From: Craig Kantola
To: Alan Plumeau
Subject: FW: hillsdale county stormwater plans
Date: Monday, May 16, 2022 10:00:23 AM

From: Matt Word <m.word@co.hillsdale.mi.us>
Sent: Monday, April 4, 2022 8:26 AM
To: Craig Kantola <ckantola@atwell-group.com>
Subject: hillsdale county stormwater plans

Craig, we currently do not have a stormwater management plan in place at this time. However, if there is a county drain near or in your worksite you would need to obtain a county drain permit from my office.

Please feel free to reach out to me if you have any further questions.

Thanks

Matt Word, Drain Commissioner
Hillsdale County
Drain Commission
33 McCollum St. Room 110
Hillsdale, MI 49242
Office: 517-437-4181
Shop: 517-523-3832
Cell: 517-617-1372
E-Mail: m.word@co.hillsdale.mi.us

Meeting Notes

Project Name: Heartwood Solar Project

Notes by: Craig Kantola, Bourke Thomas – Atwell, LLC

Subject: Heartwood Solar Stormwater

Location: Hillsdale County Drain Commission Garage
3591 Hudson Road, Osseo, MI, 49266

Date/Time: April 5, 2022 @ 10:30-11:15 AM

☒ Meeting ☐ Phone Conversation ☐ Incoming Call ☐ Outgoing Call

Attendee | ☒ Copies to Attendees (check all that apply)

☒ Matt Word – Hillsdale County

☒ Rob – Hillsdale County

☒ Toby Valentino – Ranger Power

☒ Bourke Thomas – Atwell, LLC

☒ Craig Kantola – Atwell, LLC

☐

Heartwood Solar Project

1. Introductions
    a. 150MWac Solar Project
    b. +/-1,073 acres of fenced array/substation
       +/-980 acres of existing developed agricultural land
       +/- 93 acres of existing undeveloped wooded land
    c. Project anticipates no adverse impacts to wetlands, streams, floodplains, or County Drains. Vast majority of proposed fenced array area is currently developed for agricultural crop production. Only approximately 9% of proposed fenced array is currently undeveloped natural/wooded land cover.

Discussion Summary

1. Spicer is the consultant for the Drain Commission – contact Rich Graham (Dundee office)
2. Timeframe – submit SLUP in late June 2022
3. Recently completed wind farm had many drain impacts that had to be addressed during construction – didn't go over well with the agencies. DC appreciates Ranger's proactive meeting request to discuss project.
4. Cursory review of drain map – likely few County Drain impacts associated with collection crossings
    a. County offered Atwell online access to drain maps – request form submitted 4/6/22
    b. There are enclosed County drains – they will show up on drain maps
    c. Easement/ROW widths vary, up to 100' wide

    d. Drain commissioner would request the entire drain right of way be bored with collection line crossings at a minimum depth of 4-feet below flow line.
        i. The county doesn't have current information on the designed depths of most of the county drains
5. Atwell requested stormwater standards – the Drain Commission and County don't currently have standards at this time
    a. Atwell discussed general stormwater runoff from solar farms – will not increase runoff due to change in land use from crop to grassy field with minimal gravel cover. Drain Commission was in general agreement and did not say that any stormwater management features would be needed. Only concern is impacts to County drains
6. SESC is handled by the County Building Department – contact Marty Taylor
7. The EGLE Water Resources Permitting would be handled through the Jackson District office and Kate Kirkpatrick would be the reviewer
8. Farm tiles likely present in areas, however the soils are generally sandy/gravel so the need for tiles in many areas may be minimal
    a. Atwell recommended that Ranger ask prospective landowners for any drain tile maps / information they may have available
    b. Drain Commission asked if local contractors are used for this type of work (farm tile repairs, etc). Ranger said they do like to involve local contractors when possible

Hydrologic Response of Solar Farms

Lauren M. Cook, S.M.ASCE[1]; and Richard H. McCuen, M.ASCE[2]

Abstract: Because of the benefits of solar energy, the number of solar farms is increasing; however, their hydrologic impacts have not been studied. The goal of this study was to determine the hydrologic effects of solar farms and examine whether or not storm-water management is needed to control runoff volumes and rates. A model of a solar farm was used to simulate runoff for two conditions: the pre- and postpaneled conditions. Using sensitivity analyses, modeling showed that the solar panels themselves did not have a significant effect on the runoff volumes, peaks, or times to peak. However, if the ground cover under the panels is gravel or bare ground, owing to design decisions or lack of maintenance, the peak discharge may increase significantly with storm-water management needed. In addition, the kinetic energy of the flow that drains from the panels was found to be greater than that of the rainfall, which could cause erosion at the base of the panels. Thus, it is recommended that the grass beneath the panels be well maintained or that a buffer strip be placed after the most downgradient row of panels. This study, along with design recommendations, can be used as a guide for the future design of solar farms. **DOI: 10.1061/(ASCE)HE.1943-5584.0000530.**

CE Database subject headings: Hydrology; Land use; Solar power; Floods; Surface water; Runoff; Stormwater management.

Author keywords: Hydrology; Land use change; Solar energy; Flooding; Surface water runoff; Storm-water management.

Introduction

Storm-water management practices are generally implemented to reverse the effects of land-cover changes that cause increases in volumes and rates of runoff. This is a concern posed for new types of land-cover change such as the solar farm. Solar energy is a renewable energy source that is expected to increase in importance in the near future. Because solar farms require considerable land, it is necessary to understand the design of solar farms and their potential effect on erosion rates and storm runoff, especially the impact on offsite properties and receiving streams. These farms can vary in size from 8 ha (20 acres) in residential areas to 250 ha (600 acres) in areas where land is abundant.

The solar panels are impervious to rain water; however, they are mounted on metal rods and placed over pervious land. In some cases, the area below the panel is paved or covered with gravel. Service roads are generally located between rows of panels. Altlhough some panels are stationary, others are designed to move so that the angle of the panel varies with the angle of the sun. The angle can range, depending on the latitude, from 22° during the summer months to 74° during the winter months. In addition, the angle and direction can also change throughout the day. The issue posed is whether or not these rows of impervious panels will change the runoff characteristics of the site, specifically increase runoff volumes or peak discharge rates. If the increases are hydrologically significant, storm-water management facilities may be needed. Additionally, it is possible that the velocity of water draining from the edge of the panels is sufficient to cause erosion of the soil below the panels, especially where the maintenance roadways are bare ground.

The outcome of this study provides guidance for assessing the hydrologic effects of solar farms, which is important to those who plan, design, and install arrays of solar panels. Those who design solar farms may need to provide for storm-water management. This study investigated the hydrologic effects of solar farms, assessed whether or not storm-water management might be needed, and if the velocity of the runoff from the panels could be sufficient to cause erosion of the soil below the panels.

Model Development

Solar farms are generally designed to maximize the amount of energy produced per unit of land area, while still allowing space for maintenance. The hydrologic response of solar farms is not usually considered in design. Typically, the panels will be arrayed in long rows with separations between the rows to allow for maintenance vehicles. To model a typical layout, a unit width of one panel was assumed, with the length of the downgradient strip depending on the size of the farm. For example, a solar farm with 30 rows of 200 panels each could be modeled as a strip of 30 panels with space between the panels for maintenance vehicles. Rainwater that drains from the upper panel onto the ground will flow over the land under the 29 panels on the downgradient strip. Depending on the land cover, infiltration losses would be expected as the runoff flows to the bottom of the slope.

To determine the effects that the solar panels have on runoff characteristics, a model of a solar farm was developed. Runoff in the form of sheet flow without the addition of the solar panels served as the prepaneled condition. The paneled condition assumed a downgradient series of cells with one solar panel per ground cell. Each cell was separated into three sections: wet, dry, and spacer.

The dry section is that portion directly underneath the solar panel, unexposed directly to the rainfall. As the angle of the panel from the horizontal increases, more of the rain will fall directly onto

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the ground; this section of the cell is referred to as the wet section. The spacer section is the area between the rows of panels used by maintenance vehicles. Fig. 1 is an image of two solar panels and the spacer section allotted for maintenance vehicles. Fig. 2 is a schematic of the wet, dry, and spacer sections with their respective dimensions. In Fig. 1, tracks from the vehicles are visible on what is modeled within as the spacer section. When the solar panel is horizontal, then the length longitudinal to the direction that runoff will occur is the length of the dry and wet sections combined. Runoff from a dry section drains onto the downgradient spacer section. Runoff from the spacer section flows to the wet section of the next downgradient cell. Water that drains from a solar panel falls directly onto the spacer section of that cell.

The length of the spacer section is constant. During a storm event, the loss rate was assumed constant for the 24-h storm because a wet antecedent condition was assumed. The lengths of the wet and dry sections changed depending on the angle of the solar panel. The total length of the wet and dry sections was set equal to the length of one horizontal solar panel, which was assumed to be 3.5 m. When a solar panel is horizontal, the dry section length would equal 3.5 m and the wet section length would be zero. In the paneled condition, the dry section does not receive direct rainfall because the rain first falls onto the solar panel then drains onto the spacer section. However, the dry section does infiltrate some of the runoff that comes from the upgradient wet section. The wet section was modeled similar to the spacer section with rain falling directly onto the section and assuming a constant loss rate.

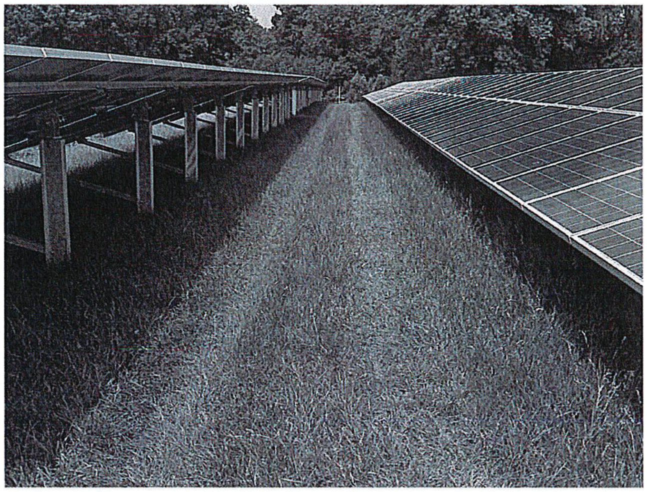

Fig. 1. Maintenance or "spacer" section between two rows of solar panels (photo by John E. Showler, reprinted with permission)

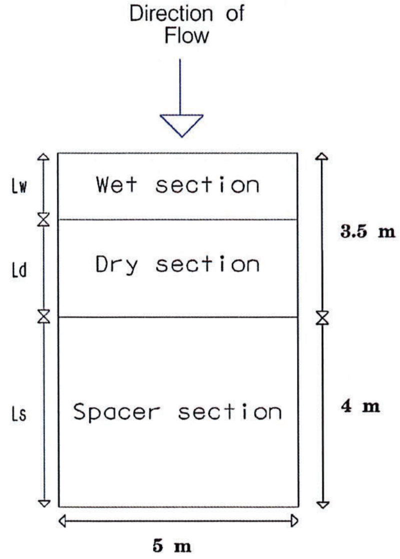

Fig. 2. Wet, dry, and spacer sections of a single cell with lengths *Lw*, *Ls*, and *Ld* with the solar panel covering the dry section

For the presolar panel condition, the spacer and wet sections are modeled the same as in the paneled condition; however, the cell does not include a dry section. In the prepaneled condition, rain falls directly onto the entire cell. When modeling the prepaneled condition, all cells receive rainfall at the same rate and are subject to losses. All other conditions were assumed to remain the same such that the prepaneled and paneled conditions can be compared.

Rainfall was modeled after an natural resources conservation service (NRCS) Type II Storm (McCuen 2005) because it is an accurate representation of actual storms of varying characteristics that are imbedded in intensity-duration-frequency (IDF) curves. For each duration of interest, a dimensionless hyetograph was developed using a time increment of 12 s over the duration of the storm (see Fig. 3). The depth of rainfall that corresponds to each storm magnitude was then multiplied by the dimensionless hyetograph. For a 2-h storm duration, depths of 40.6, 76.2, and 101.6 mm were used for the 2-, 25-, and 100-year events. The 2- and 6-h duration hyetographs were developed using the center portion of the 24-h storm, with the rainfall depths established with the Baltimore IDF curve. The corresponding depths for a 6-h duration were 53.3, 106.7, and 132.1 mm, respectively. These magnitudes were chosen to give a range of storm conditions.

During each time increment, the depth of rain is multiplied by the cell area to determine the volume of rain added to each section of each cell. This volume becomes the storage in each cell. Depending on the soil group, a constant volume of losses was subtracted from the storage. The runoff velocity from a solar panel was calculated using Manning's equation, with the hydraulic radius for sheet flow assumed to equal the depth of the storage on the panel (Bedient and Huber 2002). Similar assumptions were made to compute the velocities in each section of the surface sections.

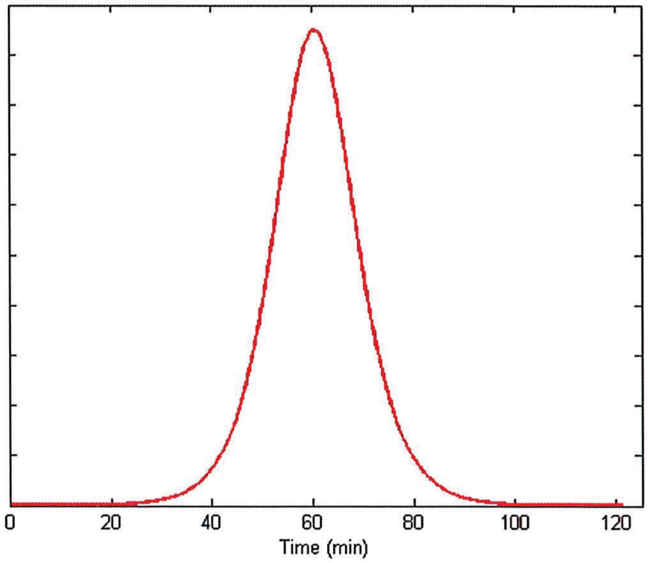

Fig. 3. Dimensionless hyetograph of 2-h Type II storm

Runoff from one section to the next and then to the next downgradient cell was routed using the continuity of mass. The routing coefficient depended on the depth of flow in storage and the velocity of runoff. Flow was routed from the wet section to the dry section to the spacer section, with flow from the spacer section draining to the wet section of the next cell. Flow from the most downgradient cell was assumed to be the outflow. Discharge rates and volumes from the most downgradient cell were used for comparisons between the prepaneled and paneled conditions.

Alternative Model Scenarios

To assess the effects of the different variables, a section of 30 cells, each with a solar panel, was assumed for the base model. Each cell was separated individually into wet, dry, and spacer sections. The area had a total ground length of 225 m with a ground slope of 1% and width of 5 m, which was the width of an average solar panel. The roughness coefficient (Engman 1986) for the silicon solar panel was assumed to be that of glass, 0.01. Roughness coefficients of 0.15 for grass and 0.02 for bare ground were also assumed. Loss rates of 0.5715 cm/h (0.225 in./h) and 0.254 cm/h (0.1 in./h) for B and C soils, respectively, were assumed.

The prepaneled condition using the 2-h, 25-year rainfall was assumed for the base condition, with each cell assumed to have a good grass cover condition. All other analyses were made assuming a paneled condition. For most scenarios, the runoff volumes and peak discharge rates from the paneled model were not significantly greater than those for the prepaneled condition. Over a total length of 225 m with 30 solar panels, the runoff increased by 0.26 m^3, which was a difference of only 0.35%. The slight increase in runoff volume reflects the slightly higher velocities for the paneled condition. The peak discharge increased by 0.0013 m^3, a change of only 0.31%. The time to peak was delayed by one time increment, i.e., 12 s. Inclusion of the panels did not have a significant hydrologic impact.

Storm Magnitude

The effect of storm magnitude was investigated by changing the magnitude from a 25-year storm to a 2-year storm. For the 2-year storm, the rainfall and runoff volumes decreased by approximately 50%. However, the runoff from the paneled watershed condition increased compared to the prepaneled condition by approximately the same volume as for the 25-year analysis, 0.26 m^3. This increase represents only a 0.78% increase in volume. The peak discharge and the time to peak did not change significantly. These results reflect runoff from a good grass cover condition and indicated that the general conclusion of very minimal impacts was the same for different storm magnitudes.

Ground Slope

The effect of the downgradient ground slope of the solar farm was also examined. The angle of the solar panels would influence the velocity of flows from the panels. As the ground slope was increased, the velocity of flow over the ground surface would be closer to that on the panels. This could cause an overall increase in discharge rates. The ground slope was changed from 1 to 5%, with all other conditions remaining the same as the base conditions.

With the steeper incline, the volume of losses decreased from that for the 1% slope, which is to be expected because the faster velocity of the runoff would provide less opportunity for infiltration. However, between the prepaneled and paneled conditions, the increase in runoff volume was less than 1%. The peak discharge and the time to peak did not change. Therefore, the greater ground slope did not significantly influence the response of the solar farm.

Soil Type

The effect of soil type on the runoff was also examined. The soil group was changed from B soil to C soil by varying the loss rate. As expected, owing to the higher loss rate for the C soil, the depths of runoff increased by approximately 7.5% with the C soil when compared with the volume for B soils. However, the runoff volume for the C soil condition only increased by 0.17% from the prepaneled condition to the paneled condition. In comparison with the B soil, a difference of 0.35% in volume resulted between the two conditions. Therefore, the soil group influenced the actual volumes and rates, but not the relative effect of the paneled condition when compared to the prepaneled condition.

Panel Angle

Because runoff velocities increase with slope, the effect of the angle of the solar panel on the hydrologic response was examined. Analyses were made for angles of 30° and 70° to test an average range from winter to summer. The hydrologic response for these angles was compared to that of the base condition angle of 45°. The other site conditions remained the same. The analyses showed that the angle of the panel had only a slight effect on runoff volumes and discharge rates. The lower angle of 30° was associated with an increased runoff volume, whereas the runoff volume decreased for the steeper angle of 70° when compared with the base condition of 45°. However, the differences (~0.5%) were very slight. Nevertheless, these results indicate that, when the solar panel was closer to horizontal, i.e., at a lower angle, a larger difference in runoff volume occurred between the prepaneled and paneled conditions. These differences in the response result are from differences in loss rates.

The peak discharge was also lower at the lower angle. At an angle of 30°, the peak discharge was slightly lower than at the higher angle of 70°. For the 2-h storm duration, the time to peak of the 30° angle was 2 min delayed from the time to peak of when the panel was positioned at a 70° angle, which reflects the longer travel times across the solar panels.

Storm Duration

To assess the effect of storm duration, analyses were made for 6-h storms, testing magnitudes for 2-, 25-, and 100-year return periods, with the results compared with those for the 2-h rainfall events. The longer storm duration was tested to determine whether a longer duration storm would produce a different ratio of increase in runoff between the prepaneled and paneled conditions. When compared to runoff volumes from the 2-h storm, those for the 6-h storm were 34% greater in both the paneled and prepaneled cases. However, when comparing the prepaneled to the paneled condition, the increase in the runoff volume with the 6-h storm was less than 1% regardless of the return period. The peak discharge and the time-to-peak did not differ significantly between the two conditions. The trends in the hydrologic response of the solar farm did not vary with storm duration.

Ground Cover

The ground cover under the panels was assumed to be a native grass that received little maintenance. For some solar farms, the area beneath the panel is covered in gravel or partially paved because the panels prevent the grass from receiving sunlight. Depending on the volume of traffic, the spacer cell could be grass, patches of grass, or bare ground. Thus, it was necessary to determine whether or not these alternative ground-cover conditions would affect the runoff characteristics. This was accomplished by changing the Manning's *n* for the ground beneath the panels. The value of *n* under the panels, i.e., the dry section, was set to 0.015 for gravel, with the value for the spacer or maintenance section set to 0.02, i.e., bare ground. These can be compared to the base condition of a native grass ($n = 0.15$). A good cover should promote losses and delay the runoff.

For the smoother surfaces, the velocity of the runoff increased and the losses decreased, which resulted in increasing runoff volumes. This occurred both when the ground cover under the panels was changed to gravel and when the cover in the spacer section was changed to bare ground. Owing to the higher velocities of the flow, runoff rates from the cells increased significantly such that it was necessary to reduce the computational time increment. Fig. 4(a) shows the hydrograph from a 30-panel area with a time increment of 12 s. With a time increment of 12 s, the water in each cell is discharged at the end of every time increment, which results in no attenuation of the flow; thus, the undulations shown in Fig. 4(a) result. The time increment was reduced to 3 s for the 2-h storm, which resulted in watershed smoothing and a rational hydrograph shape [Fig. 4(b)]. The results showed that the storm runoff increased by 7% from the grass-covered scenario to the scenario with gravel under the panel. The peak discharge increased by 73% for the gravel ground cover when compared with the grass cover without the panels. The time to peak was 10 min less with the gravel than with the grass, which reflects the effect of differences in surface roughness and the resulting velocities.

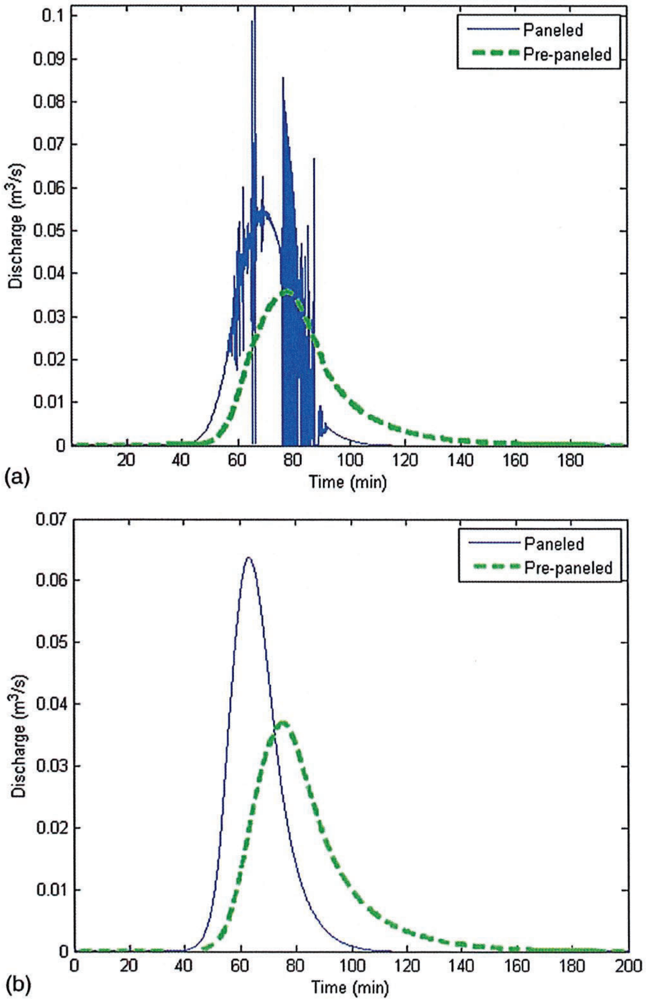

Fig. 4. Hydrograph with time increment of (a) 12 s; (b) 3 s with Manning's *n* for bare ground

If maintenance vehicles used the spacer section regularly and the grass cover was not adequately maintained, the soil in the spacer section would be compacted and potentially the runoff volumes and rates would increase. Grass that is not maintained has the potential to become patchy and turn to bare ground. The grass under the panel may not get enough sunlight and die. Fig. 1 shows the result of the maintenance trucks frequently driving in the spacer section, which diminished the grass cover.

The effect of the lack of solar farm maintenance on runoff characteristics was modeled by changing the Manning's *n* to a value of 0.02 for bare ground. In this scenario, the roughness coefficient for the ground under the panels, i.e., the dry section, as well as in the spacer cell was changed from grass covered to bare ground ($n = 0.02$).The effects were nearly identical to that of the gravel. The runoff volume increased by 7% from the grass-covered to the bare-ground condition. The peak discharge increased by 72% when compared with the grass-covered condition. The runoff for the bare-ground condition also resulted in an earlier time to peak by approximately 10 min. Two other conditions were also modeled, showing similar results. In the first scenario, gravel was placed directly under the panel, and healthy grass was placed in the spacer section, which mimics a possible design decision. Under these conditions, the peak discharge increased by 42%, and the volume of runoff increased by 4%, which suggests that storm-water management would be necessary if gravel is placed anywhere.

Fig. 5 shows two solar panels from a solar farm in New Jersey. The bare ground between the panels can cause increased runoff rates and reductions in time of concentration, both of which could necessitate storm-water management. The final condition modeled involved the assumption of healthy grass beneath the panels and bare ground in the spacer section, which would simulate the condition of unmaintained grass resulting from vehicles that drive over the spacer section. Because the spacer section is 53% of the cell, the change in land cover to bare ground would reduce losses and decrease runoff travel times, which would cause runoff to amass as it

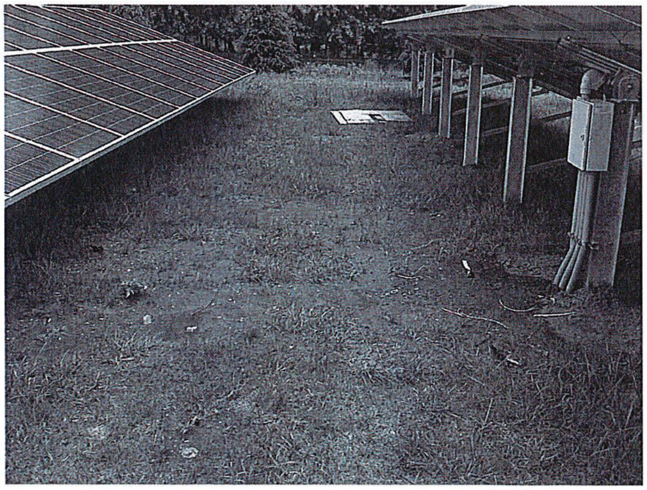

Fig. 5. Site showing the initiation of bare ground below the panels, which increases the potential for erosion (photo by John Showler, reprinted with permission)

moves downgradient. With the spacer section as bare ground, the peak discharge increased by 100%, which reflected the increases in volume and decrease in timing. These results illustrate the need for maintenance of the grass below and between the panels.

Design Suggestions

With well-maintained grass underneath the panels, the solar panels themselves do not have much effect on total volumes of the runoff or peak discharge rates. Although the panels are impervious, the rainwater that drains from the panels appears as runoff over the downgradient cells. Some of the runoff infiltrates. If the grass cover of a solar farm is not maintained, it can deteriorate either because of a lack of sunlight or maintenance vehicle traffic. In this case, the runoff characteristics can change significantly with both runoff rates and volumes increasing by significant amounts. In addition, if gravel or pavement is placed underneath the panels, this can also contribute to a significant increase in the hydrologic response.

If bare ground is foreseen to be a problem or gravel is to be placed under the panels to prevent erosion, it is necessary to counteract the excess runoff using some form of storm-water management. A simple practice that can be implemented is a buffer strip (Dabney et al. 2006) at the downgradient end of the solar farm. The buffer strip length must be sufficient to return the runoff characteristics with the panels to those of runoff experienced before the gravel and panels were installed. Alternatively, a detention basin can be installed.

A buffer strip was modeled along with the panels. For approximately every 200 m of panels, or 29 cells, the buffer must be 5 cells long (or 35 m) to reduce the runoff volume to that which occurred before the panels were added. Even if a gravel base is not placed under the panels, the inclusion of a buffer strip may be a good practice when grass maintenance is not a top funding priority. Fig. 6 shows the peak discharge from the graveled surface versus the length of the buffer needed to keep the discharge to prepaneled peak rate.

Water draining from a solar panel can increase the potential for erosion of the spacer section. If the spacer section is bare ground, the high kinetic energy of water draining from the panel can cause soil detachment and transport (Garde and Raju 1977; Beuselinck et al. 2002). The amount and risk of erosion was modeled using the velocity of water coming off a solar panel compared with the velocity and intensity of the rainwater. The velocity of panel runoff was calculated using Manning's equation, and the velocity of falling rainwater was calculated using the following:

$$V_t = 120\, d_r^{0.35} \qquad (1)$$

where d_r = diameter of a raindrop, assumed to be 1 mm. The relationship between kinetic energy and rainfall intensity is

$$K_e = 916 + 330 \log_{10} i \qquad (2)$$

where i = rainfall intensity (in./h) and K_e = kinetic energy (ft-tons per ac-in. of rain) of rain falling onto the wet section and the panel, as well as the water flowing off of the end of the panel (Wischmeier and Smith 1978). The kinetic energy (Salles et al. 2002) of the rainfall was greater than that coming off the panel, but the area under the panel (i.e., the product of the length, width, and cosine of the panel angle) is greater than the area under the edge of the panel where the water drains from the panel onto the ground. Thus, dividing the kinetic energy by the respective areas gives a more accurate representation of the kinetic energy experienced by the soil. The energy of the water draining from the panel onto the ground can be nearly 10 times greater than the rain itself falling onto the ground area. If the solar panel runoff falls onto an unsealed soil, considerable detachment can result (Motha et al. 2004). Thus, because of the increased kinetic energy, it is possible that the soil is much more prone to erosion with the panels than without. Where panels are installed, methods of erosion control should be included in the design.

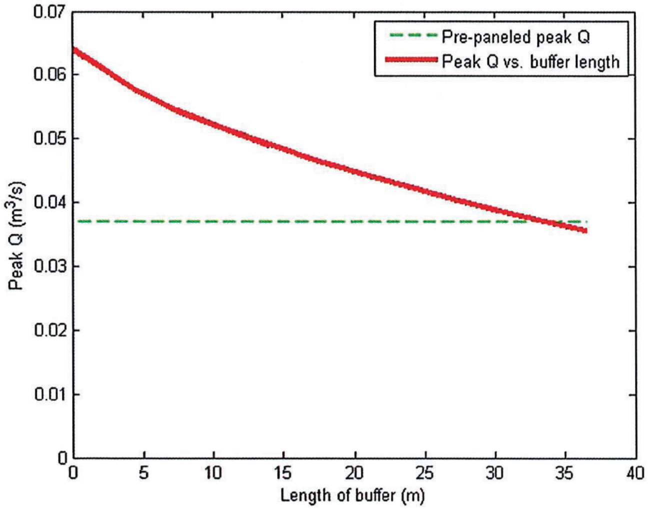

Fig. 6. Peak discharge over gravel compared with buffer length

Conclusions

Solar farms are the energy generators of the future; thus, it is important to determine the environmental and hydrologic effects of these farms, both existing and proposed. A model was created to simulate storm-water runoff over a land surface without panels and then with solar panels added. Various sensitivity analyses were conducted including changing the storm duration and volume, soil type, ground slope, panel angle, and ground cover to determine the effect that each of these factors would have on the volumes and peak discharge rates of the runoff.

The addition of solar panels over a grassy field does not have much of an effect on the volume of runoff, the peak discharge, nor the time to peak. With each analysis, the runoff volume increased slightly but not enough to require storm-water management facilities. However, when the land-cover type was changed under the panels, the hydrologic response changed significantly. When gravel or pavement was placed under the panels, with the spacer section left as patchy grass or bare ground, the volume of the runoff increased significantly and the peak discharge increased by approximately 100%. This was also the result when the entire cell was assumed to be bare ground.

The potential for erosion of the soil at the base of the solar panels was also studied. It was determined that the kinetic energy of the water draining from the solar panel could be as much as 10 times greater than that of rainfall. Thus, because the energy of the water draining from the panels is much higher, it is very possible that soil below the base of the solar panel could erode owing to the concentrated flow of water off the panel, especially if there is bare ground in the spacer section of the cell. If necessary, erosion control methods should be used.

Bare ground beneath the panels and in the spacer section is a realistic possibility (see Figs. 1 and 5). Thus, a good, well-maintained grass cover beneath the panels and in the spacer section is highly recommended. If gravel, pavement, or bare ground is deemed unavoidable below the panels or in the spacer section, it may necessary to add a buffer section to control the excess runoff volume and ensure adequate losses. If these simple measures are taken, solar farms will not have an adverse hydrologic impact from excess runoff or contribute eroded soil particles to receiving streams and waterways.

Acknowledgments

The authors appreciate the photographs (Figs. 1 and 5) of Ortho Clinical Diagnostics, 1001 Route 202, North Raritan, New Jersey, 08869, provided by John E. Showler, Environmental Scientist, New Jersey Department of Agriculture. The extensive comments of reviewers resulted in an improved paper.

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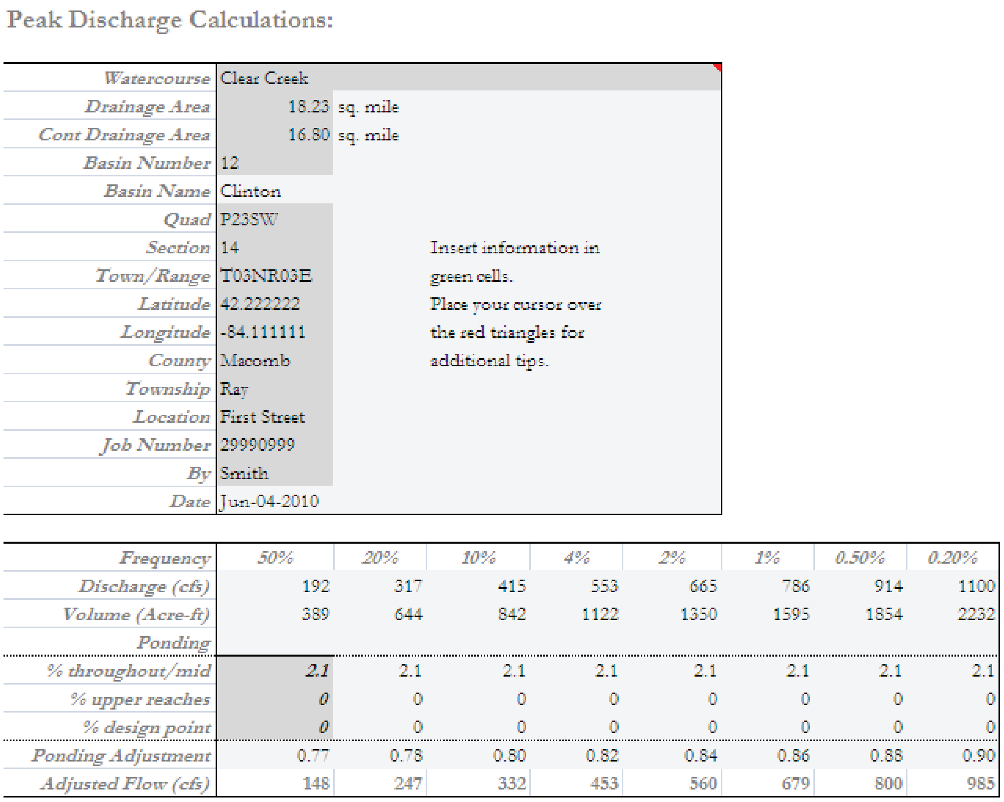
Computing Flood Discharges

For Small Ungaged Watersheds



Peak Discharge Calculations:

Watercourse	Clear Creek	
Drainage Area	18.23	sq. mile
Cont Drainage Area	16.80	sq. mile
Basin Number	12	
Basin Name	Clinton	
Quad	P23SW	
Section	14	
Town/Range	T03NR03E	
Latitude	42.222222	
Longitude	-84.111111	
County	Macomb	
Township	Ray	
Location	First Street	
Job Number	29990999	
By	Smith	
Date	Jun-04-2010	

Insert information in green cells.
Place your cursor over the red triangles for additional tips.

Frequency	*50%*	*20%*	*10%*	*4%*	*2%*	*1%*	*0.50%*	*0.20%*
Discharge (cfs)	192	317	415	553	665	786	914	1100
Volume (Acre-ft)	389	644	842	1122	1350	1595	1854	2232
Ponding								
% throughout/mid	***2.1***	2.1	2.1	2.1	2.1	2.1	2.1	2.1
% upper reaches	***0***	0	0	0	0	0	0	0
% design point	***0***	0	0	0	0	0	0	0
Ponding Adjustment	0.77	0.78	0.80	0.82	0.84	0.86	0.88	0.90
Adjusted Flow (cfs)	148	247	332	453	560	679	800	985

Richard C. Sorrell, P.E.
Michigan Department of Natural Resources and Environment
Land and Water Management Division
June 22, 2010
www.michigan.gov/hydrology

This report supersedes and replaces all previous versions that describe this method, including *Computing Flood Discharges For Small Ungaged Watersheds* (Sorrell and Hamilton, September 1991, July 2000, October 2001; *Computing Flood Discharges For Small Ungaged Watersheds* (Sorrell, July 2003 and June 2008), as well as *SCS UD-21 Method* (Sorrell, 1980 and 1985).

Revisions Summary

January 2010: Clarifies that the Appendix B hydrologic soil groups are not current and provides reference for current soils data. Clarifies maximum length for sheet flow and use of ponding adjustment at design point. Presents ordinates of Michigan unit hydrograph for use in WinTR-55. Changes unit hydrograph peak designation from Q_{up} as q_p' to match SCS designation. Contact: Linda Burke, 517-241-3720.

August 2008: Clarifies the minimum T_c applicable to the Michigan Unit hydrograph and designate the unit hydrograph peak as Q_{up} instead of Q_p. Contact: Dave Fongers, 517-373-0210.

June 2008: Revises three curve numbers that were less than 30 up to 30 (on Table 6-1) to reflect revised Natural Resources Conservation Service guidance, http://directives.sc.egov.usda.gov/media/pdf/H_210_630_9.pdf. Contact: Dave Fongers, 517-373-0210.

Table of Contents

List of Tables

List of Figures

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Computing Flood Discharges For Small Ungaged Watersheds

1. Introduction

Concern for potential flooding is a critical factor in the safe design of water-related projects. The magnitudes of floods are described by flood discharge, flood elevation, and flood volume. This report will detail a procedure that can be used to estimate both the discharge and volume of a flood given a design rainfall and a physical description of the watershed.

There are a variety of methods for estimating design floods. They can be grouped into three general categories.

1. Statistical analysis of gage data
   This method is used for streams which have a number of years of recorded flood data. It involves fitting a probability distribution to the data (usually the log-Pearson Type III) and using the parameters of the distribution to estimate large floods. Since this method utilizes actual flood data, it is generally regarded as the best estimator of design floods and should be used whenever possible.

2. Regression analysis
   This method involves correlating watershed characteristics to streamflow using data from a number of gaged streams. The predicting equation derived from this type of analysis usually expresses flood discharge as a function of multiple watershed characteristics. These equations almost always include drainage area as the most significant factor and may also include channel slope, precipitation intensity, and other characteristics related to land uses, soil types, and geologic formations in the watershed. This method can be used for ungaged stream locations.

3. Unit hydrograph techniques
   This method involves determining the peak rate of runoff, q_p', expressed in cubic feet per second (cfs) per inch of runoff from a given drainage area. This factor is primarily a function of the time it takes for runoff to travel through the basin to the design point. Once this rate of runoff is determined, it can be multiplied by the amount of runoff to produce a discharge. The versatility of this method is that it can account for changes in watershed travel time, and subsequently q_p', that are caused by alterations in the hydraulic capacity of the stream, such as channel maintenance operations, flood control structures, etc. The volume of runoff from a given amount of rainfall can also be adjusted to reflect changing land use within a watershed. This method is suitable for ungaged watersheds.

4. Drainage Area Ratio method
   Flows can be estimated if the flows are known at an upstream or downstream location using a drainage area ratio equation. Contact DNRE Hydrologic Studies program staff for more information.

This report presents a method for computing flood discharges using unit hydrograph (UH) techniques. The procedure is similar to that developed by the U.S. Department of Agriculture Soil Conservation Service (SCS), now known as the Natural Resource Conservation Service (NRCS). The “SCS Method” is described in the NRCS National Engineering Handbook (NEH), Part 630: Hydrology (2004).

The advantage of this method is that it is straightforward to apply and the physical parameters are easily determined. The primary disadvantage is that the method presented here is only valid for use with a 24-hour rainfall. For other rainfall durations, one should follow the full procedure in the NRCS reference. This method should also be limited to watersheds with a drainage area of approximately 20 square miles or less. One of the reasons for this limit is that UH theory assumes uniform rainfall and runoff from the entire drainage basin. This assumption is less reliable if the drainage area becomes too large. If a large watershed is being analyzed, it should be divided into subbasins and the flows from the individual sub-areas routed to the design location.

The SCS Method is also less accurate in cases where a large fraction of precipitation infiltrates into the ground, or for small rainfall values. In both cases, runoff is a small fraction of precipitation. Therefore, the SCS Method is not recommended to estimate low flows or small, more frequent flood flows. (See Hawkins, et. al., 1985, for a precise measure of “small”.)

The physical description of the watershed includes drainage area, soil types, land uses, and time of concentration. These are discussed in subsequent sections of this report.

A comprehensive application of the SCS Method is presented in Appendix A.

2. The Unit Hydrograph

The unit hydrograph (UH) theory was first proposed by Sherman (1932). It is defined as a surface runoff hydrograph (SRH) resulting from one inch of excess rainfall generated uniformly over the drainage area at a constant rate for an effective unit time duration. Sherman originally used the word “unit” to denote a unit of time, but since then it has often been interpreted as a unit depth of excess rainfall. Sherman classified streamflow into surface runoff and groundwater runoff or baseflow. The UH is defined for use only with surface runoff. When analyzing a recorded flood hydrograph, the baseflow contribution should be subtracted from the total flow before deriving the UH. Likewise, when using a UH to compute a design flow, a baseflow should be added to obtain the total design discharge.

The following basic assumptions are inherent to the UH:

1. The excess rainfall has a constant intensity within the unit duration.
2. The excess rainfall is uniformly distributed throughout the whole drainage area.
3. The base time of the SRH (the duration of surface runoff) resulting from an excess rainfall of a given duration is constant.
4. The ordinates of all SRH of a common base time are directly proportional to the total amount of surface runoff represented by each hydrograph.
5. For a given watershed, the hydrograph resulting from a given excess rainfall reflects the unchanging characteristics of the watershed.

Assumption 3 implies that all 24-hour rainfalls will produce a SRH where the time to peak and base time of the SRH remain constant. Assumption 4 implies that if the ordinates of the UH represent one inch of runoff, then a hydrograph representing two inches of runoff is obtained by simply multiplying each ordinate of the UH by two. If all unit hydrographs conform to a constant shape, that is, a constant amount of volume under the rising limb of the UH, then both the time and discharge ordinates can be normalized to produce a dimensionless UH. The SCS examined many hydrographs nationwide and computed a standard dimensionless UH which has 37.5 percent of the volume under the rising limb. This volume has been known to vary, according to the SCS, in the range of 23 to 45 percent.

Over the years, use of the SCS dimensionless hydrograph consistently overestimates discharges when compared to recorded gage flows for Michigan streams. To partially compensate for this, the SCS Type I rainfall distribution has been used in place of the recommended, but more intense, Type II distribution. A review of hourly rainfall data shows, however, that the Type II distribution is the appropriate one to use. Therefore, a study has been done to evaluate whether the shape of the standard SCS dimensionless UH is applicable to Michigan streams.

This study involved 24 gaged streams with drainage areas less than 50 square miles. Seventy-four different flood events were analyzed. The results from this study demonstrate that the recorded floods are best reproduced if the SCS UH is revised to have 28.5 percent of the volume under the rising limb. This value is within the SCS-acknowledged range for this parameter.

3. Design Rainfall

Atlases are available from various governmental agencies which provide design rainfall amounts for durations from 30 minutes to 24 hours and recurrence intervals from 1 to 100 years. Normal practice in Michigan has been to use 24 hours as the design rainfall duration.

Formerly, rainfall amounts were taken almost exclusively from Hershfield (1961), commonly known as the U.S. Weather Bureau's Technical Paper 40 (TP-40).

However, rainfall amounts well in excess of the frequency predicted by TP-40 have been occurring in Michigan and throughout the country for a number of years. Part of the reason may be that TP-40 utilized a shorter data set ending in 1958. Sorrell and Hamilton (1991) analyzed 24-hour rainfall data through 1986 for Michigan gages in order to update the TP-40 information. Huff and Angel (1992) also analyzed rainfall data for the Midwest, including Michigan, for durations from 5 minutes to 10 days. The 24-hour results from these two studies are similar.

Since the Huff and Angel study cover more durations and frequencies, we recommend its use to obtain design rainfall for the method presented in this report. This study was published as the "Rainfall Frequency Atlas of the Midwest" by the Midwestern Climate Center and the Illinois State Water Survey, and is commonly known as "Bulletin 71".

The Bulletin 71 study divided the state into ten climatic zones that correspond to the weather forecast divisions used by the National Weather Service at that time. These 10 climatic zones are depicted in Figure 3.1. The rainfall frequency data for each climatic zone is presented in Table 3.1. To use this map and table, locate the design point in Figure 3.1 and use the corresponding climatic zone number to obtain the rainfall amounts from the corresponding Section in Table 3.1. If the watershed straddles two or more climatic zones, use the rainfall for the zone that contains the largest percentage of the total drainage area.

The design rainfall data are point estimates and must be adjusted if the drainage area is greater than ten square miles. The adjustment ratio, listed in Table 3.2, accounts for uncertainty in the areal distribution. These adjustment ratios are taken from Figure 21.2 in Chapter 21 of the NRCS National Engineering Handbook. Values for intermediate drainage areas may be interpolated from the table.

4. Soil Type

Soil properties influence the process of generating runoff from rainfall and must be considered in methods of runoff estimation. When runoff from an individual storm is the major concern, the properties can be represented by a hydrologic parameter which reflects the minimum rate of infiltration obtained for a bare soil after prolonged wetting. The influences of both the surface and the horizons of the soil are therefore included.

Four hydrologic soil groups are used. The soils are classified on the basis of water intake at the end of long-duration storms occurring after prior wetting and an opportunity for swelling and without the protective effects of vegetation. In the definitions to follow, the infiltration rate is the rate at which water enters the soil at the surface, which is controlled by surface conditions. The transmission rate is the rate at which the water moves downward through the soil and is controlled by the horizons. The hydrologic soil groups, as defined by NRCS soil scientists, are:

A. Soils having high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well to excessively drained sands or gravels. These soils have a high rate of water transmission.

B. Soils having moderate infiltration rates when thoroughly wetted and consisting of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.

C. Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes the downward movement of water or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.

D. Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

Figure 3.1 - Climatic Zones for Michigan

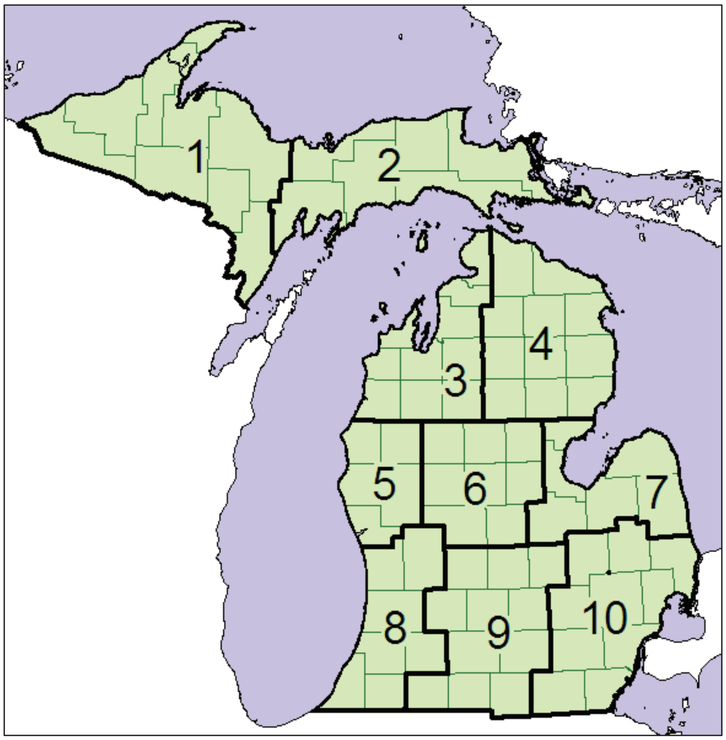

Table 3.1 - Rainfall depths corresponding to the climatic zones in Figure 3.1

Zone	Annual probability storm depth, 24-hour duration (rainfall in inches)					
	50%	**20%**	**10%**	**4%**	**2%**	**1%**
1	2.39	3.00	3.48	4.17	4.73	5.32
2	2.09	2.71	3.19	3.87	4.44	5.03
3	2.09	2.70	3.21	3.89	4.47	5.08
4	2.11	2.62	3.04	3.60	4.06	4.53
5	2.28	3.00	3.60	4.48	5.24	6.07
6	2.27	2.85	3.34	4.15	4.84	5.62
7	2.14	2.65	3.05	3.56	3.97	4.40
8	2.37	3.00	3.52	4.45	5.27	6.15
9	2.42	2.98	3.43	4.09	4.63	5.20
10	2.26	2.75	3.13	3.60	3.98	4.36

Table 3.2 - Ratios for areal adjustment of point rainfall

Area (mi^2)	Ratio
10	1.000
15	0.978
20	0.969
25	0.964
30	0.960
35	0.957
40	0.953

Appendix B tabulates the hydrologic soil group for many soil series as of March 1990, and is presented as an example only. See below for information on obtaining current soils data

As shown in Appendix B, in some cases, several possible hydrologic soil groupings may be listed for a soil series. When this occurs, the first hydrologic group shown is the native or natural group under which the soil series is usually classified when its water intake characteristics have not been significantly changed by artificial drainage, land use, or other factors. The second group shown is the probable maximum improvement that can be made through artificial drainage and the maintenance or improvement of soil structure. For example, the Adrian soil series is classified as D/A. This means that the natural hydrologic soil group is D. If a field inspection shows that drains and tiles have been constructed to improve the drainage or a county drain has been installed nearby, then the hydrologic soil group may be lowered to A. In general, those soils having several possible classifications are those with relatively high water tables so that artificial drainage measurably improves their ability to absorb rainfall and thus reduce runoff.

County soil surveys have been performed by the NRCS and were originally published in book form. Surveys published since 1970 show the soil type delineations superimposed on an aerial photograph. This format allows for determining land use at the same time the soil determinations are made.

A soil's hydrologic classification may occasionally change based upon updated experimental data defining its infiltration and transmission characteristics.

The soils listed in Appendix B were last reviewed and updated in March 1990. To obtain current soils data, visit the NRCS Soil Data Mart at http://soildatamart.nrcs.usda.gov/ (this URL is current as of the date of this report).

Soils data can be downloaded at no cost as GIS shapefiles at this site, or the Web Soil Survey interactive map can be used to generate a soils map and report for any identified project site. The GIS data file must still be downloaded to access the attribute data (file name ending in .dbf) to obtain the hydrologic group for the soils complex. This file can be opened using the Excel spreadsheet program.

5. Land Use

The SCS Method evaluates the effects of the surface conditions of a watershed by means of land use and treatment classes. Land use is a means to estimate the effects of watershed cover on infiltration and runoff, and it includes most kinds of vegetation, litter, and mulch; fallow (bare) soil, as well as nonagricultural uses such as water surfaces (lakes, swamps, etc.) and impervious surfaces, such as roads, roofs, etc. Land treatment applies mainly to agricultural land uses and includes mechanical practices such as contouring and terracing, and management practices like grazing control and crop rotation. The classes consist of land use and treatment combinations likely to be found in watersheds. The following is a brief description of various land uses.

> **Pasture or range** is grassed land that is continuously used for grazing animals. The hydrologic condition is characterized by the degree of grazing and plant cover. Poor condition is heavily grazed with plant cover on less than half of the area. Fair condition has a moderate amount of grazing with plant cover on ½ to ¾ of the area. Good condition refers to light grazing with plant cover on more than ¾ of the area.
>
> **Meadow** is a field on which grass is continuously grown, protected from grazing, and generally mowed for hay.
>
> **Woods or forest** are characterized by their vegetative condition and density of the tree canopy. Poor condition refers to those woods which are either heavily grazed, regularly burned, or have had the undergrowth cleared for recreational uses. Litter, small trees, and brush are absent in this condition. Woods in fair condition may still be grazed but have not been burned. In a good condition, the woods are protected from grazing, and litter, small trees, and shrubs cover the soil.
>
> **Fallow** is the agricultural land use and treatment with the highest runoff potential. The land is kept as bare as possible to conserve moisture for use by a succeeding

crop, the concept being that soil moisture lost to runoff is offset by the gain due to reduced transpiration.

Row crop is any field crop (corn, soybeans, and sugar beets) planted in rows far enough apart that most of the soil surface has no vegetative cover through the growing season.

Small grain (wheat, oats, and barley) is planted in rows close enough that the soil surface is vegetated except during planting and shortly thereafter.

Close-seeded legumes or rotation meadow (alfalfa, sweet clover) are either planted in close rows or broadcast. This cover may be allowed to remain for more than a year so that the soil is vegetated year-round.

The four preceding agricultural land uses are also characterized by the farming practice employed. Straight row fields are those farmed in straight rows either up and down the hill or across the slope. Where land slopes are less than about two percent, farming across the slope in straight rows is equivalent to contouring. Contoured fields are those farmed as nearly as possible to conform to the natural land contours. The hydrologic effect of contouring is due to the surface storage provided by the furrows, because the storage prolongs the time during which infiltration can take place. Terracing refers to systems containing open-end level or graded terraces, grassed waterway outlets, and contour furrows between the terraces. The hydrologic effects are due to the replacement of a low-infiltration land use by grassed waterways and to the increased opportunity for infiltration in the furrows and terraces.

The four agricultural land uses are further characterized by the crop rotation. Hydrologically, rotations range from “poor” to “good” in proportion to the amount of dense vegetation in the rotation. Poor rotations are generally one-crop land uses, such as continuous corn or wheat or combinations of row crops, small grains, and fallow soil. Good rotations generally contain alfalfa or other close-seeded legume or grass to increase infiltration.

6. Runoff Curve Number

6.1 Method

In 1954, the SCS developed a unique procedure for estimating surface runoff from rainfall. This procedure, the Runoff Curve Number (RCN) technique, has proven to be a very useful tool for evaluating effects of changes in land use and treatment on surface runoff. It is the procedure most frequently used within the NRCS and by hydrologists nationwide to estimate surface runoff from ungaged watersheds.

The combination of a hydrologic soil group and a land use and treatment class is a hydrologic soil-cover complex. Each combination is assigned a RCN, which is an index to its runoff potential on soil that is not frozen. A list of these values is shown in Table 6.1. (See TR-55 documentation, Tables 2-2a through 2-2d, for additional curve numbers.)

Table 6.1 – Runoff curve numbers for hydrologic soil-cover complexes (AMC-II conditions)

Land use	**Treatment or practice**	**Hydrologic condition**	**Hydrologic soil group**			
			A	**B**	**C**	**D**
Fallow soil	Straight row		77	86	91	94
Row crops	Straight row	Poor	72	81	88	91
		Good	67	78	85	89
	Contoured	Poor	70	79	84	88
		Good	65	75	82	86
	Contoured and terraced	Poor	66	74	80	82
		Good	62	71	78	81
Small grain	Straight row	Poor	65	76	84	88
		Good	63	75	83	87
	Contoured	Poor	63	74	82	85
		Good	61	73	81	84
	Contoured and terraced	Poor	61	72	79	82
		Good	59	70	78	81
Close-seeded legumes or rotation meadow	Straight row	Poor	66	77	85	89
		Good	58	72	81	85
	Contoured	Poor	64	75	83	85
		Good	55	69	78	83
	Contoured and terraced	Poor	63	73	80	83
		Good	51	67	76	80
Pasture or range		Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
	Contoured	Poor	47	67	81	88
		Fair	30	59	75	83
		Good	30	35	70	79
Meadow			30	58	71	78
Woods		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	30	55	70	77
Residential	⅛ acre		77	85	90	92
	¼ acre		61	75	83	87
	1/3 acre		57	72	81	86
	½ acre		54	70	80	85
	1 acre		51	68	79	84
Open spaces (parks, golf courses, cemeteries, etc.)	Good condition: Grass cover > 75% of area		39	61	74	80
	Fair condition: Grass cover 50-75% of area		49	69	79	84
Commercial or business area (85% impervious)			89	92	94	95
Industrial district (72% impervious)			81	88	91	93
Farmsteads			59	74	82	86
Paved areas (roads, drive-ways, parking lots, roofs)			98	98	98	98
Water surfaces (lakes, ponds, reservoirs, etc.)			100	100	100	100
Swamp	At least 1/3 is open water		85	85	85	85
	Vegetated		78	78	78	78

RCN values are published for wet, dry, and normal soil moisture conditions. These conditions were referred to as Antecedent Moisture Condition (AMC) I (dry), II (normal), and III (wet). The AMC is related to the amount of rainfall in the five days previous to the design storm.

Note: In the late 1990s and early 2000s it was recognized that the range of RCNs for a soil/ land use condition did not correlate well to the antecedent moisture as defined above. It was determined instead that the RCN for conditions I and III represent the outer confidence limits for RCN values, and the RCN for condition II represents the mean value within the range of accepted values. The term AMC was changed to Antecedent Runoff Condition (ARC) to clarify the change in philosophy.

However, studies in Michigan have shown a strong correlation between antecedent moisture and peak runoff. For this reason, it is recommended to continue to use the antecedent moisture conditions previously recommended by the SCS for studies in Michigan.

AMC-I has the lowest runoff potential and represents dry watershed soils. AMC-III has the highest runoff potential as it represents soils that are practically saturated from antecedent rainfall or snowmelt. The AMC can be estimated from the 5-day antecedent rainfall using Table 6.2. In this table, the “growing” season in Michigan is assumed to be June through September. The limits for “dormant” season apply the remainder of the year, except when the soils are frozen or there is snow cover on the ground.

Table 6.2 – Seasonal Rainfall Limits for AMC

Antecedent Moisture Condition (AMC)	Total 5-day antecedent rainfall (inches)	
	Dormant season	Growing season
I	< 0.5	< 1.4
II	0.5 - 1.1	1.4 - 2.1
III	> 1.1	> 2.1

Although the runoff curve numbers in Table 6.1 are for AMC-II conditions, an analysis of an actual storm event may require an equivalent RCN for AMC-I or AMC-III. They may be computed by the following equations:

$$RCN(I) = \frac{4.2 * RCN(II)}{10 - 0.058 * RCN(II)} \qquad \text{(Eq. 6.1)}$$

and

$$RCN(III) = \frac{23 * RCN(II)}{10 + 0.13 * RCN(II)} \qquad \text{(Eq. 6.2)}$$

When estimating the peak discharge for an annual percent chance storm, such as the 1% annual chance storm, it is standard practice to assume AMC-II conditions. Other AMC conditions may be assumed when estimating the peak flow for an actual event, based on the observed rainfall before the event. When evaluating pre-development and post-development peak discharge rates, it is important to assume a consistent AMC for both existing and proposed conditions.

A typical watershed is comprised of many different combinations of soil types and land uses. In using the method presented here, the runoff characteristic of the watershed is represented using a weighted average or composite RCN for the entire watershed. The most practical way to determine this is to tabulate each of the four hydrologic soil groups as a percentage of the total drainage area. Land uses should then be tabulated as a percentage within each specific hydrologic soil group, along with the appropriate RCN. Multiplying the RCN by the two percentages and summing the partial RCNs over all the different soil-cover complexes yields the average watershed RCN.

An example runoff curve number calculation follows.

6.2 Runoff Curve Number Sample Calculation:

The following table was prepared for a sample watershed. The first and second columns are a summary of soil complex by hydrologic group, presented as a percentage of the drainage area. The land use for each hydrologic group is summarized next, presented as a percentage of the total area for that hydrologic group. These values are obtained by planimetry of county soils and land use maps, or from a Geographic Information System (GIS). See below for documentation on using GIS to calculate runoff curve numbers.

The runoff curve number for each land use / hydrologic soil group combination is obtained from Table 6.1 and added to the table in the column titled "RCN".

The "Partial RCN" column is the product of the percentage of the drainage area times the percent of the soil hydrologic group, times the runoff curve number. When all the partial RCNs are summed, the result is a composite runoff curve number (also called a "weighted RCN") for the watershed.

Table 6.3 – Sample RCN Calculation Table

Hydrologic Soil Group	Percent of Total Drainage Area	Land Use	Percent of Soil Group	RCN	Partial RCN
A	30	Meadow	100	30	9.0
B	50	Woods (good cover)	25	55	6.9
		Fallow soil	75	86	32.3
C	10	Pasture (fair condition)	80	79	6.3
		Woods (poor cover)	20	77	1.5
D	10	Meadow	100	78	7.8
		Composite Runoff Curve Number:		**Sum**	**63.8**

In this instance, an average RCN of 64 would be used for this watershed. Tabulating in this manner makes it easier to estimate how a change in land use will alter runoff. Here the bulk of the Partial RCN (and therefore the runoff volume) is contributed by the fallow soil. If all of this land is developed into ¼-acre residential lots (RCN 75), the composite RCN for the watershed would decrease to 60.

On the other hand, if all of the fallow land is developed into an industrial area (RCN 88), the composite RCN would increase to 65, thereby increasing surface runoff volume.

This method of computing a composite RCN works very well if all of the individual RCNs are at least 45 or above, where the correlation between RCN and SRO is virtually linear. This method also works well if all of the individual RCNs are less than 45. But there may be an occasion where the watershed has a significant amount of very low RCNs and a large amount of very high ones. Since the RCN/SRO relationship becomes less linear for the very low RCNs, proportioning the RCN to compute a composite value as described above will produce an RCN which underestimates the correct amount of runoff.

In this instance, a more accurate runoff estimate can be made by computing the incremental surface runoff (see Section 7) for each land use and summing these to obtain the total runoff. Equations 6.1 and 6.2 may then be solved to yield the composite RCN, if desired. This method of weighting the runoff requires more work than simply proportioning the RCNs. It should only be needed if more than 20 percent of the watershed has RCNs less than 45 with most of the remaining RCNs at the higher end of the scale.

This procedure can also be performed with a Geographic Information System (GIS) using land use and soils shape files. Information describing calculation of curve numbers with Geographic Information Systems (GIS) is at www.mi.gov/deqhydrology, GIS category, "Calculating Runoff Curve Numbers with GIS".

7. Surface Runoff

The total precipitation (P) in a storm can be divided into three paths that the water will follow in the hydrologic cycle. There is some initial amount of rainfall for which no runoff will occur. This quantity is the initial abstraction (I_a) and consists of interception, evaporation, and the soil-water storage that must be satisfied before surface runoff will begin. After this initial abstraction is met, the soil has a continuing abstraction capacity (F), depending on the type of soil. A rainfall rate greater than this continuing abstraction is surface runoff (SRO). These quantities can be described by the equation:

$$P = SRO + I_a + F \tag{Eq. 7.1}$$

All parameters are as described above, in total inches for the entire storm event.

While F is a continuing abstraction, there is a potential maximum retention S characteristic to each RCN. The hypothesis of the SCS Method is that the ratio of F to S is equal to the ratio of the actual runoff SRO to the potential maximum runoff, P - I_a. This is expressed as:

$$\frac{F}{S} = \frac{SRO}{P - I_a} \quad \text{(Eq. 7.2)}$$

Combining (7.1) and (7.2) to solve for SRO:

$$SRO = \frac{(P - I_a)^2}{P - I_a + S} \quad \text{(Eq. 7.3)}$$

An empirical relation was developed by studying many small experimental watersheds:

$$I_a = 0.2 * S \quad \text{(Eq. 7.4)}$$

Substituting this into (7.3) produces:

$$SRO = \frac{(P - 0.2S)^2}{P + 0.8S} \quad \text{(Eq. 7.5)}$$

where:

$$S = \frac{1000}{RCN} - 10 \quad \text{(Eq. 7.6)}$$

where S is in inches. Therefore, for a given 24-hour rainfall depth and watershed RCN, equations (7.5) and (7.6) can be solved to compute the surface runoff volume in inches over the watershed.

8. Time of Concentration

Time of concentration (T_c) is the time it takes for runoff to travel from the hydraulically most distant point in the watershed to the design point. In hydrograph analysis, T_c is the time from the end of rainfall excess to the inflection point on the falling limb of the hydrograph. This point signifies the end of surface runoff and the beginning of baseflow recession. The time of concentration may vary between different storms, especially if the rainfall is non-uniform in either areal coverage or intensity. However, in practice, a watershed's T_c is considered to be constant.

Measuring from a recorded hydrograph provides the most accurate estimate of T_c. For ungaged watersheds, T_c is calculated by estimating the travel time from the most hydraulically distant point in the watershed. Since travel time (T) equals length (L) divided by velocity (V), it is necessary to estimate the velocity through the various components of the stream network.

There are many methods used to estimate the velocity. The method presented in this report expresses velocity in the form:

$$V = K * S^{0.5} \quad \text{(Eq. 8.1)}$$

where K is a coefficient depending on the type of flow, S is the slope of the flow path in percent, and V is the velocity in feet per second.

Three flow types are used based on their designation on U.S. Geological Survey topographic maps.

Small tributary:	Permanent or intermittent streams which appear as a solid or dashed blue line on the topo maps. This also applies to a swamp that has a defined stream channel. Man-made channels and swales as shown on engineering drawings should be considered small tributaries.
Waterway:	A travel path as shown by the curves in the elevation contours on a USGS topographic map (such as a valley, swale, or shallow drainage course), but does not have a blue streamline denoting a defined channel. This also applies to a swamp that does not have a defined channel flowing through it.
Sheet Flow:	This is any overland flow path which does not conform to the waterway definition. Studies have shown that after approximately 300 feet, sheet flow forms shallow concentrated rivulets that are better defined as “waterway” flow. For this reason, Sheet Flow reach lengths should be terminated at a maximum length of 300 feet. The remaining downstream portion of the reach should be modeled using the “Waterway” velocity equation.

An illustration of each of these flow types is included in the example in Appendix A. The coefficients for each of these in Equation 8.1 are shown in Table 7-1.

Table 7.1 – Velocity Coefficients for Flow Type

Flow type	K
Small tributary	2.1
Waterway	1.2
Sheet flow	0.48

These coefficients were derived by Richardson (1969) as a means of estimating velocities when detailed stream hydraulic data are unavailable.

Once the velocity is determined, the travel time for each flow path can be computed as:

$$Tc = \sum T_i = \sum \frac{L_i}{V_i * 3600} \qquad \text{(Eq. 8.2)}$$

where T_c is time of concentration; T_i is travel time in hours; L_i is the length in feet; and V_i is velocity in feet per second for each individual flow path segment *i*.

In most watersheds, all three flow types will be present. Starting at the basin divide, the runoff may proceed from sheet flow to waterway to small tributary, then waterway again, then small tributary, etc. The T_i for each segment should be computed and then summed to give the total T_c.

It is important that the length used to compute each T_i has a uniform slope. As an example, assume a 5,000-foot length of small tributary has a change in elevation of 10.4 feet. This slope of 0.208% produces a single $T_1 = T_c$ of 1.45 hours. However, if it is known that the upper 1,000 feet of this stream falls 10 feet, and the lower 4,000 feet only falls 0.4 feet, this would produce $T_1 + T_2$ for a total T_c of 5.42 hours. Therefore, it is best to sum T_i over the smallest possible contour interval; which is usually the contour interval given for the topographic map. This interval can be increased if a visual examination of the topographic map shows a uniform spacing between successive elevation contours.

It may be necessary to evaluate several travel paths to determine which one is most hydraulically distant from the design point (has the longest travel time as described above). The longest travel time may not occur along the main channel, if a side tributary has a flatter slope.

The discharge calculation method in this report is not applicable for watersheds with a T_c less than one hour. Another SCS method, such as WinTR-55, is recommended in this case. The Michigan-specific unit hydrograph should be used with WinTR-55 to be compatible with the method presented here. The ordinates of the Michigan-specific unit hydrograph are [0.0, 0.5, 1.0, 0.8, 0.6, 0.4, 0.2, and 0.0]. Contact DNRE Hydrologic Studies Program staff for additional assistance if needed.

9. Unit Hydrograph Peak

The unit hydrograph peak (q_p') is a function of travel time through the stream system or T_c. An expression relating q_p' to T_c was developed in the following manner.

Discharges were computed for a hypothetical watershed having a drainage area of one square mile, a runoff curve number of 75, and a 24-hour design rainfall of 5 inches. The discharges were computed using the SCS TR-20 computer program and the SCS “Type II” rainfall distribution. However, in lieu of using the standard dimensionless unit hydrograph in TR-20, these simulations used the Michigan-specific unit hydrograph determined from the gage analysis discussed in Section 2 of this report.

The T_c for this hypothetical basin was varied from 1 hour to 40 hours. The peak discharge for each different T_c was divided by the volume of surface runoff to obtain q_p' which has the units of cfs per inch of runoff per square mile of drainage area. The data set of q_p' versus T_c was analyzed using a log-linear regression to obtain:

$$q_p' = 238.6 \cdot T_c^{-0.82} \qquad \text{(Eq. 9.1)}$$

This equation is only valid for T_c equal to or greater than one hour.

Q, the peak discharge in cubic feet per second (cfs), is estimated as follows:

$$Q = q_p' \cdot SRO \cdot DA \cdot POND \qquad \text{(Eq. 9.2)}$$

Where q_p' is the unit hydrograph peak in cfs per inch of runoff per square mile of drainage area; SRO is surface runoff volume in inches; DA is contributing drainage area in square miles; and POND is the ponding adjustment factor, unitless, described in the following section.

10. Adjustments for Surface Ponding

Peak flows determined in this method assume that the topography is such that surface flow into ditches, drains, and streams is approximately uniform. In areas where ponding or swampy areas occur in the watershed, a considerable amount of surface runoff may be retained in temporary storage. The peak rate of runoff should be reduced to reflect this condition.

Table 10.1 provides adjustment factors to determine this reduction based on the ratio of ponding or swampy area (as shown by the USGS map symbol for “marsh”) to the total drainage area for a range of flood frequencies. The three sections of this table provide different adjustment factors depending on where the ponding occurs in the watershed. These values were determined by the NRCS (1975) from experimental watersheds of less than 2,000 acres. These factors may still be used for larger basins until newer data become available. For percentages beyond the range in the tables, the data may be extrapolated on semi-log paper with the reduction factor on the log scale.

In some cases, it is appropriate to apply the ponding adjustment more than once. For example, assume a watershed has ponding equal to two percent of the drainage area scattered throughout and a lake that is one percent of the drainage area located in the lower portion of the basin near the design point. If the 100-year frequency flood is being determined, the peak flow should be multiplied by 0.87 for the scattered ponding and further reduced by 0.89 for the lake. This produces a total reduction factor of 0.77.

It is important to note that the ponding adjustment factor is not intended to replace a reservoir routing procedure when such is called for. The ponding adjustment factor should not include a water body immediately upstream of a design point, such as a lake outlet or dam spillway. In this case, only the peak inflow to the water body can be estimated using the method presented here. A reservoir routing model, such as HEC-HMS, must be used to estimate the peak outflow from the water body.

Table 10.1 - Adjustment factors for ponding

Percentage of ponded and swampy area	**Annual Storm Probability**					
	50%	**20%**	**10%**	**4%**	**2%**	**1%**
Ponding occurs in central parts of the watershed or is spread throughout						
0.2	0.94	0.95	0.96	0.97	0.98	0.99
0.5	0.88	0.89	0.90	0.91	0.92	0.94
1.0	0.83	0.84	0.86	0.87	0.88	0.90
2.0	0.78	0.79	0.81	0.83	0.85	0.87
2.5	0.73	0.74	0.76	0.78	0.81	0.84
3.3	0.69	0.70	0.71	0.74	0.77	0.81
5.0	0.65	0.66	0.68	0.72	0.75	0.78
6.7	0.62	0.63	0.65	0.69	0.72	0.75
10	0.58	0.59	0.61	0.65	0.68	0.71
20	0.53	0.54	0.56	0.60	0.63	0.68
Ponding occurs only in upper reaches of watershed						
0.2	0.96	0.97	0.98	0.98	0.99	0.99
0.5	0.93	0.94	0.94	0.95	0.96	0.97
1.0	0.90	0.91	0.92	0.93	0.94	0.95
2.0	0.87	0.88	0.88	0.90	0.91	0.93
2.5	0.85	0.85	0.86	0.88	0.89	0.91
3.3	0.82	0.83	0.84	0.86	0.88	0.89
5.0	0.80	0.81	0.82	0.84	0.86	0.88
6.7	0.78	0.79	0.80	0.82	0.84	0.86
10	0.77	0.77	0.78	0.80	0.82	0.84
20	0.74	0.75	0.76	0.78	0.80	0.82
Ponding occurs only in lower reaches of watershed						
0.2	0.92	0.94	0.95	0.96	0.97	0.98
0.5	0.86	0.87	0.88	0.90	0.92	0.93
1.0	0.80	0.81	0.83	0.85	0.87	0.89
2.0	0.74	0.75	0.76	0.79	0.82	0.86
2.5	0.69	0.70	0.72	0.75	0.78	0.82
3.3	0.64	0.65	0.67	0.71	0.75	0.78
5.0	0.59	0.61	0.63	0.67	0.71	0.75
6.7	0.57	0.58	0.60	0.64	0.67	0.71
10	0.53	0.54	0.56	0.60	0.63	0.68
20	0.48	0.49	0.51	0.55	0.59	0.64

11. Summary of Method

This section summarizes the steps needed to compute discharges using the procedures in this report.

1. Delineate the watershed boundaries on a topographic map and measure the total drainage area. If there are deep depressions within this boundary or other areas that do not contribute to runoff, measure these and subtract them from the total drainage area. The area remaining is termed the 'contributing drainage area' and is the portion of the watershed which will be used in subsequent calculations.

   Note: Some judgment needs to be used when defining noncontributing areas. If a topo map with a five-foot contour interval shows two nested depression contours, we know that portions of the entire depression are at least five feet deep. The volume of the depression can be calculated and compared to the volume of runoff which drains into it. If it can contain all of the runoff, the entire area draining into the depression may be deleted as 'noncontributing area'. However, if the topo map only shows a single depression contour, it could be anywhere from a few inches deep to just under five feet deep. In this case, there is no definitive way to tell how much runoff this depression can store. In this instance, it may be necessary to conduct a field inspection of the watershed to ascertain the storage potential of the depression area.

2. Overlay the boundaries of the contributing drainage area on soil and land use maps and tabulate the hydrologic soil-cover/land use complexes in the watershed. Assign curve numbers using Table 6.1 and calculate the composite RCN as outlined in Section 6.

3. Starting at the design point and working upstream, tabulate incremental travel times using the procedure in section 8. When reaching a junction of two or more streams, follow the one which will result in the longest T_c. After reaching the most upstream point (as defined by a blue line on topo maps), determine any additional contribution to T_c due to overland and sheet flow paths. Add all of the incremental travel times to determine the watershed T_c. Compute q_p' using equation 9.1.

4. Select a design frequency and determine the 24-hour rainfall from Table 3.1. If the contributing drainage area is greater than 10 square miles, adjust the rainfall using Table 3.2.

5. Using the weighted RCN computed in step 2, calculate the surface runoff for the selected design event using equations 7.5 and 7.6.

6. Estimate surface ponding as a percent of the contributing drainage area and determine the ponding adjustment factor from Table 10.1.

7. Compute the peak discharge using Equation 9.2.

12. References

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Appendix A - Sample Application

The bridge at the Brocker Road crossing of the example watershed needs to be replaced. The watershed that contributes runoff to this point, which is depicted in Figure A.1, has a drainage area of 2.43 square miles and is undergoing urbanization. All of the areas which are currently either pasture or meadow will be developed into ¼-acre residential subdivisions. What effect will this have on the design flood produced by the 100-year, 24-hour rainfall?

Figure A.1 is an enlargement of a USGS topographic map. The contour interval for this map is 10 feet. In this figure, a thick black line is used to denote the watershed boundary. The blue lines inside the boundary show the small tributaries in the basin. The irregularly shaped blue areas show the locations of lakes and ponds, while the lighter green patches show the wooded portions of the watershed. The following table shows the different soil groups and associated land uses as they currently exist in the watershed.

Table A.1 – RCN Calculation

Hydrologic Soil Group	Percent of Total Drainage Area	Land Use	Percent of Soil Group	RCN	Partial RCN
A	7	Meadow	25	30	0.5
		Pasture (fair)	15	49	0.5
		Row crop (cont./good)	60	65	2.7
B	84	Small grain (cont./good)	60	73	36.8
		Pasture (fair condition)	25	69	14.5
		Woods (poor cover)	10	66	5.5
		Meadow	5	58	2.4
D	9	Meadow	35	78	2.5
		Woods (good cover)	5	77	0.3
		Lakes and ponds	15	100	1.4
		Swamps (vegetated)	35	78	2.5
		Swamps (open water)	10	85	0.8
				Sum	70.4

Deleting the contribution from meadows and pastures and replacing them with the RCNs for the residential lots changes the composite RCN to 73.4. Common practice is to round off the computed RCN, so this watershed would have curve numbers of 70 and 73 to represent existing and proposed development conditions, respectively.

The time of concentration is computed along the travel path beginning at the headwaters in Section 36 and proceeding in a northeastward direction. The travel path begins with a short section of sheet flow to the area shown as swamp (waterway flow), then continues to the upstream end of the tributary. The small tributary portions were generally divided into lengths which correspond with the contour interval of the topo map. The following table shows the computations:

Table A.2 – Time of Concentration Calculation

Type of flow	Length (ft)	∆ Elevation (ft)	Slope (%)	Velocity (fps)	Incremental T_c (hr)
Small trib.	1640	12	0.73	1.80	0.25
“ “	1380	10	0.73	1.79	0.21
“ “	1970	10	0.51	1.50	0.37
“ “	1520	10	0.66	1.70	0.25
“ “	6870	8	0.12	0.72	2.66
Waterway	1840	2	0.11	0.40	1.29
Sheet	150	22	14.67	1.84	0.02
				Sum	**5.05**

Summing the incremental travel times produces a total T_c of 5.05 hours. Substituting this into equation (9.1) produces a peak discharge of 63.24 cfs per square mile per inch of runoff. The table shows that the slope of the small tributary is not uniform over its entire length. If the slope is calculated as a 50-foot drop over the 13,400-foot length, the resulting total T_c is 4.21 hours. This produces a q_p’ of 65.79 cfs/square mile-in. Thus, the design discharge would have been 13 percent higher because of an error in calculating T_c. This illustrates the importance of using the most refined data available; in this case, the distance between successive 10-foot contours.

The 100-year, 24-hour rainfall obtained from Table 3.1 is 4.36 inches. Using this value and the previously computed RCNs, the runoff can be determined using equations (7.5) and (7.6). For existing conditions (RCN=70), the runoff is 1.57 inches. The runoff for proposed development conditions (RCN=73) is 1.79 inches.

The design discharge is obtained by simply multiplying the computed q_p’ by the drainage area and the computed runoff. These results are:

Existing: Q = 63.24 cfs/square mile-in * 2.43 square mile * 1.57 in
= 241 cfs

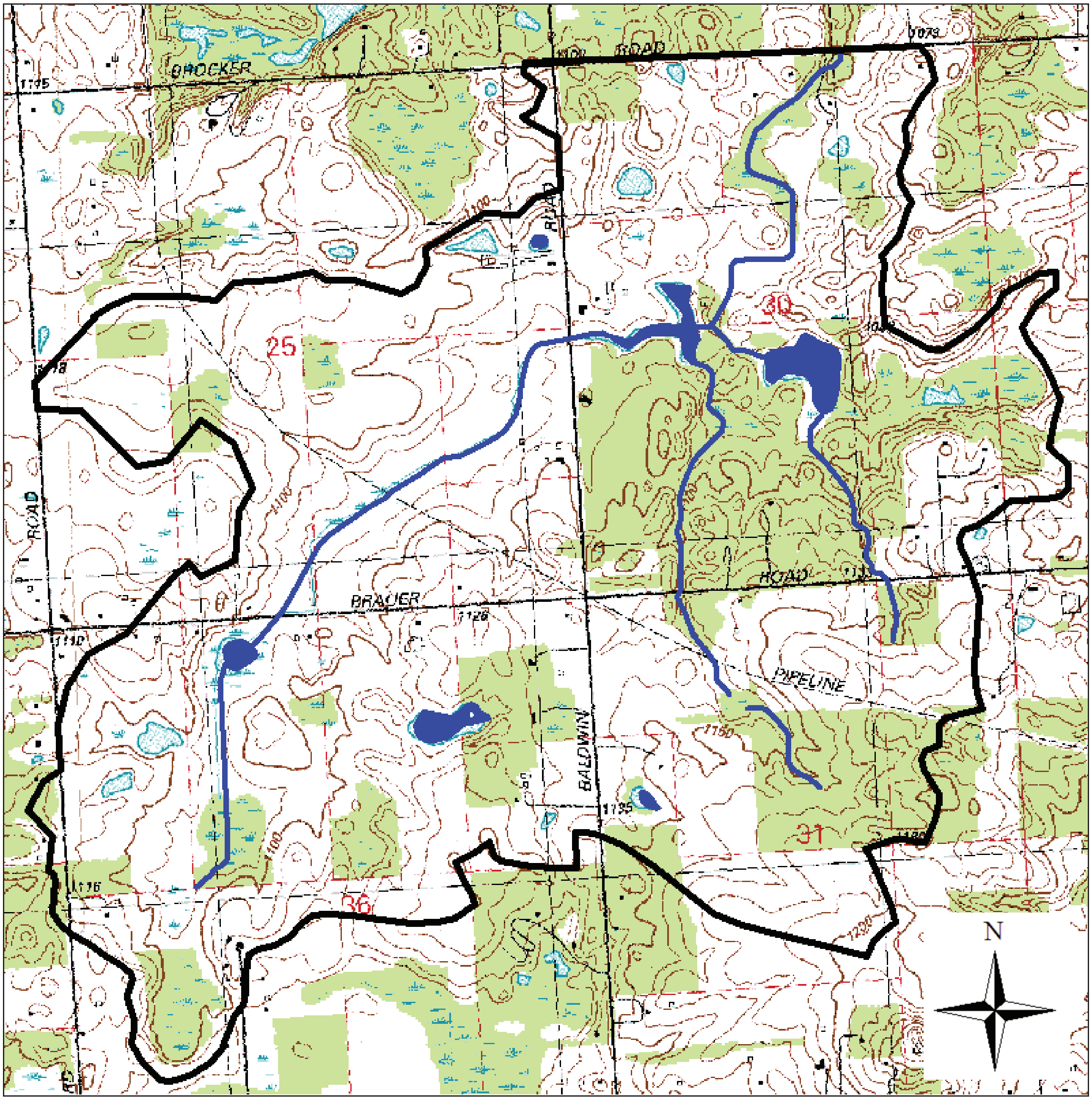
Proposed: Q = 275 cfs

These numbers need to be adjusted for ponding. The land use table shows that 5.4 percent of the watershed is either open water or swamps. These areas are spread uniformly throughout the basin. An adjustment factor of 0.77 can be interpolated from Table (10.1). The final design discharges are:

Existing: Q = 241 * 0.77
= 186 cfs

Proposed: Q = 212 cfs

Figure A.1 – Example watershed



Appendix B – Hydrologic Soil Groups for Michigan Soils

These soils data were last reviewed and updated in March 1990. To obtain current soils data by county, visit the NRCS Soil Data Mart at http://soildatamart.nrcs.usda.gov/ (this URL is current as of the date of this report).

NOTE: When two soil groups are listed (such as D/B), this indicates the hydrologic group for the soil under undrained/drained conditions.

Soil Series	Hydrologic Group	Soil Series	Hydrologic Group	Soil Series	Hydrologic Group
Abbaya	B	Abscota	A	Adrian	D/A
Alcona	B	Algansee	B	Allendale	B
Allouez	B	Alpena	A	Alstad	C
Amasa	B	Angelica	D/B	Arkona	B
Arkport	B	Arnheim	D	Ashkum	D/B
Assinins	B	Au Gres	B	Aubarque	D/C
Aubbeenaubbee	B	Aurelius	D/B	Avoca	B
Bach	D/B	Badaxe	B	Banat	B
Barry	D/B	Battlefield	D/A	Beavertail	D
Beechwood	C	Belding	B	Belleville	D/B
Benona	A	Bergland	D	Berville	D/B
Biscuit	D/B	Bixby	B	Bixler	C
Blount	C	Blue Lake	A	Bohemian	B
Bonduel	C	Bono	D	Boots	D/A
Borski	B	Bowers	C	Bowstring	D/A
Boyer	B	Brady	B	Branch	B
Brassar	C	Breckenridge	D/B	Brems	A
Brevort	D/B	Brimley	B	Bronson	B
Brookston	D/B	Bruce	D/B	Burleigh	D/A
Burt	D	Cassopolis	B	Cadmus	B
Capac	C	Carbondale	D/A	Carlisle	D/A
Cathro	D/A	Celina	C	Ceresco	B
Champion	B	Channahon	D	Channing	B
Charity	D	Charlevoix	B	Chatham	B
Cheboygan	B	Chelsea	A	Chesaning	B
Chestonia	D	Chippeny	D	Cohoctah	D/B
Coloma	A	Colonville	C	Colwood	D/B
Conover	C	Coral	C	Corunna	D/B
Coupee	B	Covert	A	Crosier	C
Croswell	A	Cunard	B	Cushing	B
Dawson	D/A	Deer Park	A	Deerton	A
Deford	D/A	Del Rey	C	Detour	B

Appendix B – Hydrologic Soil Groups for Michigan Soils, contd.

These soils data were last reviewed and updated in March 1990. To obtain current soils data by county, visit the NRCS Soil Data Mart at http://soildatamart.nrcs.usda.gov/ (this URL is current as of the date of this report).

NOTE: When two soil groups are listed (such as D/B) this indicates the hydrologic group for the soil under undrained/drained conditions.

Soil Series	Hydrologic Group	Soil Series	Hydrologic Group	Soil Series	Hydrologic Group
Dighton	B	Dixboro	B	Dora	D/B
Dowagiac	B	Dresden	B	Dryburg	B
Dryden	B	Duel	A	Dungridge	B
East Lake	A	Eastport	A	Edmore	D
Edwards	D/B	Eel	B	Eleva	B
Elmdale	B	Elston	B	Elvers	D/B
Emmet	B	Ensign	D	Ensley	D/B
Epoufette	D/B	Epworth	A	Ermatinger	D/B
Esau	A	Escanaba	A	Essexville	D/A
Evart	D	Fabius	B	Fairport	C
Fence	B	Fibre	D/B	Filion	D
Finch	C	Fox	B	Frankenmuth	C
Freda	D	Frenchette	B	Froberg	D
Fulton	D	Gaastra	C	Gagetown	B
Gay	D/B	Genesee	B	Gilchrist	A
Gilford	D/B	Gladwin	A	Glawe	D/B
Glendora	D/A	Glynwood	C	Gogebic	B
Gogomain	D/B	Goodman	B	Gorham	D/B
Grace	B	Granby	D/A	Grattan	A
Graveraet	B	Graycalm	A	Grayling	A
Greenwood	D/A	Grindstone	C	Grousehaven	D
Guardlake	A	Guelph	B	Gutport	D
Hagensville	C	Halfaday	A	Hatmaker	C
Henrietta	D/B	Hessel	D/B	Hettinger	D/C
Hillsdale	B	Hodenpyl	B	Houghton	D/A
Hoytville	D/C	Huntington	B	Ingalls	B
Ingersoll	B	Ionia	B	Iosco	B
Isabella	B	Ishpeming	A	Ithaca	C
Jacobsville	D	Jeddo	D/C	Jesso	C
Johnswood	B	Kakkawlin	C	Kalamazoo	B
Kalkaska	A	Kallio	C	Karlin	A
Kawbawgam	C	Kendallville	B	Kent	D
Keowns	D/B	Kerston	D/A	Keweenaw	A
Kibbie	B	Kidder	B	Kilmanagh	C

Appendix B – Hydrologic Soil Groups for Michigan Soils, contd.

These soils data were last reviewed and updated in March 1990. To obtain current soils data by county, visit the NRCS Soil Data Mart at http://soildatamart.nrcs.usda.gov/ (this URL is current as of the date of this report).

NOTE: When two soil groups are listed (such as D/B) this indicates the hydrologic group for the soil under undrained/drained conditions.

Soil Series	Hydrologic Group	Soil Series	Hydrologic Group	Soil Series	Hydrologic Group
Kingsville	D/A	Kinross	D/A	Kiva	A
Klacking	A	Kokomo	D/B	Koontz	D
Krakow	B	Lacota	D/B	Lamson	D/B
Landes	B	Lapeer	B	Latty	D
Leelanau	A	Lenawee	D/B	Leoni	B
Liminga	A	Linwood	D/A	Locke	B
Lode	B	London	C	Longrie	B
Loxley	D/A	Lupton	D/A	Mackinac	B
Macomb	B	Mancelona	A	Manistee	A
Manitowish	B	Markey	D/A	Marlette	B
Martinsville	B	Martisco	D/B	Matherton	B
Maumee	D/A	McBride	B	Mecosta	A
Melita	A	Menagha	A	Menominee	A
Mervin	D/A	Metamora	B	Metea	B
Miami	B	Michigamme	C	Millsdale	D/B
Milton	C	Minoa	C	Minocqua	D/B
Minong	D	Misery	C	Mitiwanga	C
Moltke	B	Monico	C	Monitor	C
Montcalm	A	Moquah	B	Morley	C
Morocco	B	Mudsock	D/B	Munising	B
Munuscong	D/B	Mussey	D/B	Nadeau	B
Nahma	D/B	Napoleon	D/A	Nappanee	D
Nester	C	Net	C	Newaygo	B
Newton	D/A	Nottawa	B	Nunica	C
Oakville	A	Ockley	B	Oconto	B
Ocqueoc	A	Ogemaw	D/C	Okee	B
Oldman	C	Olentangy	D/A	Omega	A
Omena	B	Onaway	B	Onota	B
Ontonagon	D	Ormas	B	Oshtemo	B
Otisco	A	Ottokee	A	Owosso	B
Paavola	B	Padus	B	Palms	D/A
Parkhill	D/B	Paulding	D	Pelkie	A
Pella	D/B	Pemene	B	Pence	B
Pendleton	C	Pequaming	A	Perrin	B

Appendix B – Hydrologic Soil Groups for Michigan Soils, contd.

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NOTE: When two soil groups are listed (such as D/B) this indicates the hydrologic group for the soil under undrained/drained conditions.

Soil Series	Hydrologic Group	Soil Series	Hydrologic Group	Soil Series	Hydrologic Group
Perrinton	C	Pert	D	Peshekee	D
Petticoat	B	Pewamo	D/C	Pickford	D
Pinconning	D/B	Pinnebog	D/A	Pipestone	B
Plainfield	A	Pleine	D	Ponozzo	C
Posen	B	Poseyville	C	Potagannissing	D
Poy	D	Proctor	B	Randolph	C
Rapson	B	Remus	B	Rensselaer	D/B
Richter	B	Riddles	B	Rifle	D/A
Riggsville	C	Rimer	C	Riverdale	A
Rockbottom	B	Rockcut	B	Rodman	A
Ronan	D	Rondeau	D/A	Roscommon	D/A
Roselms	D	Rousseau	A	Rubicon	A
Rudyard	D	Ruse	D	Saganing	D/A
Sanilac	B	Saranac	D/C	Sarona	B
Satago	D	Saugatuck	C	Saylesville	C
Sayner	A	Scalley	B	Schoolcraft	B
Sebewa	D/B	Selfridge	B	Selkirk	C
Seward	B	Shebeon	C	Shelldrake	A
Shelter	B	Shiawassee	C	Shinrock	C
Shoals	C	Sickles	D/B	Sims	D
Sisson	B	Skanee	C	Sleeth	C
Sloan	D/B	Solona	C	Soo	D/C
Sparta	A	Spinks	A	Springlake	A
St. Clair	D	St. Ignace	D	Stambaugh	B
Steuben	B	Sturgeon	B	Sugar	B
Summerville	D	Sundell	B	Sunfield	B
Superior	D	Tacoosh	D/B	Tallula	B
Tamarack	B	Tappan	D/B	Tawas	D/A
Teasdale	B	Tedrow	B	Tekenink	B
Thetford	A	Thomas	D/B	Tobico	D/A
Toledo	D	Tonkey	D/B	Toogood	A
Trenary	B	Trimountain	B	Tula	C
Tuscola	B	Tustin	B	Twining	C
Tyre	D/A	Ubly	B	Velvet	C

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NOTE: When two soil groups are listed (such as D/B) this indicates the hydrologic group for the soil under undrained/drained conditions.

Soil Series	Hydrologic Group	Soil Series	Hydrologic Group	Soil Series	Hydrologic Group
Vestaburg	D/A	Vilas	A	Volinia	B
Wainola	B	Waiska	B	Wakefield	B
Wallace	B	Wallkill	D/C	Warners	D/C
Wasepi	B	Washtenaw	D/C	Watton	C
Waucedah	D	Wauseon	D/B	Wautoma	D/B
Wega	B	Westbury	C	Whalan	B
Wheatley	D/A	Whitaker	C	Whitehall	B
Willette	D/A	Winneshiek	B	Winterfield	D/A
Wisner	D/B	Witbeck	D/B	Wixom	B
Wolcott	D/B	Woodbeck	B	Yalmer	B
Ypsi	C	Zeba	B	Ziegenfuss	D
Zilwaukee	D	Zimmerman	A		