NDOT Research Report

Report No. 674-19-803

Modernize Hydrologic Prediction Processes by Creating Custom Statewide SSURGO Green and Ampt Parameter Database

Task 1: Hydrologic Methodology Assessment

December 2020

Nevada Department of Transportation

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Modernize Hydrologic Prediction Processes by Creating Custom Statewide SSURGO Green and Ampt Parameter Database

NDOT ID# 19Q2-E2-01

Hydrologic Methodology Assessment

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NEVADA DEPARTMENT OF TRANSPORTATION

HYDROLOGIC METHODOLOGY ASSESSMENT

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3. Introduction

3.1 Define Problem

The current edition of the Nevada Department of Transportation (NDOT) Drainage Manual was published in December of 2006; however, new methods and technologies have emerged that have made hydrologic analyses more consistent between models with a higher degree of accuracy and reproducibility.

3.2 Describe Needs

NDOT Hydraulics is proposing to incorporate these new tools and methods, as they have been shown to significantly improve accuracy and reliability and thus improve designs and provide more consistent project cost estimates.

This Hydrologic Method Assessment Report (Assessment Report) presents the results of the principal investigator's review of collected data and includes the selected course of action based on the review and feedback received from NDOT's review committee. The Assessment Report presents the results of the research and data collection as well as a discussion of the advantages of implementing methodology changes. A review committee appointed by NDOT would make the final determination of any proposed updates.

4. Background Summary

4.1 Current NDOT Practice

NDOT presently uses the Natural Resources Conservation Service (NRCS) formerly known as Soil Conservation Service (SCS) Curve Number (CN) method for estimating runoff. The SCS CN method does not consider rainfall intensity and duration, but only total rainfall volume, and is a curve fitting empirical method.

Additionally, the CN method relies heavily on engineering judgment to assign the condition of the land cover type for a given hydrologic soil group (e.g. poor, fair, good) which greatly influences the selection of CN values and resulting computed runoff volume. Furthermore, assignment of HSG 'D' is often given to common soils in semi-arid environments that have caliche or other hard pan layers at depths. However, in many instances, the hard pan layers lie below the depth to which single event infiltration commonly reaches during typical engineering design storms like those used by NDOT for drainage design.

4.2 What others are doing

Hydrology manuals and hydrologic methods in use by neighboring state transportation and related county and local agencies were collected and reviewed. In summary, most continue to use methods in the NRCS National Engineering Handbook 4 (NEH-4). Those methods are the familiar SCS Methods including curve numbers, the velocity method time of concentration, and the unit dimensionless hydrographs. American Association of State Highway and Transportation Officials (AASHTO) presents these methods in their model drainage manual, so it is no surprise that many transportation agencies have adopted these approaches.

NDOT, intends to adopt alternate approaches including the Green and Ampt rainfall loss estimation method. Numerous other agencies within the southwest use similar hydrologic methods including Arizona Department of Transportation (ADOT), Maricopa, Mohave, Yavapai, and Pinal Counties in Arizona, and the Arizona Department of Water Resources through State Standard SS10-07 – State Standard for Hydrologic Modeling Guidelines.

4.3 Why New Research?

Through this process NDOT proposes to use the Green and Ampt rainfall loss estimation method. This method is a physically based rainfall loss determination method that can give a better estimate of soil infiltration. NDOT is proposing to develop statewide Green and Ampt parameters to bring current hydrologic modeling procedures more in line with nearby similar states and locales, with the goal being repeatable improved forecasting and modeling of runoff. Recently as an example, NDOT's Design Build project for USA Parkway used the Green and Ampt rainfall loss estimation method. The Engineer had to develop their own generic, texture only based parameters, which resulted in less accurate predictions of infiltration and runoff.

5. Rainfall Loss Research

5.1 Define Objectives

For the research project, it is anticipated that the project will include five distinct tasks. The process follows the accepted and scientifically defensible procedures used in the ADOT's Green and Ampt parameter soil processing database published online as part of the 2014 ADOT Hydrology Manual. This Assessment Report is the initial task in the process. Subsequent tasks include developing Green and Ampt rainfall loss parameters for the State of Nevada, applying the Green and Ampt parameters to a test watershed and developing an internal NDOT training document.

5.2 Historical use of rainfall losses using Green and Ampt rainfall loss estimation method

Historically, the Green and Ampt rainfall loss estimation method required input of the following variables on the LG record within HEC-1.

– Initial loss (IA),

– Volumetric moisture deficit (DTHETA),
– Wetting front suction (PSIF),
– Saturated hydraulic conductivity (XKSAT), and
– Percent of subbasin which is effectively impervious (RTIMP).

The following paragraphs explain what work went into the 2014 ADOT Hydrology Manual and will be a basis for what will be provided in the NDOT Drainage Manual.

The 1993 ADOT Hydrology Manual presented tables, Table 3-1, and Table 3-2, to estimate the surface retention loss and the other Green and Ampt parameters, respectively. Table 3-1 presents the surface retention loss values for various land-use and/or surface cover types. Table 3-2 presents the parameters such as volumetric moisture deficit (DTHETA), wetting front suction (PSIF) and saturated hydraulic conductivity (XKSAT) for various soil texture classifications.

The 1993 ADOT Hydrology Manual recommended that soil texture be evaluated for the top 6 inches of soil for purpose of estimating the Green and Ampt parameters to compute rainfall losses for design rainfall events. Two sources of information can be used to classify the soil texture for this purpose: 1) NRCS soil surveys where detailed surveys are available and 2) general soil maps and accompanying reports prepared by NRCS. The NRCS soil surveys are to be used where detailed surveys are available and the general soil maps in the other situations.

The XKSAT values are estimated for each subbasin through a log-weighted averaging procedure using the various soil components found within a subbasin. The composite values of PSIF and DTHETA are then determined from the composite value of XKSAT. An adjustment to XKSAT is then made to account for the presence of vegetation cover. The value of XKSAT before this adjustment is used in the estimation of PSIF and DTHETA. Three variations of DTHETA values are defined:

1) Dry – for non-irrigated lands such as desert and rangeland,
2) Normal – for irrigated lawn, turf, and permanent pasture, and
3) Saturated – for irrigated agricultural lands

Figure 3-3 in the 1993 ADOT Hydrology Manual presented curves of DTHETA for dry and normal conditions. The 1993 ADOT Hydrology Manual recommended the use of one of the two curves as found appropriate for the subbasin; finally, an area-weighted value of effective imperviousness (RTIMP) is computed to arrive at the composite RTIMP value for the subbasin.

The 1993 ADOT Hydrology Manual values for each soil texture class were determined based on research presented by Rawls and Brakensiek (1983).

5.3 Updated Green and Ampt Parameter Estimation

5.3.1 Soil Horizon Depths

In 2014, ADOT developed Green and Ampt rainfall loss parameters statewide for the top 6 inches of the soil horizon. At the time, 6 inches was consistent with the previous ADOT Hydrology Manual and current hydrology manuals for Maricopa County Flood Control District. In a recent presentation hosted by the Arizona Floodplain Management Association (AFMA), a staff member of the Maricopa County Flood Control District Special Projects Branch discussed ongoing research into the controlling horizon for Green and Ampt modeling. This ongoing research indicates that the use of the top 3 inches of the soil's horizon yields the best comparison with measured precipitation gage hyetographs and stage gage hydrographs. This depth is considered a reasonable infiltration depth for 100-year storm rainfall in Nevada and for transportation projects with lower recurrence intervals. A greater depth could be considered for infrequent storms such as the 500-year storm event or Probable Maximum Precipitation storm used for dam safety purposes. For the purposes of developing statewide Green and Ampt rainfall loss parameters in support of transportation projects, the top 3 inches of the soil horizon will be used.

5.3.2 Additional Research

Rawls and Brakensiek (1983) research has been subsequently refined by Saxton and Rawls (2006). These newer procedures provide computed values for any given soil based on data readily available in NRCS soil survey databases – specifically percentages of sand, clay, gravel, organic, and salinity. The Saxton and Rawls (2006) equations have a correction for salinity. This correction was not used in the 2014 ADOT Hydrology Manual.

The Saxton and Rawls (2006) procedures are based on extensive research using 2,000 A-horizon and 2,000 B-horizon samples from the NRCS. The A-horizon is the top soil layer; the B-horizon the second layer below the surface. These two horizons (generally) cover the surface soils, which is the area of concern for this analysis.

The 2006 methodology has been successfully applied by ADOT and others to compute Green and Ampt parameters for application to engineering design since the 2014 ADOT Hydrology Manual. While many agencies in Arizona continue to use HEC-1 with Saxton and Rawls (2006) procedures, it is understood that NDOT wishes to move to the more modern HEC-HMS software to compute design flood hydrographs and peak discharges. Therefore, the remainder of this assessment report will focus on application of Green and Ampt in HEC-HMS with infiltration parameters computed using the Saxton and Rawls (2006) procedures.

6. Recommendations for Surface Retention Loss and Green and Ampt Procedure

Use of the Green and Ampt equation in HEC-HMS involves the simulation of rainfall loss as a two-phase process, as illustrated in **Figure 1**. The first phase is the simulation of the surface retention loss. These losses are modeled in two parts in HEC-HMS – the Canopy Method and Surface Method. The second phase of the rainfall loss process is the infiltration of rainfall into the soil matrix.

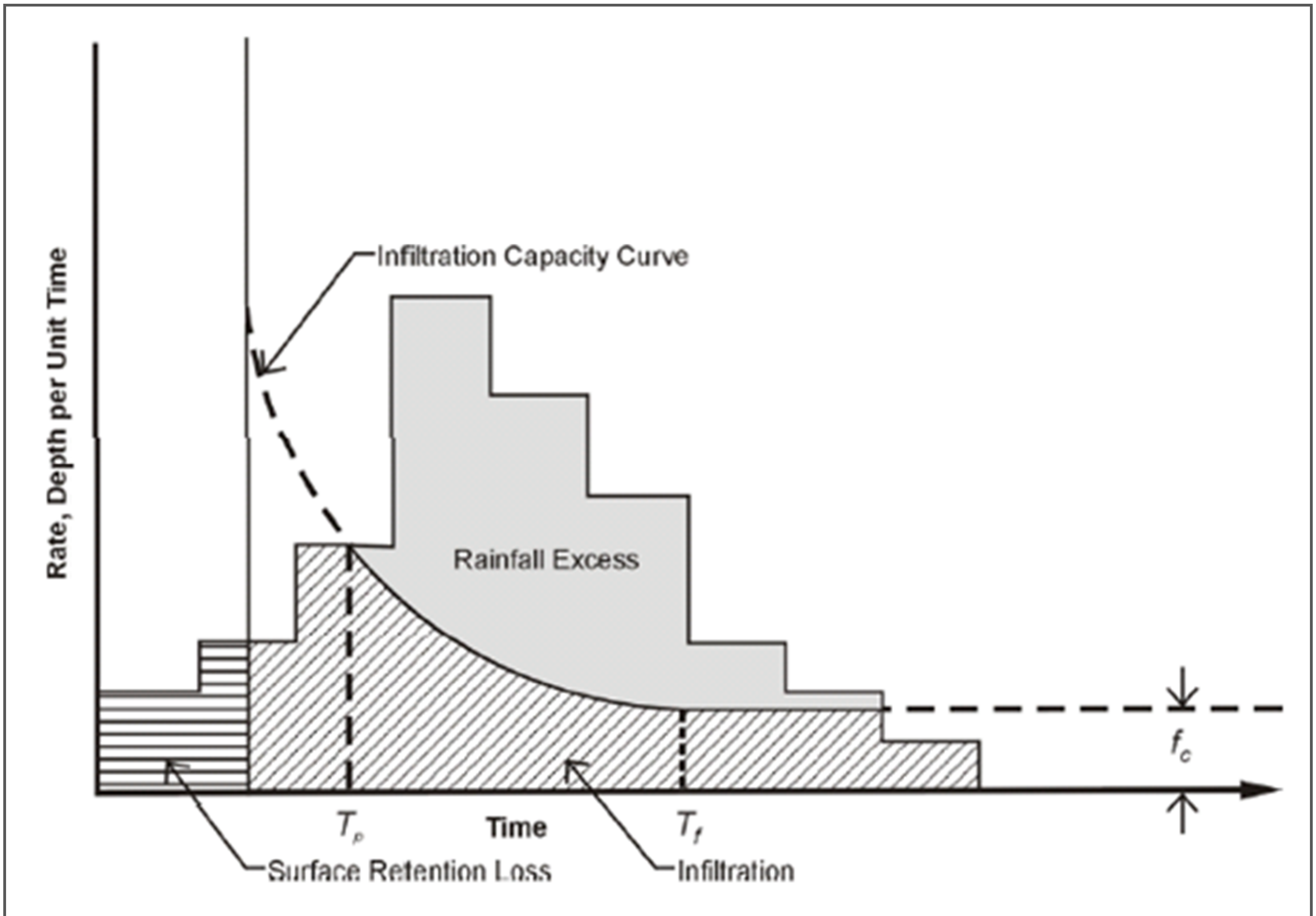

Figure 1 Simplified Representation of Rainfall Losses

6.1 Surface Retention Loss (Surface Method and Surface Tab)

Surface retention loss is the summation of all rainfall losses other than infiltration. The major component of the surface retention loss is depression storage; relatively minor components of surface retention loss are due to interception and evaporation.

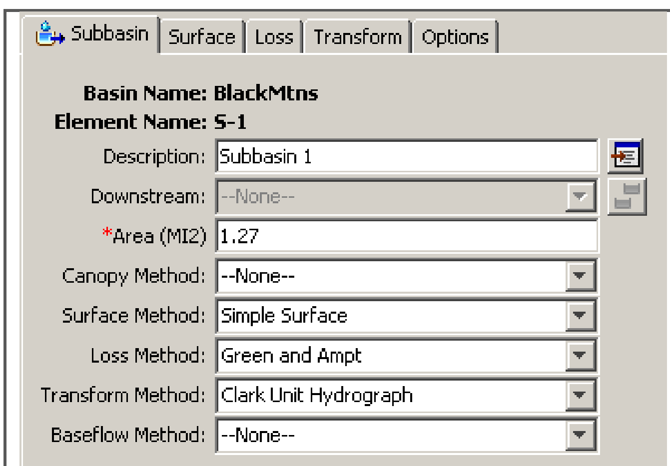

Figure 2 Subbasin loss and transform method selection form in HEC-HMS

6.1.1 Surface Methods and Canopy

From HEC-HMS**,** surface retention loss is specified with the Surface Method in **Figure 2** while the surface retention loss has two parameters specified as shown in **Figure 3** – 'initial storage (%)' and 'max storage (in)'.

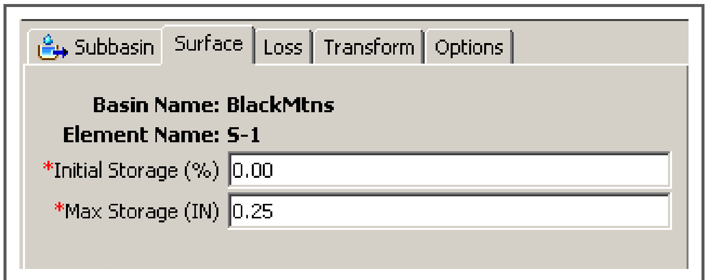

Figure 3 Example of Surface Loss data form in HEC-HMS

Surface Method parameters are defined as follows:

- Initial Storage (%) - initial loss storage volume, in percent. Normally set to zero (0).
- Max Storage - surface retention loss, in inches.

For the purposes of developing parameters for NDOT, the 'max storage (in)' is to be taken as the sum of all initial losses including surface depression storage and interception losses. Interception losses could be specified separately, if known separately, by additional use of the Canopy Method. However, the tables from existing guidance generally include both losses together. Therefore, the more simplified approach lumping all initial losses into the Surface Method is recommended. This is consistent with modeling recommendations in the 2014 ADOT Hydrology Manual.

In special circumstances where interception losses are believed to be significant and separable from surface depression losses, the Canopy Method may also be applicable. These might include heavily forested areas where significant tree canopy captures additional rainfall preventing it from reaching the ground. The real reason to separate the two types of initial losses is for continuous modeling or forensic modeling of storms with multiple rainfall bursts and periods of little or no rainfall in between. In those cases, HEC-HMS is able to drain the surface depression storage and make it available again for subsequent rainfall as compared to interception (canopy) losses that are filled only once in a single simulation.

The initial storage (%) will generally always be taken as 0 percent for drainage design applications. For saturated soil conditions such as agricultural fields or special forensic investigations initial storage would be 100 percent of the maximum storage.

Sources for surface loss parameters can be found in Table 3-1 in 2014 ADOT Hydrology Manual, Table 6-1 in USACE EM 1110-2-1417, Table 7.11 in Mohave County Drainage Design Manual 2018 (provided below), and Table 4.2 in Maricopa County Drainage Design Manual 2018.

Table 7.11 *IA* and *RTIMP* estimates for various land uses

(Source: Derived from ADOT, 1993; FCDMC, 2013a)

Land-use and/or Surface Cover (1)		Surface Retention Loss (*IA*), inches (2)	*RTIMP*, percent	
			Mean (3)	Range (4)
Natural				
Natural grasslands (flat slope)		0.50		
Rangeland, flat slope (moderate vegetation)		0.35	varies	varies
Rangeland, hill slopes (moderate vegetation)		0.15	varies	varies
Mountain, flat slope (vegetated)		0.50	varies	varies
Mountain, steep slopes (vegetated)		0.25	varies	Varies
Developed (Residential and Commercial)				
Single Family Residential	1/4 acre	0.25	40	25-55
	1/3 acre	0.25	30	20-40
	1/2 acre	0.25	23	15-30
	1 acre	0.30	18	10-25
	>=2 acres	0.30	15	5-25
Multi-Family Residential		0.25	50	40-60
Commercial		0.10	75	50-95
Industrial		0.20	70	50-90
Non-irrigated Landscape		0.10	varies	varies
Lawn and Turf		0.20	0	0
Pavement and Roof Tops		0.05	95	95
Agricultural				
Tilled fields irrigated pasture		0.50	0	0

Figure 4 Mohave County Drainage Design Manual (2018) Table 7.11

6.2 Green and Ampt Rainfall Losses Procedure (Loss Tab)

Determination of Green and Ampt parameters will be based on *Soil Characteristic Estimates by Texture and Organic Matter for Hydrologic Solutions* (Saxton and Rawls (2006)), which is a continuation of the 1983 work by Rawls, Brakensiek and Miller.

Green and Ampt parameters are defined as follows:

Initial Content — Dry - Volumetric soil moisture content expressed as wilting point at start of rainfall, in inches,

Normal - Volumetric soil moisture content expressed as field capacity at start of rainfall, in inches,

Saturated Content — Volumetric soil moisture content at saturation, in inches,

Suction — Wetting front capillary suction, in inches,

Conductivity — Bare ground effective hydraulic conductivity at natural saturation, in inches/hour, and

Impervious % — Effective impervious area, in percent.

In HEC-HMS, the selection of Green and Ampt as the "Loss Method" is made first under the subbasin tab within the Basin Model (**Figure 2**). **Figure 5** shows an example of the Green and Ampt parameters on the Loss tab.

Most drainage areas or subbasins will be composed of several subareas of different soil map units (SMUs). Therefore, the modeler needs to determine composite values for the Green and Ampt parameters to be applied to the drainage areas or subbasin. For the conductivity and soil suction parameters, the composite value is determined using the average of the area-weighted logarithms of the individual subarea values. Composite values of soil moisture content and effective impervious area values shall be computed by a simple arithmetic area-weighting procedure.

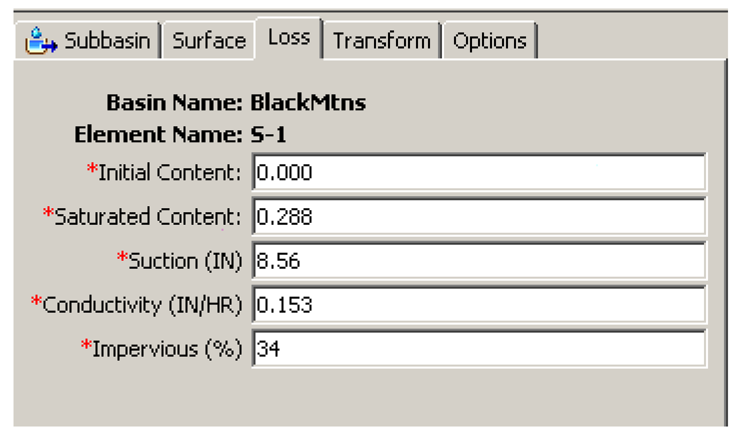

Figure 5 Subbasin Green and Ampt Rainfall Loss Estimation Method parameter input form in HEC-HMS

6.2.1 Initial and Saturated Content

The Saturated Content is the maximum water holding capacity in terms of volume ratio, which is often assumed to be equivalent to the total porosity of the soil. In HEC-HMS, the initial content for the dry condition shall be set to the wilting point moisture content. For the normal condition, initial content shall be set to the field capacity moisture content. For the wet or saturated condition, the initial saturation equals the saturated content. Saturated content is computed from bare ground values per equations in **Section 6.4**. More information is available in the 2014 ADOT Hydrology Manual.

6.2.2 Suction

Wetting front capillary suction (Suction) is the measurement of the combined adhesive forces that bind the water molecules to solid walls and the cohesive forces that attract water molecules to each other. Soil suction is computed from bare ground values per equations in **Section 6.4**. More information is available in the 2014 ADOT Hydrology Manual.

6.2.3 Conductivity

Conductivity using the Saxton and Rawls (2006) procedures is computed based on the percent volume by weight of sand and clay for a given matrix[1] soil and corrected based on the percentage of gravel and organic matter in the bulk soil, and the relative level of compaction of the bulk soil. See equations in **Section 6.4**.

The hydraulic conductivity values calculated per Saxton and Rawls (2006) are for saturated conditions. When soils are not completely saturated, all or a portion of the void space between particles in the soil matrix is filled with air. When water begins to fill the soil matrix the displaced air must escape up through the soil matrix back into the atmosphere. The bubbling up of this air through the soil matrix slows the infiltration of water into the soil. This 'bubbling up' reduces the effective rate of infiltration. Bouwer (1966) suggested the use of 0.5 as a reasonable 'effective' rate. This ratio has been used by ADOT and others for purposes of engineering design studies for decades. More recent research by Desert Research Institute for Maricopa

[1] The soil matrix is the entirety of the soil column which includes organic and inorganic matter as well as the void spaces.

County, Arizona has found from rainfall simulator studies that the effective ratio can range from 0.1 to 0.7. Therefore, it is recommended to use 0.5*Ks per Bouwer (1966) when converting the Saxton and Rawls (2006) results to effective field condition hydraulic conductivity. This is consistent with methods presented in the 2014 ADOT Hydrology Manual.

Soil map unit hydraulic conductivity values will be evaluated based on the controlling soil horizon of the upper 3 inches as noted above. Hydraulic conductivity values for individual soil types are computed based on data in the NRCS soil surveys. Bare ground hydraulic conductivity will be adjusted for vegetation cover following the equation shown in Figure 3-1 in the 2014 ADOT Hydrology Manual.

6.2.4 Impervious

Effective impervious area is the proportion of the subbasin where rainfall is directly connected to the subbasin outlet. That is, all the rainfall that falls on that portion of the subbasin contributes directly to runoff with no rainfall loss. All precipitation for that portion of the subbasin becomes rainfall excess. Usually, effective impervious surfaces are things like roof tops, parking lots, and streets. Natural watersheds with significant areas of rock outcroppings may also have effective impervious areas. Natural rock outcropping is normally expected to be less effective than urban impervious areas.

Values for effective impervious area can be found in numerous sources. Table 3-2 in the 2014 ADOT Hydrology Manual is still considered applicable. Additional sources include Table 6-6 in EM 1110-2-1417 (USACE, 1996), Table 7.11 in Mohave County Drainage Design Manual 2018 (provided above), and Table 4.2 in the Maricopa County Drainage Design Manual (2018).

6.3 Extraction and Manipulation of Soils Data

The Green and Ampt parameters are based on the soil characteristics found in the NRCS databases. The key inputs are percentages of sand, clay, gravel, and organic matter. The NRCS database provides soil surveys which contain different geographical areas identified by the soil map unit (SMU). Each map unit contains various soil components at different percentage compositions. Each component has different layers or horizons which identify values of soil characteristics along with the different layer's depths.

The location of the top boundary of each horizon is identified as hz_deptr parameter in the NRCS database. The NRCS database contains percentage values for sand, clay, gravel, and organic matter for each layer/horizon for each soil component. These values were obtained from the NRCS database for each horizon within a component. The Green and Ampt parameters are computed for each horizon based on the Saxton and Rawls (2006) procedures.

6.4 Equations used to determine Green and Ampt Parameters

The equations used for computation of Soil Moisture Content, Suction, Conductivity and the corrections for gravel content, organic matter and compaction are listed below. The Green and Ampt parameters will be computed using a script routine with data from the NRCS soil survey databases.

The equations from Saxton and Rawls (2006), are summarized as follows:

<u>Wilting Point (WPoint)</u>

Predict = -0.024 * Sand + 0.487 * Clay + 0.006 * OrgMat + 0.005 * Sand * OrgMat - 0.013 * Clay * OrgMat + 0.068 * Sand * Clay + 0.031

WPoint = Predict + (0.14 * Predict - 0.02)

Field Capacity (FCapac)

Predict = -0.251 * Sand + 0.195 * Clay + 0.011 * OrgMat + 0.006 * Sand * OrgMat - 0.027 * Clay * OrgMat + 0.452 * Sand * Clay + 0.299

FCapac = Predict + (1.283 * Predict ^ 2 - 0.374 * Predict - 0.015)

Saturation (Sat)

Predict = 0.278 * Sand + 0.034 * Clay + 0.022 * OrgMat - 0.018 * Sand * OrgMat - 0.027 * Clay * OrgMat - 0.584 * Sand * Clay + 0.078

S33 = Predict + (0.636 * Predict - 0.107)

Sat = FCapac + S33 - 0.097 * Sand + 0.043

Adjustment for organic matter and compaction

DensityO = (1 - Sat) * 2.65

DensityC = DensityO * DensityFactor

PorO = 1 - (DensityC / 2.65)

PorC = PorO - (1 - DensityO / 2.65)

M33C = FCapac + 0.25 * PorC

PM33C = PorO - M33C

If PM33C < 0 Then PM33C = 0

Conductivity

Gadj = (1 - Gravel) / (1 - Gravel * (1 - 1.5 * ((DensityC) / 2.65)))

B = (Ln(1500) - Ln(33)) / (Ln(M33C) - Ln(WPoint))

A = e^(Ln(33) + (B * Ln(M33C)))

λ = 1 / B

$XKSAT_{(full\ saturation)}$ = 1930 * (PM33C ^ (3 - **λ**)) * 0.0393700787 * Gadj

KsCF = 0.5

$XKSAT_{(natural)}$ = $XKSAT_{(full\ saturation)}$ * KsCF

If $XKSAT_{(natural)}$ < 0.01 Then

$XKSAT_{(natural)}$ = 0.01

Suction (per Rawls, Brackensiek & Miller, 1983)

BubblingPressure = -21.674 * Sand - 27.932 * Clay - 81.975 * PM33C + 71.121 * Sand * PM33C + 8.294 * Clay * PM33C + 14.05 * Sand * Clay + 27.161

BPadj = BubblingPressure + (0.02 * BubblingPressure ^ 2 - 0.113 * BubblingPressure - 0.7)

If BubblingPressure >= 0 Then

PSIF = (2 * **λ** + 3) / (2 * **λ** + 2) * BubblingPressure / 2 * 4.014630787

If BPadj >= 0 Then

PSIFadj = (2 * **λ** + 3) / (2 * **λ** + 2) * BPadj / 2 * 4.014630787

The documentation for Saxton and Rawls (2006) is found at:

https://hrsl.ba.ars.usda.gov/SPAW/Index.htm

The documentation is included as a part of the SPAW computer program available on that web page. A spreadsheet available as a part of the "Soil Water Characteristics" portion of the SPAW may be download from this website can be used to check the computations made using these equations.

6.5 Soils Data Sets

NRCS soil survey data is now available in GIS and MS Access database formats for most of the state of Nevada. These databases can be leveraged to explicitly calculate hydraulic conductivity values for each soil map unit using the Saxton and Rawls (2006) methods.

The state of Nevada includes:

- 53 Soil survey sub areas within the state.
  - 48 Detailed Soils Surveys (SSURGO)
  - 5 areas where soils data is not determined, or surveys are incomplete
- General Soils survey (STATSGO2) that covers the entire state.

Green and Ampt parameters with be provided in several formats, including a GIS database and Excel Spreadsheets; NDOT will determine the data format most useful. Database files will document input data used and resultant Green and Ampt parameters calculated for each soils map unit (SMU).

As noted above for areas labeled as incomplete or for areas with missing data, it is recommended that the NRCS statewide soil survey be used. **Figure 6** shows a map of the detailed soil survey areas.

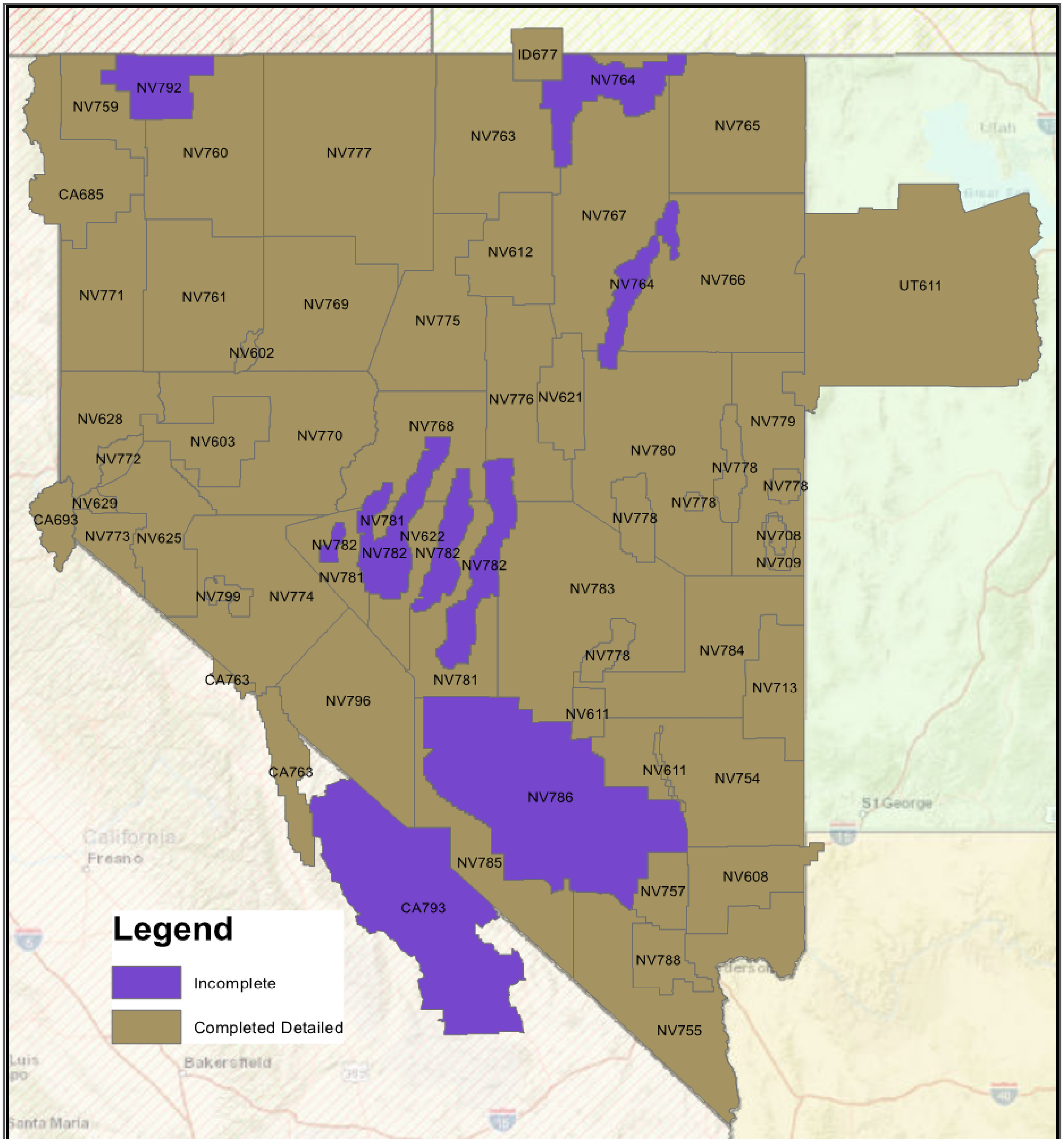

Figure 6 Map of detailed soil survey areas in Nevada

For GIS shapefile deliverables, only the horizons in the top 3 inches of soil will be considered. Within the top 3 inches, the horizon with the lowest Conductivity values will be selected as the controlling horizon. This selection is made to provide a conservative estimate with minimum infiltration and maximum runoff set by the controlling soil horizon.

6.6 Independent Data Checks

Data independent quality checks will be conducted on a sample of the Green and Ampt parameter data using the public domain Soil Water Characteristics - Hydraulic Properties Calculator Version 6.02.75. This program uses the Saxton and Rawls series of equations to estimate soil water tension, conductivity and water holding capability based on the soil texture, organic matter, gravel content, salinity, and compaction. Soil Water Characteristics is a program included with the SPAW installation. It is used to simulate soil water tension, conductivity and water holding capability based on the soil texture, with adjustments to account for gravel content, compaction, salinity, and organic matter. When using the given values, it is important to understand that they are estimations and may not reflect the actual values for a given situation. Upper and lower limits of input values have been set to maintain the validity of calculations.

7. Recommendations

It is recommended that NDOT apply the use Green and Ampt rainfall loss estimation method for computing rainfall losses consistent with the 2014 ADOT Hydrology Manual.

This includes:

- Consideration be given to compilation of supplemental guidance for selection of surface retention loss values and effective impervious areas. Reference to data provided in 2014 ADOT Hydrology Manual, Arizona ADWR State Standard SS10-07, Maricopa County Drainage Design Manual, and Mohave County Drainage Design Manual will be collected and presented to assist determination of these parameters in the updated NDOT Rainfall Loss Parameters.
- Use of soil conductivity and suction based on work by Saxton and Rawls (2006). This is similar to methods presented in 2014 ADOT Hydrology Manual and Mohave County, Arizona. Additional studies have been undertaken by Arid Hydrology & Hydraulics, LLC, and work at Flood Control District of Maricopa (FCDMC) with Desert Research Institute.
- Use of Initial/Saturated Content relationships along the lines of work presented in 2014 ADOT Hydrology Manual and the Mohave County Drainage Design Manual (2018).

We also anticipate compilation and/or development of GIS databases containing the new parameters for the Statewide (STATSGO2) Soil Survey as well as the existing published detailed (SSURGO) surveys.

Preparation of a guidance document that outlines the computational database processing technique used to develop Green and Ampt parameters for Nevada soil surveys.

Prepare an internal self-help document to aid NDOT in the application of the Green and Ampt methods when using HEC-HMS.

8. References

Arizona Department of Transportation, 2014, Highway Drainage Design Manual Hydrology, prepared by JE Fuller Hydrology and Geomorphology, Inc.

Arizona Department of Transportation, 1993, Highway Drainage Design Manual Hydrology, ADOT Report No. FHWA-AZ93-281, George V. Sabol Consulting Engineers & NBS/Lowry Engineers & Planners.

Arizona Department of Water Resources, 2007, State Standard for Hydrologic Modeling Guidelines, State Standard No. 10-07, prepared by Stantec Consulting & JE Fuller/ Hydrology & Geomorphology, Inc.

Arkell, R.E. and Richards, F., 1986, Short duration rainfall relations for the Western United States: in conference on Climate and Water Management: A Critical Era, and Conference on the Human Consequences of 1985's Climate American Meteorological Society, pp. 136-141.

Bouwer, H., 1966, Rapid Field Measurement of Air Entry Value and Hydraulic Conductivity of Soil as Significant Parameters in Flow System Analysis, Water Resources Research, Vol. 2, No. 4, p. 729-738.

Chen, L., J. Miller, T. Caldwell, G. Dalldorf, K. Chief, M. Young, and L. Xiang, 2010, Terrain, Soils and Runoff Potential in the Rainbow Wash Watershed, Maricopa County, Arizona, report prepared by Desert Research Institute for US Army Corps of Engineers and Flood Control District of Maricopa County, 82 p.

Chow, V.T., Maidment, D.R., and Mays, L.W., 1988, Applied Hydrology, McGraw-Hill, New York, NY.

Flood Control District of Maricopa County, 2011, Drainage Design Manual for Maricopa County, Hydrology, revision dated Feb. 10, 2011.

Flood Control District of Mohave County, 2009, Drainage Design Manual for Mohave County, first edition, dated Aug. 24, 2009.

Mohave County Flood Control District. (May 2018). Drainage Design Manual for Mohave County, 3rd Edition

Rawls, W.J., and Brakensiek, D.L., 1983, A procedure to predict Green and Ampt infiltration parameters, Proceedings of the American Society of Agricultural Engineers Conference on Advances in Infiltration, Chicago, Illinois, pp. 102-112.

Saxton, K. E., and W. J. Rawls, 2006, Soil Water Characteristic Estimates by Texture and Organic Matter for Hydrologic Solutions, Soil Science Society of America Journal 70:1569-1578

SSURGO (Soil Survey Geographic Database) detailed soil survey data and STATSGO2 (State Soil Geographic Database) general soil survey data obtained from the NRCS

U.S. Army Corps of Engineers, 2000, Hydrologic Modeling System, HEC-HMS, Technical Reference Manual, March 2000, U.S. Army Corps of Engineers Hydrologic Engineering Center, A.D. Feldman, editor, CPD-74B, Davis, CA, 148 p.

U.S. Army Corps of Engineers, 1998, HEC-1 Flood Hydrograph Package, Hydrologic Engineering Center, Davis, CA.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration National Weather Service, 2011, NOAA Atlas 14 Precipitation-Frequency Atlas of the United States, Volume 1 Version 5.0: Semiarid Southwest (Arizona, Southeast California, Nevada, New Mexico, Utah) Geoffrey M. Bonnin, Deborah Martin, Bingzhang Lin, Tye Parzybok, Michael Yekta, David Riley, Silver Spring, Maryland, 2004, revised 2006 and 2011.

Yavapai County Flood Control District. (June 2014). Drainage Design Manual for Yavapai County.

List of additional references are provided as an attachment.

9. Attachment

Data Collection Summary

Project	Document	DOCUMENT				
Library No.	Reference No.	Title	Reference Type	Author	Date	File Name
NDOT001		Truckee River Watershed Regional Hydrologic Model. Model Documentation Report	Report PDF(32 separate files)	Kimley-Horn	7/10/2014	Various PDF
NDOT002	J. Hydrol. Eng., 2019, 24(10): 04019034	SCS Curve Number and Green-Ampt Infiltration Models	Technical Paper	Giorgio Baiamonte	4/1/2019	(ASCE)HE.1943-5584.0001838.pdf
NDOT003	J. Irrig. Drain Eng., 2019, 145(4): 06019002	Anomalous Behavior of the Curve-Number Infiltration Model	Technical Paper	David A. Chin	6/1/2019	(ASCE)IR.1943-4774.0001381.pdf CN overprediction.pdf
NDOT004	J. Hydrol. Eng., 2019, 24(7): 06019003	Understanding the Basis of the Curve Number Method for Watershed Models and TMDLs	Technical Paper	Richard H. Hawkins, F.ASCE Fred D. Theurer, Ph.D. and Mehdi Rezaeianzadeh, Ph.D.	6/1/2019	CN basis.pdf
NDOT005		MASTER DRAINAGE STUDY FOR TRADITIONS VILLAGE 1 Dayton, Lyon County, Nevada	Drainage Study	Stan Lucas	9/24/2018	Traditions 1 drainage report2.pdf
NDOT006		United States Department of Agriculture, Natural Resources Conservation Service, Part 630 Hydrology, National Engineering Handbook, Chapter 9: Hydrologic Soil-Cover Complexes	Technical Paper (Draft)	ASCE	9/30/2017	NRCS CN directive.pdf
NDOT007	J. Hydrol. Eng., 2018, 23(8): 04018032	Consequences of Changes to the NRCS Rainfall-Runoff Relations on Hydrologic Design	Technical Paper	G. E. Moglen, F.ASCE R. H. McCuen, M.ASCE and R. L. Moglen	4/1/2018	(ASCE)HE.1943-5584.0001681.pdf nrcs equations.pdf
NDOT008	WA-RD 872.2	Stormwater Infiltration in Highway Embankments – Saturated Hydraulic Conductivity Estimation for Natural Low Plasticity Silts	Research Report	Tony M. Allen (WSDOT)	12/1/2018	872-2.pdf
NDOT009		Arizona Department of Transportation, Highway Drainage Design Manual, Volume 2 Hydrology	Technical Manual	JE Fuller	1/1/2014	2014_ADOT_Hydrology_Manual.pdf
NDOT010		Arizona Department of Transportation, Highway Drainage Design Manual, Volume 2 Hydrology, Appendix	Technical Manual	JE Fuller	1/1/2014	2014_ADOT_Hydrology_Manual_Appendix.pdf
NDOT011		Nevada Department of Transportation, Drainage Manual, 2nd Edition.	Technical Manual	NDOT Hydraulics Section	12/1/2006	drainage_manual2006.pdf
NDOT012		Clark County Regional Flood Control District, Hydrologic Criteria and Drainage Design Manual	Technical Manual	CCRFCD	8/12/1999	hcddm.pdf
NDOT013	FHWA-NHI-02-001	U.S. Department of Transportation, Federal Highway Administration, Hydraulic Design Series No. 2, Second Edition, Highway Hydrology	Technical Manual	Richard H. McCuen, Peggy A. Johnson, Robert M. Ragan	10/1/2002	hif02001.pdf
NDOT014		United States Department of Agriculture, Natural Resources Conservation Service, Web Soil Survey	Electronic Soil Survey Geographic (SSURGO) Database (51 folders)	NRCS	Varies	Varies. Shapefiles, txt, xml, mdb

Project	Document	DOCUMENT				
Library No.	Reference No.	Title	Reference Type	Author	Date	File Name
NDOT015		United States Department of Agriculture, Natural Resources Conservation Service, Web Soil Survey	Electronic Soil Survey Geographic (STATSGO) Database (Nevada)	NRCS	10/13/2016	Varies. Shapefiles, txt, xml, mdb
NDOT016		Mohave County Flood Control District. (December 2018). Drainage Design Manual for Mohave County, 3rd Edition.	Technical Manual	Mohave County	5/1/2018	DDM for Mohave County Appendices 3rd Ed 2018.pdf
NDOT017		Soil Water Characteristic Estimates by Texture and Organic Matter for Hydrologic Solutions. Soil Science Society of America Journal (70), 1569-1578.	Research Report	Saxton, K. E., & Rawls, W. J. (2006)	8/3/2006	sssaj-70-5-1569.pdf
NDOT018	Hydrol. Process. 27, 1265–1275 (2013)	Curve-Number/Green–Ampt mixed procedure for streamflow predictions in ungauged basins: Parameter sensitivity analysis	Technical Paper	S. Grimaldi, A. Petroselli and N. Romano	1/1/2013	731235.pdf cn and g and a.pdf
NDOT019	(JAWRA) 54(1): 148-159	Managing Uncertainty In Runoff Estimation With The U.S. Environmental Protection Agency National Stormwater Calculator, Journal of The American Water Resources Association Vol. 54, No. 1 American Water Resources Association	Technical Paper	L.A. Schifman, M.E. Tryby, J. Berner, and W.D. Shuster	2/1/2018	197704349.pdf epa stormwater calculator.pdf
NDOT020	J. Irrig. Drain Eng., 2017, 143(9): 07017015	Closure to “Return Period–Dependent Rational Formula Coefficients for Two Locations in Texas”	Technical Memo	David C Froehlich	1/1/2017	(ASCE)IR.1943-4774.0001229.pdf
NDOT021	J. Irrig. Drain Eng., 2018, 144(1): 04017056	Field-Obtained Soil Water Characteristic Curves and Hydraulic Conductivity Functions	Technical Paper	Elvis Ishimwe, Johnathan Blanchard; and Richard A. Coffman	1/1/2018	(ASCE)IR.1943-4774.0001272.pdf
NDOT022	J. Hydrol. Eng., 2017, 22(6): 06017001	Estimating the Parameters of the Curve Number Model	Technical Note	David A. Chin	1/1/2017	CN and initial abstraction.pdf
NDOT023		Modeling Highway Stormwater Runoff and Groundwater Table Variations with SWMM and GSSHA	Technical Paper	Mitchell F. Moore; Jose G. Vasconcelos; and Wesley C. Zech	1/1/2017	GSSHA vs SWMM using G and A.pdf
NDOT024		Curve Number Estimation Accuracy on Disturbed and Undisturbed Soils	Technical Paper (Draft)	Reid D. Christianson, P.E.; Stacy L. Hutchinson, and Glenn O. Brown, P.E; A.M.ASCE	1/1/2016	CN from KSAT.pdf
NDOT025		Modified CN Method for Small Watershed Infiltration Simulation	Technical Paper	Shu-Mei Zhou; David N. Warrington, Ting-Wu Lei; Qi-Xiang Lei; Man-Liang Zhang	1/1/2015	Modified CN method.pdf
NDOT026		Curve Number: Empirical Evaluation and Comparison with Curve Number Handbook Tables in Sicily	Technical Paper	Francesco D' Asaro; Giovanni Grillone; Richard H. Hawkins, F	1/1/2014	CN use Ia of 0.05.pdf
NDOT027		Modified Green-Ampt Infiltration Model for Steady Rainfall	Technical paper	J.Almedij and I.I.Esen	1/1/2014	Modified G and A steady rainfall.pdf
NDOT028		Curve Number Method: Time to Think Anew?	Technical Paper	Richard H. Hawkins, Ph.D.,P>E.;ASCE	1/1/2014	(ASCE)HE.1943-5584.0000954.pdf CN method re evaluation.pdf

Project	Document	DOCUMENT				
Library No.	Reference No.	Title	Reference Type	Author	Date	File Name
NDOT029		Method for Estimating Concentration Time and Storage Coefficient of the Clark Model Using Rainfall-Runoff Measurements	Technical Paper	Chulsang Yoo, Ph.D., A.M.ASCE; Jiho Lee, Ph.D., A.m.ASCE, Changyeol Park, Ph.D., A.M.ASCE; and Changhyun Jun, A.M.ASCE	3/1/2014	Clark TC and Storage Coeff.pdf
NDOT030		Determination of Clark's Unity Hydrograph Parameters for Watersheds	Technical Paper	Daniel Che ; Mandar Nangare ; and Larry W. Mays, F.ASCE	2/1/2014	Clark Unit Hydrographs Parameters.pdf
NDOT031		Relationship between Runoff Curve Number and PET	Technical paper	S. K. Mishra; S. S. Rawat; R. P. Pandey; Shiulee Chakraborty; M. K. Jain; and U. C. Chaube	2/1/2014	CN from PET.pdf
NDOT032		Determination of Optimal Unit Hydrographs and Green-Ampt Parameters for Watersheds	Technical Paper	Daniel Che, M.ASCE; Mandar Nangare, M.ASCE; and Larry W. Mays, F.ASCE	2/1/2014	Determination Unit Hydrographs and G&A Parameters.pdf
NDOT033		Spatial and Temporal Scale Effect in Simulating Hydraulic Processes in a Watershed	Technical Paper	Zhongbo Yu; Qingguan Lu; Jianting Zhu; Chuanguo Yang; Qin Ju; Tao Yang; Xi Chen;and Edward A. Sudicky	1/1/2014	G&A spatial variability.pdf
NDOT034		Characteristics of Ephemeral Hydrographs in the Southwestern United States	Technical Paper	Rina Schumer; Anna Knust; and Douglas P. Boyle	1/1/2014	Hydrographs in SouthWest USA.pdf
NDOT035		Flood Investigations in Nevada: A Partnership of the USGS and Nevada Department of Transportation	Fact Sheet	USGS	5/1/1998	USGS flow report.pdf
NDOT036		Using the KINEROS2 Modeling Framework to Evaluate the Increase in Storm Runoff from Residential Development in a Semiarid Environment	Technical Paper	Jeffrey R. Kennedy; David C. Goodrich, M.ASCE; and Carl L. Unkrich	1/1/2013	SP3 modified G&A infiltration.pdf
NDOT037		Curve Number Determination methods and Uncertainty in Hydrolic Soil Groups from Semiarid Watershed Data	Technical Paper	Dave Stewart, P.E., M.ASC1; Evan Canfield, Ph.D., P.E., M.ASCE; and, Richard Hawkins, Ph.D., P.E., F.ASCE	1/1/2012	semi arid CN.pdf
NDOT038		Effects of Measurement Method, Scale, and Landscape Features on Variability of Saturated Hydraulic Conductivity	Technical Paper	Wei Hu; Mingan Shao; Quanjiu Wang; and Dongli She	1/1/2013	Soil hydraulic conductivity.pdf
NDOT039		Peak Files	zip	USGS	unknown	peak_kml.zip, peak_sites.txt, and peak_table.txt
NDOT044		Standard Guideline for the Geostatistical Estimation and Block-Averaging of Homogeneous and Isotropic Saturated Hydraulic Conductivity	Technical paper	ASCE	1/1/2010	asce geostatistical estimation KSAT.pdf
NDOT045		Calculation of the Saturated Hydraulic Conductivity of Fine-Grained Soils	Technical Paper	ASCE	1/1/2017	ASCE KSAT Publication.pdf
NDOT046		Standard Guideline for Fitting Saturated Hydraulic Conductivity Using probability Density Functions --- Standard Guideline for Calculating the Effective Saturated Hydraulic Conductivity	Technical Paper	ASCE	1/1/2008	ASCE std for calc effective KSAT.pdf
NDOT047		Curve Number Hydrology - State of the Practice	Technical Paper	Richard H. Hawkins, Timothy J. Ward, Donald E. Woodward, Joseph A. Van Mullem	1/1/2009	CN Handbook.pdf

Project	Document	DOCUMENT				
Library No.	Reference No.	Title	Reference Type	Author	Date	File Name
NDOT048		Comparison of Infiltration Equations and Their Field Validation by Rainfall Simulation	Technical Paper	Ellen Turner, University of Maryland	1/1/2006	Maryland G&A vs CN.pdf
NDOT049	J. Hydrol. Eng., 2019, 24(10): 04019034	SCS Curve Number and Green-Ampt Infiltration Models	Technical Paper	Giorgio Baiamonte	4/1/2019	scs and G&A.pdf
NDOT050	Article in Journa l of Irrigation and Drainage Engineering · March 1993	Asymptotic Determination of Runoff Curve Numbers From Data	Technical Paper	Richard H. Hawkins	3/1/1993	1993AsymptCNASCE.pdf
NDOT051	Article in Hydrol ogical Processes · April 2013	Curve-Number/Green-Ampt mixed procedure for streamflow predictions in ungauged basins: Parameter sensitivity analysis	Technical Paper	S. Grimaldi, A. Petroselli and N. Romano	4/1/2013	Curve-NumberGreen-Ampt_mixed_procedure_for_streamf.pdf
NDOT052	Article in Water Resources Management · September 2009	Estimation of the Runoff Curve Number via Direct Rainfall Simulator Measurements in the State of Iowa, USA	Technical Paper	Mohamed Elhakeem, Thanos Papanicolaou, University of Tennessee	9/1/2009	Estimation_of_the_Runoff_Curve_Number_via_Direct_R.pdf
NDOT053	Article in Hydrol ogical Processes · April 2013	Green-Ampt Curve Number mixed procedure as an empirical tool for rainfall-runoff modelling in small and ungauged basins	Technical Paper	S. Grimaldi, A. Petroselli and N. Romano	4/1/2013	Grimaldietal2013Green-AmptCurveNumbermixedprocedure.pdf
NDOT054	Article in Journa l of Hydrology and Hydromechanics · June 2015	Optimal parameters for the Green-Ampt infiltration model under rainfall conditions	Technical Paper	Li Chen, Long Xiang, Michael H. Young, Jun Yin, Zhongbo Yu, Martinus Th. van Genuchten	6/1/2015	johh-2015-0012.pdf
NDOT055		Applications of the Green-Ampt infiltration model to watersheds in Montana and Wyoming	Thesis	Joseph Alphonse Van Mullem	1/1/1989	Montana G and A.pdf
NDOT056	Article in Water Resources Management · October 2006	An Improved IaS Relation Incorporating Antecedent Moisture in SCS-CN Methodology	Technical Paper	S. K. MISHRA, R. K. SAHU, T. I. ELDHO and M. K. JAIN	10/10/2006	Rks-wrm-2006.pdf
NDOT057	Article in Water Resources Research · July 2012	The Green-Ampt limit with reference to infiltration coefficients	Technical Paper	D.Triadis andP.Broadbridge	7/1/2012	TriadisBroadbridge12.pdf
NDOT058		Hydrologic Modeling System (HEC-HMS) Adaptions for the Province of Ontario	PPT	Bill Scharffenberg, PhD HEC-HMS Lead Developer Hydrologic Engineering Center	3/5/2019	TechTransfer2019_5_Sharffenberg_HEC-HMS_Adaptions_For_Ontario.pdf
NDOT059		Object-GAWSER Object-Oriented Guelph All-Weather Storm-Event Runoff Model Phase 1: Training Manual Application of Object-Oriented Simulation to Hydrologic Modeling	Manual	John A Hinckley, Jr.	2/1/1996	gawser manual.pdf
NDOT060		Green-Ampt Infiltration Parameters from Soils Data	Technical Paper	Walter J. Rawls, Donald L. Brakensiek, and Norman Miller	1/1/1983	(asce)0733-9429(1983)109_1(62) Rawls 1983.pdf
NDOT061		Hydrologic Properties of Porous Media	Paper	R.H. Brooks and A. T. Corey Colorado State University	3/1/1964	Brooks_Corey_1964_Hydraulic_Properties_ERMS241117.pdf
NDOT062		Drainage Design Manual for Yavapai County	Manual	Yavapai County Flood Control District	5/1/2014	2014_DDMforYavapaiCountyFinal.pdf

Project	Document	DOCUMENT				
Library No.	Reference No.	Title	Reference Type	Author	Date	File Name
NDOT063		Probabilistic Dam Breach Modeling Users Manual. Version 5.0.7	Manual	Kleinschmidt	6/1/2019	McBreach507UsersManual.pdf
NDOT064		Simulating runoff generation and its spatial correlation with environmental factors in Sancha River Basin: The southern source of the Wujiang River	Technical Paper	HOU Wenjuan, GAO Jiangbo	1/1/2019	karst china.pdf
NDOT065		SWAT-BASED STREAMFLOW AND EMBAYMENT MODELING OF KARST-AFFECTED CHAPEL BRANCH WATERSHED, SOUTH CAROLINA	Technical Paper	D. M. Amatya, M. Jha, A. E. Edwards, T. M. Williams, D. R. Hitchcock	1/1/2011	karst flow modeling ja_2011_amatya_001.pdf
NDOT066		SHORT DURATION RAINFALL RELATIONS FOR THE WKSTEKB UNITED STATES	Technical Paper	Richard E. Arkell and Frank Richards	8/4/1986	Arkell_Richards.pdf
NDOT067		The impact of rainfall distribution patterns on hydrological and hydraulic response in arid regions: case study Medina, Saudi Arabia	Technical Paper	Mohamed Abdulrazzak, Amro Elfeki, Ahmed Samy Kamis, Mostafa Kassab, Nassir Alamri, Kashif Noor & Anis Chaabani	5/1/2018	66617.pdf
NDOT068		Green-Ampt infiltration model to watersheds in Montana and Wyoming	Technical Paper	Joseph Alphonse Van Mullem	5/1/1998	Montana G and A.pdf
NDOT069		Impact of Infiltration Process Modeling on Runoff Simulations: The Bonis River Basin	Technical Paper	Giovanni Ravazzani , Tommaso Caloiero, Mouna Feki and Gaetano Pellicone	7/30/2018	proceedings-02-00638-v2 g and a.pdf
NDOT070	Scientific Investigations Report 2014-5035	U.S. Geological Survey Karst Interest Group Proceedings, Carlsbad, New Mexico,	Report	USGS	4/29/2014	usgs 2014 karst K26-03299-sir2014-5035.pdf

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