

# Technical Memo



**To:** Forrest Kelley & Luke Martinkosky, Capitol Region Watershed District

**From:** Todd Shoemaker, PE (MN, IA), CFM  
Eric Osterdyk, EIT

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**Subject:** Soil Compaction and Runoff Volume Study

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## Introduction

Capitol Region Watershed District (CRWD) requested Wenck study the relationship between soil compaction from construction and stormwater runoff volume. The goal of this study is to ensure that permit applicants correctly account for the impacts of soil compaction in their stormwater calculations, which are used by applicants to demonstrate compliance with CRWD rules.

It is widely accepted that construction activity increases soil compaction, which can then increase runoff rate and volume. However, the degree of soil compaction and increase in runoff is not as widely understood. Some cities and watershed districts in the Twin Cities require applicants to increase curve numbers from existing to proposed conditions to account for increased runoff volume due to soil compaction. However, there is minimal literature to justify the magnitude of that increase.

The sections below summarize how soil compaction is considered in the *Minnesota Stormwater Manual (MSM)*, detail United States Department of Agriculture (USDA) software to quantify the effect of compaction on saturated hydraulic conductivity and offer recommendations for permit applicants.

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## Soil Compaction Considerations in the *Minnesota Stormwater Manual*

The *MSM* considers compaction in terms of a soil's bulk density. Bulk density is the weight of a soil divided by its volume. This volume includes the volume of soil particles and volume of pores among soil particles. Bulk density is typically expressed in grams per cubic centimeter ( $\text{g/cm}^3$ ) or pounds per cubic foot ( $\text{lb/ft}^3$ ).

The *MSM* lists typical surface bulk densities for undisturbed soil types. Much of CRWD is comprised of sandy soils, which have a bulk density range in the *MSM* of  $1.1\text{--}1.4 \text{ g/cm}^3$ . As soils are compacted, porosity decreases, and bulk density increases. The *MSM* lists a range of increase in bulk density due to construction activity of  $0.17$  to  $0.4 \text{ g/cm}^3$ . When applied to sandy soils, the average increase in bulk density due to construction is approximately 22% (Table 1).

**Table 1. Percent Increase in Soil Compaction from Construction Compaction.**

Soil Status	Bulk Density (g/cm <sup>3</sup> )		Percent Increase		
	Low Range	High Range	Low Range	High Range	Average
Uncompacted Sandy Soils	1.10	1.40	N/A	N/A	N/A
Construction Activity	1.27	1.80	15%	31%	22%

In our research for this study, however, there is no peer-reviewed or commonly accepted guidelines that correlate the increase in bulk density to an increase in runoff. Therefore, we shifted our focus to how the soil infiltration rate may change due to construction compaction.

### **Compaction, Soil Infiltration Rate, and Curve Number**

In this section, we will use the term “saturated hydraulic conductivity” to refer to water moving in the soil profile vertically *and* laterally under saturated conditions.

One of the most common runoff calculation methods is the Natural Resources Conservation Service (NRCS) Curve Number method. It uses relatively simple equations to calculate the approximate amount of runoff from a rainfall event in an area. Curve numbers range from 30 to 100 with larger numbers indicating a larger runoff potential. The lower the curve number, the more permeable the soil is. Curve numbers are assigned based on soil properties and then classified by Hydrologic Soil Group (HSG, A through D). HSG A represents a lower curve number (less runoff) and HSG D a higher curve number (more runoff).

As soils are compacted, bulk density increases thereby decreasing soil porosity. Porosity is important because it governs the soil’s capacity to hold water, infiltrate runoff, and allow roots to penetrate. As porosity decreases, saturated hydraulic conductivity decreases thereby increasing surface runoff. Therefore, it is advantageous to correlate a change in bulk density and saturated hydraulic conductivity to a change in curve number.

Saxton and Rawls (2006) developed equations, derived from correlations of a 1,722-sample dataset, to predict soil-water characteristics based on soil texture and structure. The USDA Agricultural Research Service used these equations to create the *Soil Water Characteristics Calculator* (Calculator) that predicts soil-water characteristics based on changes to organic matter, salinity, gravel, compaction, and moisture content. Wenck used the Calculator to determine the change in saturated hydraulic conductivity caused by compaction and a reduction in percent organic matter. We then compared the new/reduced saturated hydraulic conductivity to HSG classification to assign a new/compacted Curve Number.

Wenck used the Calculator default values to obtain the “pre-compaction” saturated hydraulic conductivity for twelve different soil textures. We then determined the appropriate HSG by comparing Calculator saturated hydraulic conductivity values to ranges provided in the *National Engineering Handbook* (Figure 1; NRCS, 2007). The *Handbook* makes a distinction between soils that have water-impermeable layers at depths less than and greater than 40 inches; we chose values for water-impermeable soil layers greater than 40 inches because it is more representative of CRWD.

**Table 7-2** Criteria for assignment of hydrologic soil groups when any water impermeable layer exists at a depth greater than 100 centimeters [40 inches]

Soil property	Hydrologic soil group A	Hydrologic soil group B	Hydrologic soil group C	Hydrologic soil group D
Saturated hydraulic conductivity of the least transmissive layer	>10 $\mu\text{m/s}$ (>1.42 in/h)	$\leq 10.0$ to >4.0 $\mu\text{m/s}$ ( $\leq 1.42$ to >57 in/h)	$\leq 4.0$ to >0.40 $\mu\text{m/s}$ ( $\leq 0.57$ to >0.06 in/h)	$\leq 0.40$ $\mu\text{m/s}$ ( $\leq 0.06$ in/h)
	and	and	and	and/or
Depth to water impermeable layer	>100 cm [>40 in]	>100 cm [>40 in]	>100 cm [>40 in]	>100 cm [>40 in]
	and	and	and	and/or
Depth to high water table	>100 cm [>40 in]	>100 cm [>40 in]	>100 cm [>40 in]	>100 cm [>40 in]

**Figure 1. Hydrologic Soil Group assignment parameters. Note the “typo” under the HSG B column; it should be 0.57 in/h, not 57 in/h. (Source: NRCS, 2007)**

Wenck then evaluated how the saturated hydraulic conductivity changes due to construction activity (“post-construction”). For each of the twelve soil textures, we changed the compaction setting in the Calculator from “normal” to “dense” and the organic matter from 2.5% to 0.5%. As previously noted, there is minimal literature available relating soil density to conductivity, so the compaction setting is an empirical adjustment factor using qualitative terminology: “loose, normal, dense, hard and severe.” We chose to simulate a moderate increase in compaction by going from normal to dense conditions.

Topsoil contains most of the organic matter in a soil profile, often evident by darker soil with lower value and chroma numbers. Therefore, a discussion of topsoil disturbance and handling is necessary to understand the reduction in organic matter.

Wenck reduced the organic matter from 2.5% to 0.5% to account for the reduction of organic matter due to disturbance from common construction practices. Many projects within CRWD involve stripping, stockpiling, and replacing topsoil in addition to surface grading. Each of these construction activities contribute to the overall reduction in organic matter. Topsoil stripping reduces organic matter because a portion of the topsoil is lost during transportation. Depending on the project, topsoil stockpiles may remain inactive for more than a year. Organic carbon levels in stockpiles have been shown to decrease as much as thirty percent possibly due, in part, to environmental extremes such as drying, higher temperatures and freeze-thaw conditions (Visser and others 1984).

The 2% reduction is merely an assumption based on knowledge and expertise of physical, chemical and biological soil processes during the construction activities. Field verification is necessary to precisely account for the organic matter reduction.

Table 2 summarizes our analysis and findings. It lists soil textures, infiltration rates, and HSGs from the *MSM* adjacent to the findings from the Calculator. For example, a sandy loam soil is considered HSG A by the *MSM* and the Calculator in an uncompacted condition. Following construction, however, the Calculator indicates the sandy loam will generate runoff like an HSG B soil.

**Table 2. Comparison of *MSM* HSG and *the Calculator* in uncompacted and compacted conditions.**

MSM Soil Texture	MSM Inf Rate (in/hr)	Uncompacted				Compacted		CRWD "Post-Construction" HSG
		MSM HSG	SWC Texture	SWC Sat Cond (in/hr)	SWC HSG	SWC Sat Cond (in/hr)	SWC HSG	
Gravel	>1.63	A	Not Included in Soil Water Characteristic Calculator					A
Sandy gravel	>1.63							
Silty gravel	1.63							
Gravelly sands	1.63							
Sand	1.63		Sand	4.5	A	2.77	A	B
Sand	0.8		Sand	4.5	A	2.77	A	
Loamy sand	0.8		Loamy sand	3.6	A	2.00	A	
Sandy loam	0.8		Sandy loam	1.99	A	0.82	B	
None	0.45	B	Silt	0.76	B	0.05	D	D
Loam	0.3		Loam	0.74	B	0.16	C	
Silt loam	0.3		Silty loam	0.49	C	0.05	D	
Sandy clay loam	0.2	C	Sandy clay loam	0.31	C	0.07	C	
Clay loam	0.06	D	Clay loam	0.18	C	0.02	D	
Silty clay loam	0.06		Silty clay loam	0.24	C	0.02	D	
Sandy clay	0.06		Sandy clay	0.03	D	0.00	D	
Silty clay	0.06		Silty clay	0.15	C	0.01	D	
Clay	0.06		Clay	0.03	D	0.00	D	

## Mitigating the Effects of Soil Compaction

The sections above document effects of soil compaction caused by construction activity. The *MSM* lists several methods to mitigate compaction: tilling/ripping/subsoiling, soil amendments, compost amendments, and time. Time refers to natural processes such as freeze-thaw cycles and root growth.) Of those, the *MSM* reports that soil or compost amendments are the most effective methods to immediately restore soil to a pre-construction condition. The *MSM* also notes that time (natural processes) can nearly mitigate soil compaction, but soil or compost amendments are preferred because:

- ▲ Natural processes can take many years to loosen up soil;
- ▲ Time will primarily loosen the first foot or so of soil, and construction compaction often extends two or more feet; and
- ▲ Severe soil compaction prohibits plant and soil microbe growth such that time can no longer reduce soil compaction.

The two most common methods for alleviating soil compaction are soil ripping (also called subsoiling or tilling) and addition of organic matter (also called soil/compost amendments). These two methods are typically combined for maximum effectiveness.

Compacted layers typically develop 12 to 22 inches below the surface when heavy equipment is used, and ripping should occur to a depth of one (1) to two (2) inches below the compacted layer. Therefore, soil ripping should occur to a depth of approximately 24 inches to alleviate compaction from construction. A minimum separation of one (1) foot should be maintained between the bottom of the subsoiled zone and the water table or top of bedrock. The *MSM* recommends following ground contours while tilling/ripping whenever possible to increase water capture, protect water quality and reduce soil erosion. Lastly, soil moisture must be between field capacity and wilt point during soil ripping for maximum effectiveness.

The *MSM* recommends the following procedure for compost amendments:

- ▲ Spread compost or manure to an average depth of 2.5 to 4 inches over the compacted soil.
- ▲ Comingle soil and compost using a tree spading machine, tined bucket, or similar equipment to a depth of 24 inches. Use the tines of the bucket to break apart clumps, if necessary, such that fifty percent (50%) of the soil is in clumps six (6) inches in diameter or smaller and no clumps of compacted soil are larger than 12 inches in diameter.
- ▲ Use existing topsoil or replace topsoil and rototill to four (4) inches or up to eight (8) inches if severely disturbed.

This procedure should not be applied:

- ▲ in areas where tree roots are to be protected, which generally extends to the tree canopy dripline;
- ▲ on slopes exceeding ten percent (10%) unless permanent erosion control measures are implemented;
- ▲ when surface soils are saturated or wet (exceed field capacity) or on dry soils;
- ▲ surface drainage is toward an existing or proposed building foundation; or
- ▲ the contributing impervious surface area exceeds the surface area of the amended soils.

### Recommendations for Permit Applicants

Based on the findings reported above, Wenck recommends that CRWD permit applicants follow these guidelines when preparing stormwater calculations:

Land Cover	Pre-Construction Condition	Post-Construction Condition
Pervious	Assign CN based on land cover type (grass, woods, etc.) and soil boring results or NRCS Web Soil Survey.	<ul style="list-style-type: none"><li>• If pervious is HSG A, assign HSG A, except for sandy loam.</li><li>• If pervious is sandy loam, assign HSG B.</li><li>• For all other HSG or soil textures, assign HSG D.</li></ul>
Impervious	CN = 98	<ul style="list-style-type: none"><li>• If remains impervious, CN = 98.</li><li>• If converted to pervious, assign CN based on HSG D.</li></ul>

Applicants that specify soil and compost amendments per *MSM* recommendations may:

- Assign HSG A for sandy loam, or
- Assign HSG C for all other soil textures.

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## References

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