Improving Accuracy in Continuous Hydrologic Modeling:

Guidance for Selecting Pervious Overland Flow Manning's *n* Values in the San Diego Region

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Abstract

Since the inception of the San Diego Hydromodification Management Plan (SD HMP), Tory R. Walker Engineering (TRWE) has become the local leader in site-specific hydromodification management BMP design using the EPA Storm Water Management Model (SWMM). TRWE has designed hydromodification management BMPs for over 100 projects throughout San Diego County. TRWE also continues to collaborate with San Diego Water Board staff, Copermittees, professional trade organizations, and environmental groups to inform and guide hydromodification management efforts within the San Diego Region. Keeping with our leadership and expertise, TRWE has taken the opportunity to provide additional guidance for practitioners who seek to design hydromodification management BMPs using SWMM. Specifically, this white paper serves as a technical resource for selecting appropriate pervious overland flow Manning's *n* values (N-Perv), as permitted by Appendix G of the San Diego Region Model BMP Design Manual (Model BMPDM) and subsequently adopted BMP Design Manuals for each San Diego County Copermittee. The desired outcome of this technical resource is to quickly guide those practitioners who seek to develop site-specific SWMM models that most accurately simulate the pre- and post-development hydrologic behavior exhibited throughout the San Diego Region. We have summarized our findings in a helpful table. We gladly welcome any comments, suggestions, or inquiries on the subject matter.

Introduction

The Model BMPDM Appendix G offers limited guidance to users of continuous simulation models, including Hydrological Simulation Program-Fortran (HSPF), San Diego Hydrology Model (SDHM), and Storm Water Management Model (SWMM). The guidance is provided through a series of narratives, tables, and figures. Sections G.1.4.2 to G.1.6.2 provide some direction to SWMM users, with the bulk of the information presented in Table G.1-4. The San Diego Copermittees have since adopted Model BMPDM Table G.1-4 into their own jurisdiction-specific BMP Design Manuals. When TRWE reviewed the Copermittees' BMP Design Manuals, we found that a source of significant inaccuracy has been propagated throughout: *the default assignment of short prairie grass for all pervious land surface cover*.

The Default Value Will Likely Compromise Model Accuracy

The implication of implementing the default pervious Manning's *n* value (N-Perv, or simply *n*) is that San Diego SWMM users will now regularly model all pervious surfaces as if they were covered by short prairie grass. We find several issues with this guidance.

First, there is no context provided as to what land surface cover is defined by "short prairie grass." In our dealings with this issue, we have found that opinions vary: some perceive short prairie grass to be any lightly to moderately vegetated surface cover, while others perceive it to describe a dense grass range. In the absence of a proper context, each is left to a subjective interpretation of the term. Therefore, TRWE conducted a scrupulous literature review to uncover the origin of "short prairie grass," in order that the appropriate interpretation may be understood by all vested parties. From our literature review we came to a clear definition of short prairie grass, as presented by the research that introduced the term.

David A. Woolhiser, a former United States Department of Agriculture (USDA) research hydraulic engineer, led a research effort to describe overland flow for small native short-grass prairie rangeland watersheds in western South Dakota[1]. In the literary record, we find the Manning's *n* for short prairie grass to be within the range 0.10 – 0.20, with the average (*n* = 0.15) taken as the conventional estimate (Woolhiser, 1975, p. 502), best described as short grasses with notable litter and nearly no exposed bare soil.

Having obtained a proper definition, we sought next to investigate the local existence of short prairie grass[2]. Based on our research and our experience in San Diego site development, we find that there are infrequent scenarios where an undeveloped open space hosts a pervious prairie-like surface cover—scenarios such as these may warrant the default estimate if they fit the above description. However, we find that redevelopment projects are normally characterized by a different set of known conditions, such as highly compacted soils, barren surface cover, or light vegetation. This reality leads to our second issue with the default estimate.

The BMP Design Manuals offer no distinction to assess what classification of pervious surface warrants the default estimate. In SWMM hydromodification management BMP design, pre- and post-development models are created to simulate the pre- and post-development hydrology, yet Table G.1-4 makes no differentiation between these scenarios. Also, as previously mentioned, no distinction is made between N-Perv application for new developments versus redevelopment projects, where existing site cover would differ considerably. Therefore, it is apparent in the BMP Design Manuals that pervious surfaces are also, by default, assumed to be short prairie grass in both the pre- and post-development scenarios, regardless of the project type, which is certainly not the case in reality. For instance: suppose a proposed redevelopment project seeks to develop a bare, existing graded lot into a multi-family residential dwelling. In the existing (pre-development) state, the site is completely pervious and has little to no vegetation. In the proposed (post-development) state, the site is mostly impervious, with a few lightly vegetated landscaped features. It is known that short prairie grasses (or similar) are not present either before or after development. In this scenario, the universal assignment of short prairie grass to all pre- and post-developed pervious surfaces would inevitably produce a hydrologic response that has no basis in reality, resulting in an incorrectly sized BMP footprint. We find that in order to model site-specific hydrology, selection of an alternative Manning's *n* value must be permitted, which leads to our third and final concern.

The BMP Design Manuals allow for a land surface description other than short prairie grass to be used for hydromodification BMP design only if documentation provided is consistent with Table A.6 of the SWMM 5 User's Manual. SWMM 5 User's Manual Table A.6 presents a short list of 18 land surface descriptions—most of which are rarely encountered in San Diego. The pervious land surface descriptions offered by SWMM 5 User's Manual Table A.6 are predominantly agricultural and fail to adequately describe local vegetation: fallow soils, cultivated soils, natural range, short prairie grass, dense grass, Bermuda grass, and woods with either light or dense underbrush. As one can readily infer from these

[1] This research is summarized on page 6 under "Summary of Research by David A. Woolhiser"
[2] Our findings are summarized on page 6 under "Local Existence of Short Prairie Grass"

listed surface descriptions, SWMM 5 User's Manual Table A.6 is notably limited for local application. Due to these limited options, the absence of additional references suitable for local use, and the streamlining appeal of a de facto value, we anticipate that jurisdictions will not be inclined to approve land surfaces other than short prairie grass. Therefore, in order to provide SWMM users with a wider range of land surfaces suitable for local application and to provide Copermittees with confidence in the design parameters, we recommend using the values published by Yen and Chow in Table 3-5 of the EPA SWMM Reference Manual Volume I – Hydrology.

SWMM-Endorsed Values Will Improve Model Quality

In January 2016, the EPA released the SWMM Reference Manual Volume I – Hydrology (SWMM Hydrology Reference Manual). The SWMM Hydrology Reference Manual complements the SWMM 5 User's Manual and SWMM 5 Applications Manual by providing an in-depth description of the program's hydrologic components (EPA 2016). Table 3-5 of the SWMM Hydrology Reference Manual expounds upon SWMM 5 User's Manual Table A.6 by providing Manning's *n* values for additional overland flow surfaces[3]. The values are provided in Table 1:

Table 1: Manning's *n* Values for Overland Flow (EPA, 2016; Yen 2001; Yen and Chow, 1983).

Overland Surface	**Light Rain (< 0.8 in/hr)**	**Moderate Rain (0.8-1.2 in/hr)**	**Heavy Rain (> 1.2 in/hr)**
Smooth asphalt pavement	0.010	0.012	0.015
Smooth impervious surface	0.011	0.013	0.015
Tar and sand pavement	0.012	0.014	0.016
Concrete pavement	0.014	0.017	0.020
Rough impervious surface	0.015	0.019	0.023
Smooth bare packed soil	0.017	0.021	0.025
Moderate bare packed soil	0.025	0.030	0.035
Rough bare packed soil	0.032	0.038	0.045
Gravel soil	0.025	0.032	0.045
Mowed poor grass	0.030	0.038	0.045
Average grass, closely clipped sod	0.040	0.050	0.060
Pasture	0.040	0.055	0.070
Timberland	0.060	0.090	0.120
Dense grass	0.060	0.090	0.120
Shrubs and bushes	0.080	0.120	0.180
Land Use			
Business	0.014	0.022	0.035
Semibusiness	0.022	0.035	0.050
Industrial	0.020	0.035	0.050
Dense residential	0.025	0.040	0.060
Suburban residential	0.030	0.055	0.080
Parks and lawns	0.040	0.075	0.120

[3] Further discussion is provided on page 6 under "Discussion of Differences Between Manning's *n* Values"

For purposes of local hydromodification management BMP design, these Manning's *n* values are an improvement upon the values presented by Engman (1986) in SWMM 5 User's Manual Table A.6. Values from SWMM 5 User's Manual Table A.6, while completely suitable for the intended application to certain agricultural land covers, come with the disclaimer that the provided Manning's *n* values are valid only for shallow-depth overland flow that match the conditions in the experimental plots (Engman, 1986, p. 51). Engman's experimental plots (predominantly agricultural) subject to high simulated rainfall intensities (2 to 4 inches/hour) do not represent typical conditions in San Diego County. Furthermore, it has been well documented that an increase in rainfall intensity produces a corresponding increase in the overland flow roughness factor for laminar flows on smooth surfaces (Engman, 1986, pp. 43, 51; Liang, 2010, p. 126; Wenzel, 1970, p. 23; Yen, 2001, p. 6.51); this relationship is noteworthy due to the common occurrence of sparsely vegetated overland flow surfaces in San Diego County. Based upon review of the Project Clean Water Oceanside hourly rainfall data, the range of geomorphically significant (Q_2 through Q_{10}) peak flow events are, on average, precipitated by rainfall events with intensities of less than 0.2 inches/hour (with an average maximum storm intensity of 0.55 inches/hour). Therefore, we recommend the use of "Light Rain" (or "Low") Table 1 values for site-specific SWMM design because: (1) these parameters provide estimates that describe land surfaces commonly encountered in San Diego, (2) account for the effect of local rainfall intensities, (3) are acknowledged to reflect empirical runoff behavior, (4) were developed for storm drainage facility design, and (5) are recommended for generalized use with EPA SWMM by the EPA (EPA, 2016; Yen, 2001; Yen and Chow, 1983). The Table 1 values are consistent with the intent and use of SWMM as a continuous simulation tool and provide both the SWMM user and Copermittee with a suite of locally relevant design values published by an authoritative source and intended for kinematic wave modeling purposes.

References

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ADDITIONAL REFERENCES

Summary of Research by David A. Woolhiser

As presented in the 1970 publication of Woolhiser's research, vegetation samples from within each experimental watershed collectively defined short prairie grass as a compilation of the following short grasses and sedges (p. 344):

- buffalograss (*Buchloe dactyloides*)
- blue grama (*Bouteloua gracilis*)
- threadleaf sedge (*Carex filifolia*)
- needleleaf sedge (*Carex eleocharis*)
- Sandberg's bluegrass (*Poa secunda*)

Basal covers from these experimental watersheds were composed of *at least* 58% of the said short grasses and sedges, 23% litter, and 8% forbs, rocks, and bare soil (Woolhiser, 1970, p. 344). Woolhiser (1975) later summarized his research into a textbook that presented the overland flow roughness for short prairie grass in terms of a Manning's *n* value. For the first time in the literary record, we find the Manning's *n* for short prairie grass to be within the range 0.10 – 0.20, with the average (*n* = 0.15) taken as the conventional estimate (Woolhiser, 1975, p. 502). Therefore, we reasonably conclude that "short prairie grass" land cover is best described by a given area with basal cover composed by at least half of any combination of the five aforementioned (or similar) short grasses with notable litter and nearly no exposed bare soil.

Local Existence of Short Prairie Grass

According to the United States Department of Agriculture (USDA) and National Resources Conservation Service's (NRCS) PLANTS Database, only Sandberg's bluegrass (*Poa secunda*) is present within San Diego County. The San Diego County Plant Atlas has established the existence of unspecified densities of *Poa secunda* within predominantly undevelopable localities (Anza-Borrego Desert State Park, Camp Pendleton Marine Corps Base, Cleveland National Forest, Palomar Mountain State Park, etc.). In 2011, Sproul, Keeler-Wolf, Gordon-Reedy, Dunn, Klein, and Harper produced the Vegetation Classification Manual for Western San Diego County, which serves to confirm the limited existence of *Poa secunda*, as suggested by the SD County Plant Atlas (pp. 5-32, 5-43, 5-51, 5-53). Based upon the findings provided through available literature, there emerges a significant lack of evidence to support the notion that short prairie grasses are representative of developable pervious land surfaces (rural or urban) within San Diego watersheds. Therefore, to assume pervious land surfaces to be dominated by the 6 to 12 inch tall blue grama or the densely-rooted sod-like structure of buffalograss is found to have no technical basis for default assignment within the San Diego Region.

Discussion of Differences Between Manning's *n* Values

Table 3-5 of the SWMM Hydrology Reference Manual provides Manning's *n* values for overland flow published by Crawford and Linsley (1966) from calibration of the Stanford Watershed Model, Engman

(1986) from runoff plot data originally collected for erosion studies, and Yen (2001) for SWMM application by kinematic wave analysis modified for composite land surfaces of heterogeneous nature. The SWMM Hydrology Reference Manual recommends the values for use in SWMM in conjunction with adjusting the subcatchment width parameter to calibrate the model. However, in the absence of recorded rainfall-runoff data for each proposed site development, site-specific model calibration is not possible for BMP design purposes. The inability to calibrate does not prohibit physically based site-specific hydrologic models from calculating reasonable outputs, so long as the model inputs reflect the site conditions (Yen 2001).

It has been well documented that increases in rainfall intensity produce a corresponding increase in the overland flow roughness factor for laminar flows on smooth surfaces (Engman, 1986, pp. 43, 51; Liang, 2010, p. 126; Wenzel, 1970, p. 23; Yen, 2001, p. 6.51). Engman's (1986) experimental plots were subject to high rainfall intensities (2 to 4 inches/hour) (p. 51), were assumed to be turbulent (p. 44), and had varying degrees of non-vegetated cover (p. 51). If the flows from these experimental plots were incorrectly assumed to be turbulent, then the sensitive relationship between rainfall intensity and surface roughness may explain the higher *n* values for Engman's non-vegetated surfaces when compared with those from Yen & Chow. Yen's values address this sensitive relationship through the inclusion of a rainfall intensity constant in the development of his Manning's *n* values (low, medium, and high roughness values corresponding to low, medium, and high rainfall intensities).

Manning's *n* comparison between various authors is also not straightforward due to the ambiguous relationship between terms. Engman provides *n* values for fallow ground, chisel plow, disk/harrow, no till, moldboard plow, coulter, range, and grass (1986, p. 51). When compared to Yen's land surface descriptions, no clear equation between terms can be clearly established. Therefore, we find that the inconsistency between values does not compromise the integrity of either dataset, but should be observed with the unique experimental context in mind, as has been conducted by Engman (1986, pp. 49-51). Based upon the literature review, we believe that Yen's values lend themselves to be a more reliable set of values for site-specific hydrology of lightly vegetated sites subject to known low rainfall intensities, whereas Engman's values favor application for densely vegetated undisturbed sites subject to higher rainfall intensities. Finally, we note that the same source should be used for selection of both pre- and post-developed pervious roughness values, as selecting separate values from differing sources will undoubtedly compromise model accuracy.