

<u>Wet Plain Soils</u>
From previous research and experience, we postulate that reduction features are relatively reliable indicators of water table depth in soils that have light-colored surface horizons (ochric epipedons), are not sandy (sands and loamy sands), have a relatively high water table (soils are poorly or somewhat poorly drained), and are on plains underlain by an aquitard (e.g., dense till, fragipans, etc.). Most of these soils are on slopes ≤3%. These soils are mainly Aqualfs, with some Aquents, and Aquepts according to *Soil Taxonomy*. For brevity we call them Wet Plain Soils.

The first task is to determine the water table (saturation) relations that correspond to DRD in these soils. This procedure is illustrated for the Avonburg soil, a member of this set. We plotted the depth to water table in this soil for a nine-years (Fig. 1, Jenkinson, 1998). From this curve, we determined the percent of time the soil was saturated at various depths (Fig. 2). To do this, for each depth, we measured the time below the curve in Fig. 1, divided by the total time of the study, and multiplied by 100 to get the percent time saturated. Then, from a pedon description, we determined DRD (definition above),

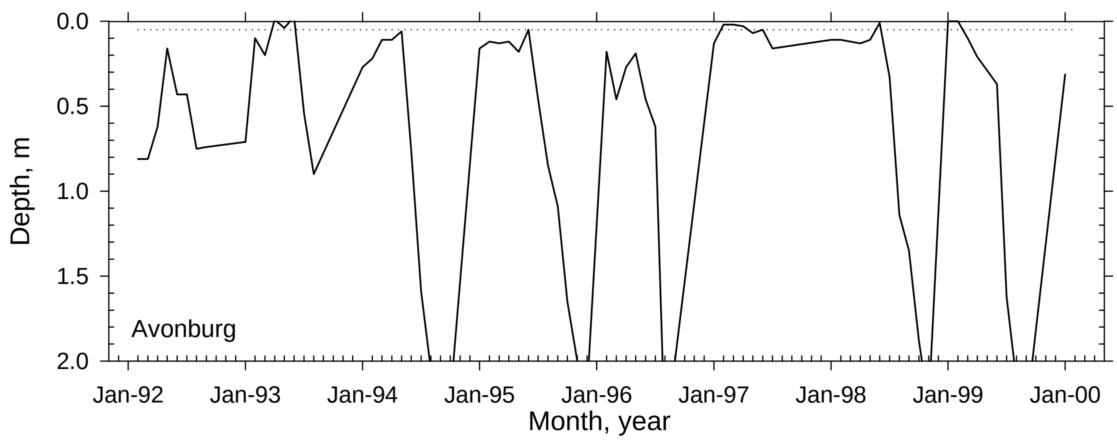
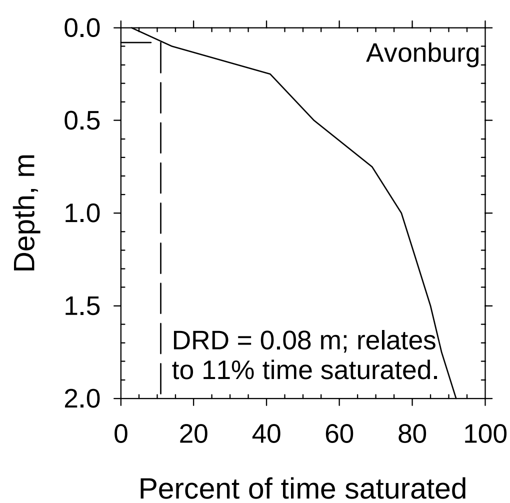


Figure 1 (above). Water table depths in the Avonburg soil.

Figure 2, (right). Percent of time saturated for the Avonburg soil.



represented by the horizontal line in Fig. 2. Where this line intersected the saturation (solid) line, we dropped a vertical line to the X axis to read percent time saturated. In this case the DRD was 8 cm, which corresponds to 11% time saturated. We did this for 11 other soils (Table 1), and learned that, on average, DRD corresponded to saturation 8.3 % of time. From this, we defined DSat8:

DSat8 *is the depth below which the soil is saturated more than 8% of the time.*

We concluded that, on average, it takes about 29 days (0.08 x 365) of saturation to develop significant reduction depletions. The studies referenced did not distinguish between consecutive and cumulative days, but we believe this period is equivalent to the phrase "20 or more consecutive days or 30 or more cumulative days in a normal year" used often in *Soil Taxonomy*. DSat8, in general terms, is the depth to which the water table commonly rises, and it corresponds to what we believe to be the dominant perception of "seasonal high water table." It is possible, however, that with further studies the critical percent of time saturated could be other than 8%, so in the future, the term could become DSat6, Dsat10 or something else.

Bevel Soils

We further postulate that reduction features are less reliable in predicting water table depth in soils on bevels that descend from plains underlain by an aquitard, a layer that holds up the water table. Often the soils on the plain are poorly and somewhat poorly drained and thus qualify as a Wet Plain soils. In some cases, however, upslope soils are better drained, but water still moves downslope over the aquitard. The Bevel Soils are usually well or moderately well drained, but many are seepy in places. They have a relatively high water table but lack reduction features. Some of them have oxyaquic soil moisture regimes according to *Soil Taxonomy*. Fig. 3 is a graph showing the water table depth in the Rossmoyne soil, representative of the Bevel Soils set, and Fig. 4 shows the percent time saturated. DRD is 120 cm, and DSat8 is 15 cm. Thus the limiting condition of DSat8 (the depth to which the water table commonly rises) is 105 cm higher than predicted by soil color (DRD). Data for seven other soils of this set are included in Table 1. For most soils DSat8 is higher in the soil than DRD, but for some it is not.

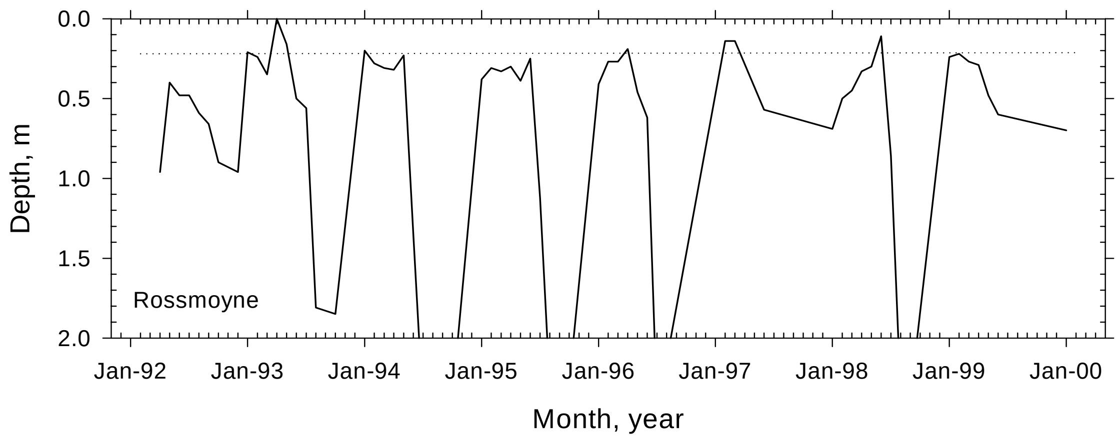
Dark, Wet Soils

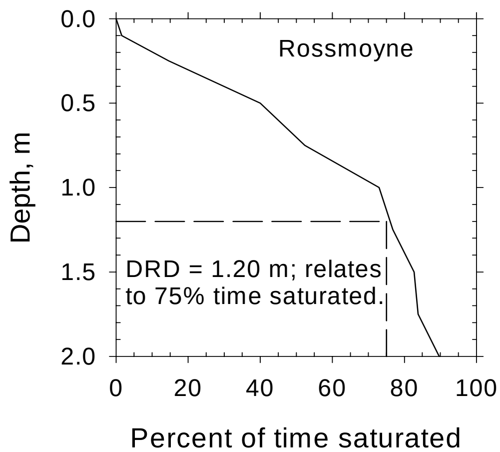
We also postulate that reduction features are also a less reliable indicator of water table depth in soils with deep, dark surface horizons (mollic epipedons: value$\leq$3, chroma $\leq$3, >25 cm thick) overlying subsoils that have gray reduction depletions and are usually dominantly gray. They are mainly poorly drained and are Aquolls in *Soil Taxonomy*. In these soils, the dark color of organic matter masks the gray color of silicate minerals. The Ragsdale soil is an example. Fig. 5 is a graph showing the water table depth in the Ragsdale soil, and Fig. 6 shows the percent time saturated. DRD is 40 cm, and DSat8 is 8 cm. Thus the limiting condition of DSat8 (the depth to which the water table commonly rises) is 32 cm higher than predicted by soil color (DRD). Data for four other soils of this set are included in Table 1. Again, for most soils DSat8 is higher in the soil than DRD.

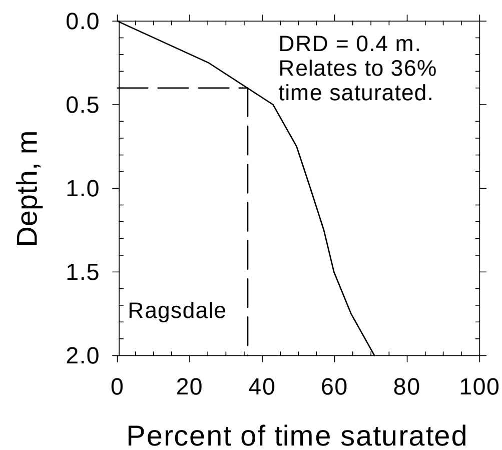
Table 1. Saturation and reduction characteristics o three sets of soils. Data were presented in graphs for the three soils with names in bold font.

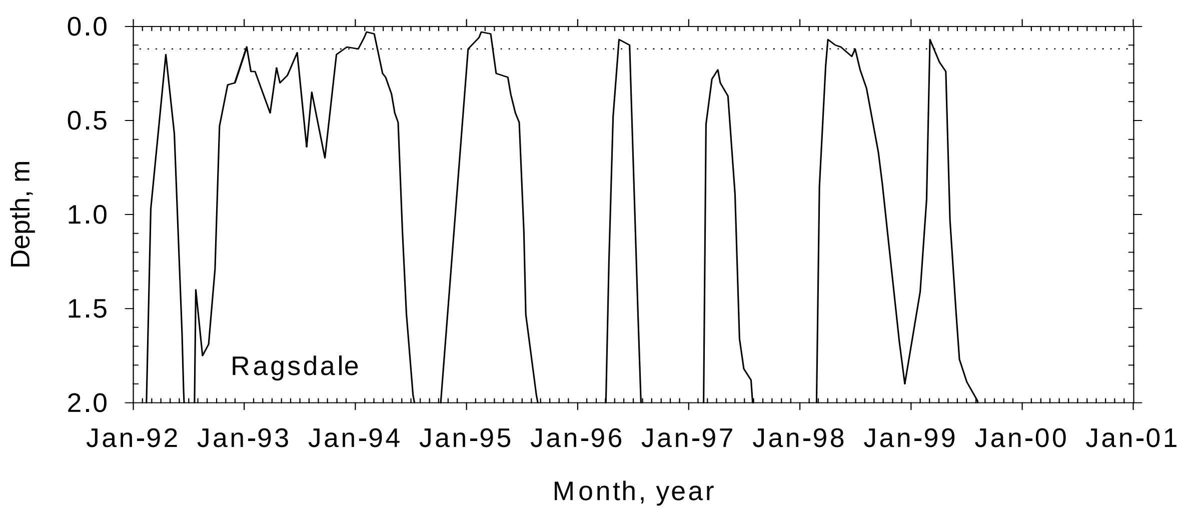
Soil Series	Ref.*	DRD (cm)	% time saturated at DRD	DSat8 (cm)
Wet Plain Soils. Soils with light-colored surface horizons on plains underlain by aquitards.				
Blount	1	13	8	13
Glynwood	1	18	4	25
Clermont	5	5	15	3
Avonburg	5	**8**	**11**	**5**
Delmar	4	7	15	0
Fincastle	4	22	2	40
Fincastle	3	33	10	30
Fincastle I	2	33	15	25
Fincastle II	2	5	0	25
Crosby	3	18	6	25
Hoosierville	1	11	0	23
Iva	1	23	14	8
Average			8.3	
Bevel Soils. Soils on bevels descending from Wet Plains.				
Zanesville	1	66	23	20
Rossmoyne	5	**120**	**75**	**15**
Cincinnati	5	51	4	76
Russell*	4	133	27	66
Russell	3	74	6	95
Miami	2	84	22	50
Celina	2	48	18	28
Strawn	3	61	10	50
Dark-Wet Soils. Wet soils with thick, dark surface horizons.				
Maumee	6	50	38	<0
Newton	6	27	8	30
Ragsdale	4	**40**	**36**	**8**
Montgomery	3	25	55	<0
Treaty	2	30	12	28

*References: 1, Franzmeier et al., 1984; 2, Evans and Franzmeier, 1986 (McCormick's Woods); 3, Evans and Franzmeier, 1986 (Soldiers' Home Woods); 4, Jenkinson et al., 2002; 5, Jenkinson, 1998; 6, Jenkinson, 2002.


Rossmoyne
Depth, m
Month, year
0.0
0.5
1.0
1.5
2.0
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Jan-00


Rossmoyne
DRD = 1.20 m; relates
to 75% time saturated.
Depth, m
Percent of time saturated
0.0
0.5
1.0
1.5
2.0
0
20
40
60
80
100


DRD = 0.4 m.
Relates to 36%
time saturated.
Ragsdale
Depth, m
Percent of time saturated
0.0
0.5
1.0
1.5
2.0
0
20
40
60
80
100


Ragsdale
Depth, m
Month, year
0.0
0.5
1.0
1.5
2.0
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Jan-00
Jan-01

DISCUSSION AND SUGGESTED INTERPRETATIONS

Other Soils

For soils other than Bevel Soils and Dark, Wet Soils, we assume that DRD is a reliable predictor of DSat8. This includes, e. g., soils on hillslope positions with no upslope source of soil water, soils on sand dunes, soils on outwash deposits, and many other soils. Further studies might show, however, that DRD is not reliable for some of these soils.

Comparison among soils

In Figures 1, 3, and 5 the dotted lines represent DSat8. This line is a quantitative representation of the general concept of "the depth to which the water table usually rises." The figures also show that in some years the water table never rises as high as DSat8, and in other years it is above DSat8 for several weeks.

Figure 7 shows a comparison of DRD and DSat8 for the three sets of soils. The area above the 45^o line represents cases in which DRD is greater than DSat8 or, in other words, the limiting condition of periodic saturation is higher in the profile than indicated by gray colors in the profile. In the Rossmoyne soil, for example, DRD (gray color) occurs at 120 cm, but periodic saturation occurs at 15 cm. Designing an onsite sewage disposal system based on wet conditions at 120 cm when they actually occur at 15 cm might lead to a failure of the system. Thus, the area above the 45^o line can be thought of as being *risky* for an onsite system because there is more a chance of system failure. Conversely, the area below the curve can be considered *safer* for a system.

Approximately equal numbers of squares representing Wet Plain Soils are plotted on both sides of the line (Fig. 7). This is largely because data from this set were used to define DSat8. Also, the points are clustered near the line suggesting that this group of soils is more homogeneous and predictable than the other sets.

For the Bevel Soils, however, six of the eight triangles are above the 45^o line, some well above it. These soils have horizons that are saturated much of the time but do not have reduction depletions. Bevel Soils are lower in elevation than the nearby Wet Plain soils. The following is our explanation of these results. Little water moves downward through the wet plains because of the aquitards. Instead, water becomes stagnant, but moves *slowly* across the plain toward the sloping bevels. There it moves more *rapidly* on the steeper slopes and picks up oxygen on the way, so the soils become saturated but do not become anaerobic and thus have no redox depletions. Subsoil water, however, does not flow as a uniform sheet, but rather moves more readily through some avenues than others. These avenues have higher water tables than surrounding parts of the bevel. These different avenues account for the scattering of Bevel Soil points.

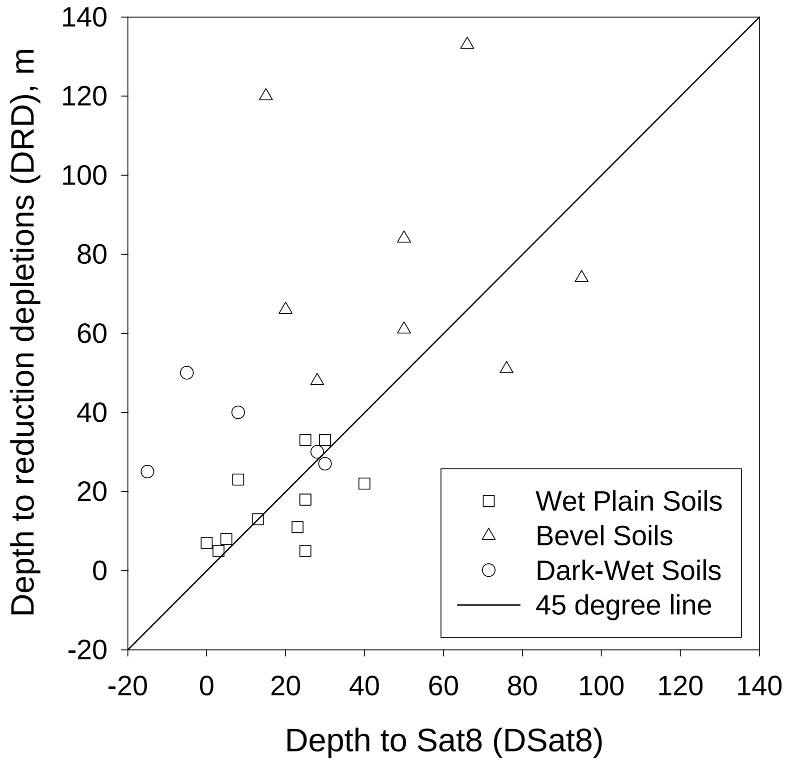


Figure 7. Relation of DRD and DSat8 for the three sets of soils.

Three circles representing Dark, Wet Soils are well above the 45^o line ("risky" area) and two are near the line. For this set, two of the DSat8 values are negative, meaning that the soil was ponded >8% of the time. The depth of ponding, however, was not measured, so negative DSat 8 values were estimated from the shape of the % time saturated curve. It is likely that Fe was reduced and leached from the dark (mollic) horizons of the Dark, Wet Soils, but the gray color of the silicate minerals is masked by the dark color of organic matter.

Implications for Onsite Sewage Disposal

Soil reduction depends mainly on four factors (Franzmeier, et al., 2004 p. 35): 1) saturation with water and depletion of O_2, 2) presence of microorganisms, 3) food for microorganisms, and 4) suitable temperatures. Compared to conditions in a natural soil, conditions in a soil used as an absorption field would favor reduction because 1) the height of saturation rises because of extra water applied as effluent, 2) effluent is rich in microorganisms, 3) effluent is rich in food for microorganisms, and 4) effluent is generally warmer than the native groundwater.

Because of these relationships, any saturated zone in an absorption field will likely become reduced. *Thus, the primary limiting condition should be DSat8 instead of DRD.*

As shown above, DRD is similar to DSat8 for Wet Plain Soils, and it is assumed to be similar for the Other Soil group. Also as shown, using soil color for predicting saturated conditions is often risky for Bevel Soils and Dark, Wet Soils. How, then, should DSat8 be predicted for these two sets of soils? The guidelines proposed below are based on the studies quoted in this paper, and on general principles. They are conservative in that in cases of uncertainty, water table depths are predicted to be *high*. If these soils are to be used for absorbing effluent from a septic tanks, the guideline provide a warning that the water table might be high, so supplementary drainage should be installed to lower the water table level if a system is installed.

Proposed guidelines for estimating DSat8

The suggestions that follow are meant to be guidelines rather than rules for estimating DSat8 and DRD. We have presented the bases for them. They do not cover every possible situation in the field, so soil scientists must use their judgment in applying them.

Wet Plain and Other Soil groups

Use DRD to estimate DSat8.

Dark, Wet Soils.

In similar soils in Minnesota, the thicker and the darker the A horizon, the higher is the water table (Thompson and Bell, 2001). Our observations confirm that this generalization also applies in Indiana. Also, it has also been observed that reddish mottles in the mollic material are associated with wetland vegetation (Hosteter, persona communication, 2004). According to these relations, we suggest the following guidelines:

1) if any A subhorizon has chroma $\leq$1, place DSat 8 at the soil surface.
2) for other soils. if high-chroma (reddish) redox accumulations are described, place DSat8 at the upper boundary of the horizon containing these accumulations.
3) for other soils, place DSat8 half way between the surface and DRD.

Bevel Soils

Several studies have shown that Bevel Soils underlain by an aquitard often have water tables almost as high as Wet Plain Soils even though gray colors are relatively deep in the Bevel Soils (see references in Table 1). For these soils, the suggested guidelines are:

1) if soils upslope from the site are mainly poorly or somewhat poorly drained, place DSat8 at a depth of 12 to 18 inches.
2) if soils upslope from the site are moderately well or better drained, place DSat8 12 inches above the aquitard (limiting layer).

Testing Guidelines

These guidelines are based on the research quoted and on our observations. They are conservative and, if used, should result in fewer onsite system failures. In an effort to make the interpretation of soil and landscape evaluation reports more accurate and more consistent among different soil scientists, we propose that these guidelines be followed unless it can be documented that they do not apply to a particular situation.

We also realize that the guidelines can be improved. Therefore, we suggest that soil scientists test these guidelines, and the one mentioned earlier that in sandy soils reduction depletions are recognized by chroma ≤ 3 (instead of ≤ 2),and that they suggest changes to them based on their data and observations.

Applications to Permits and Design

We propose that the quantitatively defined terms DSat8 and DRD be reported on soil evaluation reports instead of the more ambiguous "seasonal high water table." We further recommend that future rules that deal with onsite permits and design refer to these two terms. Until the rules are changed, however, SHWT should be interpreted as DSat8 or DRD, *whichever is highest in the soil profile.*

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