

Synoptic Literature Review of Shallow Groundwater Related to On-Site Septic Systems

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EXECUTIVE SUMMARY

The ability to predict the occurrence of shallow groundwater is the principal question dealt with in this review. Soil colors and mottling patterns have been the classic predictor for many years. The reliability of this indicator for evaluating soil suitability for on-site systems, however, is in question.

Mottles take time to form, and for the most part the period required for their formation far exceeds any reasonable safety factor for consideration of groundwater impacts on on-site sewage facilities (OSSFs). When identified, mottles are a very reliable indication of seasonal wetness. But their absence does not imply the lack of a seasonal water table. Mottles in some soils take months to form, and there are many soils with long-duration seasonal wetness with no mottles or other color indication of that wetness.

More robust indicators must be developed if on-site evaluation of shallow groundwater is to be effective. Climate, landscape position, and internal soil morphology could be used to develop regional models for the occurrence of unsuitably wet soils. The advent of Geographic Information Systems and digital topographic data enable the development of cost-effective and reliable maps that could be used on a county level. The data for developing simple but effective models is available, and equivalent models have been developed in other parts of the country. More refined and precise models could be developed by quantifying soil-water-landscape relationships at a few key sites across the state. Maps of unsuitable soils, while subject to significant error, would be considerably more consistent and accurate and much less contentious than the present system which involves professional judgements that are often difficult even for the most experienced soil scientists, let alone the majority of those who must make such judgements without equivalent training.

INTRODUCTION

“The presence of groundwater shall be determined by a site evaluator.”¹ This cut and dried statement, the sum total of the regulatory mandate, belies the complexity inherent in predicting the occurrence of groundwater at an on-site sewage facility (OSSF). There is just no simple way to make a reliable prediction at any one site. And yet the presence of groundwater, even if only seasonal, must be assessed with some degree of reliability to insure public safety. Raw sewage that passes through saturated soil is not completely treated, and thus the potential for public exposure is great when this sewage passes from saturated soils directly to the surface or into groundwater (Reuter et al., 1998; Bicki and Brown, 1990; Harris, 1996).

Although not stated in the regulations, the common assumption is that soil color or drainage mottles can be used as reliable indicators of seasonal wetness. This report will review that supposition and its weaknesses, and explore additional factors that can be used to predict seasonal soil wetness. This review is not intended to be an in-depth review of soil hydrology; rather it looks at those factors of most interest for on-site evaluations of unsuitable soils with respect to shallow groundwater. “Unsuitable” in this review means that the soil cannot accept untreated sewage without a properly engineered design. In addition, we look at the movement and survival of pathogens in saturated soils.

Few people have problems recognizing marshes or other wetlands with near-permanent wetness. By the same token, soils in the dry West Texas deserts are seldom mistakenly identified as wet soils. But *seasonal* wetness is much harder to recognize, and is at the root of our problems in the on-site evaluation of groundwater. Because we usually only have opportunity to view a site within a narrow window of time, we must make inferences about the presence of a water table if we do not observe one while on site, and while there are some very powerful tools available to help us make these inferences, we have to recognize that inferences automatically lead to errors. The only absolutely positive way to assess the risk of groundwater in areas of seasonal wetness would be to make on-site measurements over at least a 5-year period, a luxury no one

¹ TAC§285.30(f)

can afford. Because we are going to make some mistakes, we need to understand what kinds of errors are inherent in on-site evaluation, so that we can learn to minimize those errors that are most harmful to the public health.

WETLANDS, HYDRIC SOILS, AND SOIL EVALUATION FOR OSSFs.

Most of the literature dealing with indicators of soil wetness has been associated with wetlands, especially in the last 15 years. Soils that meet wetland criteria are referred to as hydric soils. Hydric soils cannot be directly correlated with unsuitable soils for OSSFs. All hydric soils are definitely unsuitable with respect to soil saturation, but not all soils that are too wet for standard OSSFs are hydric soils. Hydric soils require at least a two-week saturation and reduction period to be considered hydric (Environmental Laboratory, 1987). So while we must rely on the wetland literature for much of what we know about soil color patterns and drainage status, it is important to recognize the key differences between hydric soils and unsuitably wet soils with respect to OSSFs, differences that are primarily related to the duration of wetness.

THE FORMATION OF SOIL DRAINAGE COLORS.

Some terms need to be defined at the outset. A soil is **saturated** when all of its pores are filled with water. A saturated soil may eventually become **anaerobic**, that is, lacking in oxygen, and may then become **reduced** with respect to particular chemical species. The **redox potential** is a measure of how reduced a soil is, expressed in voltage units as **Eh**. A soil is unsuitable when it is saturated, irrespective of whether it becomes reduced or not.

Groundwater is the saturated portion below the capillary fringe and the top of the groundwater is the **water table**. The **capillary fringe** is located above the water table. The capillary fringe is saturated but the water is held in place by capillary forces and cannot be measured with piezometers.

Soil color is described in terms of the matrix or background colors (Soil Survey Staff, 1993). Iron stains on this background are referred to as **mottles**, or the newer term “**redoximorphic concentrations**”. In this review, we use the older term “mottles”, and refer the reader to Vepraskas (1994) for more details on the newer terminology.

Iron is the primary coloring agent in mineral soils². Iron has two redox states: oxidized or ferric, and reduced or ferrous. Iron in a well drained soil tends to be in an oxidized state, while iron in a waterlogged or poorly drained soil tends to be reduced or ferrous. Oxidized iron is usually red or yellow, whereas reduced iron is usually gray or black. Colors are quantified with the Munsell soil color charts (1994 Revised Edition. Munsell Corp. 617 Little Britain Road New Windsor, NY 12553-6148.: 800-622-2384). Colors on these charts with chromas of 2 or less are considered to be gray.

At least in principal, then, the color of a mineral soil should be a good predictor of its drainage status, with reddish soils being well drained, and gray soils poorly drained. This is indeed the basic model, and in general works well, but requires many exceptions and caveats in order to be used as a predictive model for our purposes. In spite of these caveats, gray soils should always be viewed with caution, and assumed to be unsuitable until proven otherwise.

Iron mottles form in soils because of redox heterogeneity within the soil. Soils with seasonal wetness in particular will have considerable variability on a microsite scale within the soil (Dobermann and Mutscher, 1989). As the soil wets, for example, significant areas will lag as dry zones, and as a soil dries, large patches may remain wet for extended periods. Few seasonally wet soils will be either all reddish or all gray, but will have significant mottling or staining reflective of the variation in drainage and redox status in the soil. One might thus observe reddish soils with gray mottles, or gray soils with reddish mottles. Most of the remaining discussion on drainage colors will focus on mottles, but the reader is advised that the same principles apply to soils with gray matrix colors, or other redoximorphic features³.

A reddish mottle of oxidized iron is a still sign of saturation and reduction because iron cannot concentrate as a mottle unless it first goes through a reduced phase. This is because oxidized or ferric iron is a solid in the pH range of most soils, and is therefore not mobile (Sposito, 1989). Ferrous or reduced iron is mobile in the soil solution, and

² Calcium carbonate, other salts, and organic matter can mask the color of iron in soils. Very little iron is required to color a soil, often less than 1 percent.

³ Nodules, concretions, and depletion zones are the other principal redox features found in soils. Vepraskas (1994) provides a good review of all the features.

when it comes in contact with oxidized zones, it will precipitate out as the solid oxidized form, creating a mottle.

Saturation alone is not sufficient to change oxidized iron to reduced iron. The process of reduction in soils is a sequential one, where all of the oxygen must be removed before other elements are reduced (Maussbach and Richardson, 1994). The reduction process is microbially driven, and follows the sequence outlined in Table 1.

Table 1.Reduction Sequence for Common Soil Solutes at pH 7.

Reaction	E_h
$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$	0.816V
$NO_3^- + 2H^+ + 2e^- \rightarrow NO_2^- + H_2O$	0.421V
$MnO_2 + 4H^+ + 2e^- \rightarrow Mn^{2+} + 2H_2O$	0.396V
$Fe(OH)_3 + 3H^+ + e^- \rightarrow Fe^{2+} + 3H_2O$	-0.182V
$SO_4^{2-} + 10H^+ + 8e^- \rightarrow H_2S + 4H_2O$	-0.215V
$CO_2 + 8H^+ + 8e^- \rightarrow CH_4 + 2H_2O$	-0.244

From Schlesinger, 1991.

PROBLEMS WITH MOTTLES AS PREDICTORS.

Time.

Time required for formation is the first and most fundamental problem associated with soil mottles. In one sense, time itself is not really a factor – it is the *summation* of all of the other factors, which interact in varying degrees to retard or accelerate the formation of mottles. Because these factors are all interrelated, one cannot ascribe a discrete time function to any single variable. Likewise, it is not possible to ascribe either frequency or duration of hydrologic events to mottle character (i.e., thickness, percent cover, prominence, etc), other than that the more prominent and thick any given mottle is, the longer the saturation and reduction period is relative to other similar soils.

The length of saturation and reduction required to form an iron mottle varies widely in the literature, with periods ranging from at least 1 week under the most optimal conditions (Vepraskas et al., 1995) to over four months continuous saturation and reduction (see under Redox Potential, below). Even if all mottles formed in the minimum time period of a week or two, soil drainage mottles would still not be fully

reliable indicators of wetness problems with respect to on-site systems. What about soils wet for more than a day or two, but less than 2 weeks?

It was not the purpose of this review to establish the minimum time a soil needs to be saturated before it is unsuitable, but one week of soil saturation clearly seems to be too long⁴. And there are many, many soils where much longer periods of saturation and reduction are required to form observable mottles. When present, mottles *may* be good indicators of soil saturation, but the *lack* of mottling does *not* imply the lack of saturation that may impact an on-site system. Over reliance on mottling as the sole indicator of soil wetness can result in the danger of falsely identifying a soil as suitable when in fact it experiences significant periods of wetness.

Amount of Iron.

It is a simple truism to state that lack of iron will result in the lack of iron mottling, but this simple fact is often overlooked. The review of the literature did not uncover any minimal values of free iron that might be required.

On the other hand, red soils with abundant iron often pose some special problems with respect to formation of mottles or gray matrix colors. Mokma and Sprecher (1994b) found that the red soils with abundant hematite they studied in Michigan were not as gray as would have been predicted.

Amount and State of Organic Matter.

The reduction process is microbially mediated. Without a source of carbon, microbes are ineffective, and the reduction process requires orders of magnitude increases in time for iron reduction. Daniels and Buol (1992) found it necessary to have 10 mg/l of dissolved organic carbon in solution for reduction to occur, while Vepraskas and others (1995) found that redox features did not form in soils with less than 1.5% organic matter.

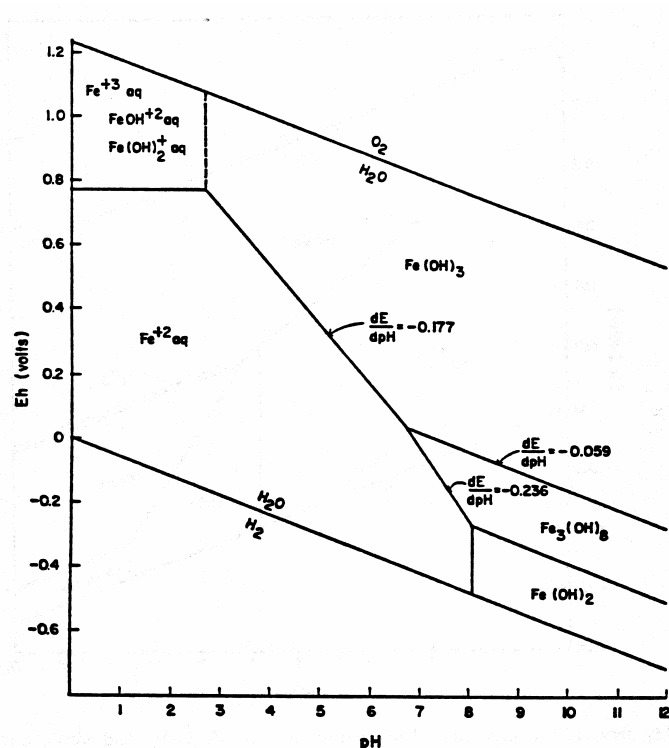
Some soils have more than sufficient carbon in soil organic matter (SOM), but the SOM may be bound so tightly to clay that it is not available as a microbial energy source.

⁴ This assumes one week of saturation *after* the end of a rainfall or flooding event.

This is particularly true of many of the very clayey wet Vertisols that make up much of the Gulf Coastal plain (Jacob et al. 1997).

Redox Potential and pH.

Iron cannot be reduced unless the redox potential is low enough. As is evident in Table 1, the reduction process is a sequential one, and one species is not generally reduced until all of the species with higher redox potential are reduced. Thus, iron will not be reduced in a soil until all of the O_2 , NO_3^- , and Mn^{2+} species are reduced. This is a very significant fact because it means that a soil could remain saturated for long periods of time without ever having a redox potential low enough to reduce iron. Abundant nitrate,



for example, could buffer Eh at a high enough level that iron would not be reduced.

pH is a corollary factor to the redox potential. Figure 1 shows the relationship between Eh and pH. The slope of the lines in this figure indicate that higher pH soils will require a lower Eh than a lower pH soil to reduce iron, all other things being equal. This means that an alkaline soil will require a much longer saturation and reduction period to form mottles than a correspondingly lower pH soil. Tentative results from high pH red soils

on the Lower Brazos bottom, for example, suggest that up to four to six months saturation may be required before observable mottles form (Wes Miller, NRCS hydric soil specialist, personal communication).

THE QUESTION OF MOTTLE CONTEMPORANEITY

Once a mottle forms, how long does it last? Available evidence suggests that if thick enough, mottles could last many thousands of years in some soils, given the right conditions and lack of bioturbation or other disturbances.

We are obviously not interested in whether a soil was saturated in the distant past. We want to know the state of the soil today: is it wet enough now to be considered unsuitable with respect to a standard on-site septic system?

Many of the soil surfaces along the Texas Gulf Coast are extremely ancient. Outside of the floodplains, the vast majority of the surfaces there are in excess of 30,000 years in age (McGowen et al., 1976). The potential for ancient or relic mottles not related to current wetness conditions is clearly very high, and relic mottling features in the soils of this area are well documented (Tucker et al., 1994).

There are at least two important considerations here. The first is that most of the areas where relic mottling has been identified are in soils that underlie some very flat surfaces that by definition are very poorly drained, particularly on the upper coast. So even if some mottles can be positively identified as relic in these soils, it is still very likely that wetness is a problem, given the topography of the area. It is important to remember these mottles have been identified as relic with respect to wetland hydrology, not suitability for an OSSF.

Second, any mottles identified in the near surface, i.e., the upper 10–15 inches, can automatically be assumed to be contemporaneous, even in a soil of great age, because bioturbation turns the surface soil over periodically.

Much research has gone into determining which mottling patterns are relic and which are contemporaneous. The reader is referred to Vepraskas (1994) and Hurt et al. (1998) for an excellent review of mottling patterns and their significance. In general, mottles that are associated with active surfaces in the soil can be considered to be

contemporaneous. Thus, oxidized iron linings on soil structural faces or along soil pores can generally be considered recent, whereas masses not associated with any current surface may often be regarded as relic. Richardson and Daniels (1993) review the significance of various redoximorphic patterns in soils in terms of the duration and frequency of saturation and reduction events.

For the purposes of soil suitability for OSSFs, all mottles should probably be considered contemporaneous until proven otherwise. Following this logic, it is possible that some dry sites could be identified as wet, but the implications of this error are much less than the opposite error, identifying wet sites as dry (see below).

SUMMARY ON USE OF MOTTLES AS WETNESS INDICATORS.

Mottles, if not relic, are an excellent indicator of soil wetness conditions.

Contemporaneous mottling can be relied upon almost absolutely as indicators of seasonal wetness. And because most relic mottles occur in level-sloped soils of great age, their relic nature can to a certain extent be ignored⁵.

Because soil drainage mottles are such good indicators of soil wetness, it is natural to assume that their absence implies a lack of soil wetness. This assumption is the most dangerous aspect of using mottles as sole indicators. Drainage mottles take time to form, and we miss a great many wet soils if we rely on mottles alone. Many studies have demonstrated the existence of soils with significant wetness periods that do not exhibit concomitant gray colors or mottling patterns (Evans and Franzmeier, 1986; Griffin et al., 1992; James and Fenton, 1993; Mokma and Sprecher, 1994a; Pettry et al., 1995; Pickering and Veneman, 1984; Simonson and Boersma, 1972; Vepraskas et al., 1999; Wakely et al., 1996).

Because the use of mottles in on-site investigations is going to identify only the wettest soils, the presence of mottling and/or gray matrix colors clearly do not constitute a safe threshold for identification of unsuitable soils. Table 1 shows the expected utility of a given prediction for given states of wetness. Identifying a dry site as wet has some

⁵ Care would have to be exercised in attributing soil wetness to the *depth* at which the relic mottles occurred. While it is true that relic mottles are in a great many cases associated with level surfaces that experience saturation, the saturation may or may not occur at the level of the relic mottling.

negative utility, mainly the inconvenience imposed upon the owner who must unnecessarily invest in an engineered system, but the error associated with misidentifying a wet site as dry has much graver implications in that raw sewage could potentially surface or enter groundwater. We must of course strive to eliminate all errors, but minimizing one of the errors in Table 1 will tend to maximize the other error. It should be obvious where we should concentrate our efforts at error minimization. Over-reliance on soil mottling will maximize the error in the upper right hand quadrant, the worst possible error for public safety.

Table 2. Expected utility for false and correct predictions

		<u>Predicted State</u>	
		WET	DRY
Actual State	WET	+	-
	DRY	-	+

Key: + positive result, - negative results.
Shaded areas are zones of error.

OTHER INDICATORS OF SOIL WETNESS

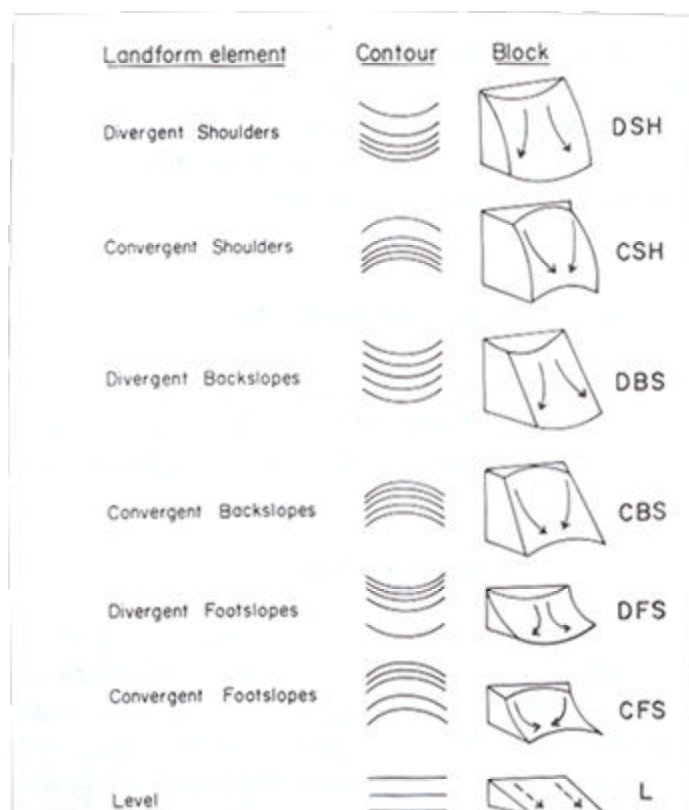
If mottles are not sufficiently precise indicators of soil wetness, what else is left? It turns out that no other single indicator can be used in isolation reliably, but there are several indicators that when used as a package could provide powerful predictive abilities. These indicators include climate, and landscape position, internal soil morphology other than mottles, and soil surveys.

CLIMATE AND LANDSCAPE

Wetter soils occur in wetter climates and in wetter landscape positions. A simple truism, but one that could be built into a powerful predictive model. We intuitively know that wet soils will only occur in the wettest, most concave parts of the landscape in West Texas, but that unsuitably wet soils can occur in many more areas in East Texas. The question

is whether or not this intuition can be quantified into a model usable in a regulatory context.

Considerable research has gone into building predictive models of soil water states based on landscape position (e.g., Moore et al., 1991, 1993; Thompson et al., 1997; Bell et al., 1994; Dietrich et al., 1992; and Zheng et al. 1996), and the relationship between topographic or landscape elements and soil drainage is well established. Landscape elements have been fairly well quantified (e.g., Hall and Olson, 1991 and Fig. 2). Landscapes can be conceptually divided into water gathering or water shedding



positions. Areas of convergent flow are water

Figure 2. Slope shapes and water convergence/divergence from Hall and Olson, 1991.

gathering positions and are obviously going to be zones of high probability for seasonal soil saturation (e.g., Khan and Fenton, 1994), at least in climates ranging from sub-humid to humid.

The availability of Geographic Information Systems (GIS) and Digital Elevation Models (DEMs) has opened up interesting new possibilities for developing large-scale drainage status maps. 30-m DEMs are available for the entire state of Texas, with 10-m resolution in the works (<http://www.tnris.state.tx.us/DigitalData/DEMs/dems.htm>). Zheng et al. (1996) developed a powerful predictive large-scale map with digital elevation data using a topographic index that combined upslope or drainage area and slope angle for each pixel. Bell et al. (1994) used a GIS combined with a soil landscape model to develop a landscape map of soil drainage classes on a watershed scale. These examples clearly demonstrate the feasibility of developing such models rather cheaply on a wide scale for mapping unsuitable soils for on-site septic systems. No intensive data would be required to develop initial maps for specific regions in Texas, but some intensive data would be needed in a few locations across the state to help quantify landscape and climate interactions.

In the absence of digital models and maps, it is still possible to intuitively develop some coarse but robust models. We know for example that flat areas on the Upper Gulf Coast are subject to seasonal saturation. It is not necessary to see soil mottling to be assured of this fact. (In fact, many of the highly alkaline soils on the Gulf Coast will not form mottles even with extended periods of saturation (see Jacob et al., 1997)).

We could probably extend this observation to say that flat surfaces east of I-35 and I-37 will be saturated in most years. Certainly some sloping areas in East Texas will also be saturated. In my experience, planar slopes of up to 3-4% will also be unsuitable in most areas east of I-45. Areas of convergent flow are probably unsuitably wet much farther to the west of I-35. There is probably sufficient local expertise between soil surveyors and on-site evaluators to develop some initial rough models that would take care of at least the very wettest areas. Site-specific, intensive studies could help quantify these relationships.

INTERNAL SOIL MORPHOLOGY – CLAY PANS

Internal soil morphology, apart from soil mottling, can also be used as a powerful predictive tool. This morphology includes texture, structure, and restrictive layers. The effects of texture and structure are covered elsewhere- clays impede drainage, texture

may improve it. Claypans are one important hydrologic feature, however, that are not well recognized in the on-site community.

Clay pans are an abrupt change in texture from an overlying to an underlying layer. Quite simply, the clay slows infiltrating water to such an extent that it stands on the clay pan. Saturated conditions frequently occur over clay pans; how thick the saturated layer is and how often it forms depends on the local climate, landscape position (amount of receiving water), depth of the overlying horizon, and amount of clay in the clay pan.

The clay pan is recognized taxonomically as an abrupt texture change (ATC) (Soil Survey Staff, 1998), and is also recognized in the on-site evaluation regulations as a restrictive layer [TAC§285.30(e)]. The ATC is not precisely defined in the regulations other than the implication that it is a clayey subsoil. The definition in Soil Taxonomy is much more precise: if the clay content of the overlying horizon is less than 20%, then the clay content must double within 3 inches or less; if the clay content of the overlying material is greater than 20%, then there must be an absolute increase in clay content of 20% within 3 inches.

From the Soil Taxonomy definition, it is possible to have an ATC even with a loamy subsoil. In the right climate and landscape position, even a loamy “clay” pan can have a profound hydrologic impact, by backing up water and creating saturated conditions.

Consider the following profile: 50 inches of loamy sand over a clay loam, with no mottling, in East Texas. Most site evaluators would automatically classify this as a suitable soil. But this soil will definitely stand water over the clay loam, well above 50 inches, certainly within less than 2 feet below any standard trench. Clay pans clearly need greater attention from site evaluators.

SOIL SURVEYS

Soil surveys cover most of the state and are woefully underutilized by the site evaluator. The soil surveys were never intended for detailed site-specific studies, but they have a wealth of information on specific soils, and are precise enough to make some first approximations with respect to on-site evaluations.

Specific water table information is usually provided for every soil in a published soil survey. Detailed studies were performed in only a few cases in the development of this information, and so while some of it may be unreliable, it is still an excellent database for referral, and will at least give a credible ranking of local soils in terms of wetness, and the seasonality of the wetness.

Soil series are based on Soil Taxonomy (Soil Survey Staff, 1998). The elements of interest from the point of view of shallow groundwater evaluation are “aquic conditions” and the “aquic moisture regime”. Aquic conditions refer to “continuous or periodic saturation and reduction”. An aquic moisture regime is a “reducing regime that is free of dissolved oxygen.” Neither of these elements specifies a time period, but the aquic moisture regime obviously implies a sufficient period to attain reducing conditions. Any time the formative element “aquic” is used in a taxonomic name of a soil series, wetness is a significant problem. For example, *Vertic Albaqualf* has the “aqu” element at the suborder level, while ***Aquic Udifluvent*** has the formative element at the subgroup level. Whatever level it occurs at should raise a red flag for the site evaluator. As with the definition of hydric soils, the aquic component is not all encompassing for unsuitable soils with respect to an OSSF. All soils with an aquic component are unsuitable, but there may be some unsuitably wet soils that are not considered aquic. The aquic taxa, however, are probably more closely matched with unsuitable soils than hydric soils. In terms of the minimum wetness, hydric is wetter than aquic which is wetter than OSSF unsuitable.

One possible regulatory alternative is to make any soil mapped with any aquic qualifiers as unsuitable by default. A variance could be obtained, but only if documented by a certified professional soil scientist. An examination of the Harris County Soil Survey (Soil Survey Staff, 1976) reveals that 84% of the county would be considered unsuitable with respect to moisture by this method, a figure not at all unreasonable given what we know about the flat, wet landscapes of the Upper Gulf Coast.

PUTTING IT ALL TOGETHER: Summary and Recommendations

We have some excellent tools available for evaluating shallow water tables, but none are reliable enough to stand alone. Soil mottles are good indicators as far as they go, but have some serious limitations for recognizing soils on the drier end. Climate and landscape are powerful predictors, but would require intensive data acquisition by themselves to be powerful models. Clay pans and other internal soil morphologies provide important information, but are very limited as stand alone factors. Soil surveys have a wealth of information, but their use must be tempered with the knowledge that most of the information is not site specific.

This review should make clear that the site evaluator must use a robust procedure when making soil and site evaluations with respect to groundwater. H/She must use all the tools at their disposal to put together a reasonably accurate picture of soil wetness conditions. A highly trained professional earth scientist can use the available tools with a great deal of reliability. The vast majority of those called upon to determine soil suitability, however, do not have this kind of training, and the reliability of the evaluations is sometimes questionable. We are increasingly aware of county-level disputes over regulatory determinations that are perceived as arbitrary. A more consistent system is urgently needed.

The advent of inexpensive geographic information systems that can be run on desktop computers makes possible the development of comprehensive models and maps with real predictive power. Just using existing data [soil surveys (soils with clay pans, soils with aquic conditions), digital elevation models (to quantify slope shapes), floodplains, and climate], maps could be developed immediately that would be a great improvement over the current situation. A county-level map of unsuitable sites would make locating an OSSF on the map the most difficult part of site evaluation. Because even the most accurate maps are subject to some error, a mechanism for variances would need to be established. We propose that such variances only be granted upon the endorsement of a certified professional soil scientist or equivalent professional. A program to develop a pilot county map should be undertaken immediately.

Installation of soil monitoring sites at selected locations across the state would allow for more quantitative assessments of the relationships of soil wetness to specific landscape positions in specific climatic zones. This kind of quantitative information would allow for very precise models at a relatively low cost, and should be considered immediately for densely populated areas with high densities of OSSFs.

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