MEMORANDUM

To: Eli Varol
R3 Gateway LLC

From: Theresa McGreevy
Kimley-Horn and Associates, Inc.

Date: October 24th, 2025

Subject: R3 Gateway LLC – Preliminary Hydrology Analysis

This memorandum provides a general overview of the existing and proposed conditions for the Gateway Solar Project in Randolph County, Illinois. This preliminary analysis is intended to summarize existing and proposed site conditions within the project limits of disturbance regarding soil, topography, ground cover, hydrologic impacts, and anticipated runoff as depicted by the ground cover curve number per NRCS TR-55.

Existing Conditions

The project area limits of disturbance, including the site layout and an additional buffer to account for erosion control measures during construction, consists of approximately 1,510 acres of farmland with small wooded areas, wetlands, and streams located throughout the site. The project area is located at the intersection of Zeigler Mine Road and Michael Road. It is bound to the north, east, and south by agricultural land, and to the west by State Route 4 and the city of Sparta, IL. The existing topography for the site has mostly moderate slopes (2%-9%) with areas in the western and southern regions of the site having some steep slopes up to 15%. Per available Natural Resources Conservation Service (NRCS) soil mapping, the on-site soils generally consist of silty loams, with 93% being non-hydric to predominantly non-hydric soils (hydric rating of 0% to 32%) and approximately 7% of the site being mapped as predominantly hydric (hydric rating of 67% to 99%). Refer to **Attachment 1 - NRCS Hydric Soil Rating Map** for additional information. A majority of the soils present on the site are hydrologic soil group C/D, which typically provides a low rate of water transmission into the soil. Refer to **Attachment 2 - NRCS Hydrologic Soil Group Map** for additional information. For the purpose of this report, the site has been assumed to belong in hydrologic soil group D across the entire project area.

United States Department of Agriculture (USDA) NRCS National Engineering Handbook has national standard Curve Numbers (CN) based on soil classification and land use for each subbasin drainage area. Curve Numbers are generally used in hydrologic calculations to estimate the runoff of a given area. Curve Number (CN) values range from 30 to 100, where 30 represents permeable soils with high infiltration rates and 100 represents impervious surfaces with no infiltration rates. A higher curve number leads to a higher stormwater runoff rate and volume, and a lower curve number contributes to lower stormwater runoff rates and volumes.

The portions of the existing crop area are straight row crop, which has a curve number (CN) of 91 per NRCS TR-55. The existing forested area can be considered Woods in the fair condition with a CN of 79 per NRCS TR-55. The existing wetland and stream areas can be considered Water with a CN of 98. The existing paved area can be considered Impervious areas with a CN of 98 per NRCS TR-55. Refer to **Attachment 3 - Hydrologic Soil-Cover Complexes,** published by the NRCS in Part 630 Hydrology - National Engineering Handbook for additional information on curve numbers.

Post-Development Runoff

The proposed development will include solar panels, aggregate access drives, associated electrical inverter pads, a substation, a switchyard, and an operations and maintenance building. The project will be surrounded by a perimeter fence. The proposed area of disturbance in Randolph County is approximately 1,510 acres. Solar panels will be mounted on piles and elevated above the ground as to preserve existing underlying soil and allow for revegetation. Access roads are spaced out among several rows of solar arrays to maximize the amount of ground that will be ultimately revegetated. These access roads are proposed to be aggregate placed over compacted subgrade. As discussed within **Attachment 4 - Hydrologic Response of Solar Farms**, published by the American Society of Civil Engineers (ASCE), with well-maintained vegetation underneath the panels, the solar panels themselves do not have much effect on total volumes of the runoff or peak discharge rates as the net increase in impervious ground surface is negligible. Rainfall that falls directly on a solar panel runs to the pervious areas around the surrounding panels. In the post-developed condition, the existing cultivated farmland will be converted to provide year-round ground cover increasing stabilization and infiltration of the surface layer.

For the purpose of this report, the site is considered to behave most like hydrologic soil group D. This post-condition will be similar to the meadow cover type, in fair condition, which has a CN of 78 per NRCS TR-55. The access roads and substation pad are reflected in stormwater calculations as gravel, which has a CN of 91 per NRCS TR-55. The inverters are on concrete pads and therefore are reflected as an impervious surface, which has a CN of 98. Refer to **Attachment 3 - Hydrologic Soil-Cover Complexes,** published by the NRCS in Part 630 Hydrology - National Engineering Handbook for additional information on curve numbers.

Summary of Pre-Development vs. Post-Development Curve Numbers

A final hydrology and stormwater report will be prepared for this development as part of Final Engineering. The report will summarize pre and post development runoff flows from each of the sub-catchment areas of the site. The report will also analyze runoff velocities and scour potential to allow for further analysis to reduce sediment erosion and loss. In the absence of the final hydrology and stormwater report, the table below summarizes the pre-development condition versus the post-development condition as it relates to general imperviousness of the ground cover (and corresponding general stormwater runoff). All acreages are calculated based on the preliminary site design layout and are subject to change during Final Engineering.

Pre-Development Curve Number		
Area (AC)	**Land Condition**	**Curve Number (CN)**
1501.55	Row Crops – Straight Row (SR) – Poor Condition	91
3.57	Woods – Fair Condition	79
0.87	Water	98
	Existing Composite Curve Number	**~91**

Post-Development Curve Number		
Area (AC)	**Land Condition**	**Curve Number (CN)**
1476.93	Meadow – Fair Condition	78
28.07	Impervious – Gravel Access Roads and Substation Pad	91
0.17	Impervious – Concrete Inverter Pads and Operations and Maintenance Building	98
0.82	Water	98
	Proposed Composite Curve Number	**~78**

As reflected in the table above, the post-development condition results in a net decrease in the runoff potential from the site based on the curve number reduction. A reduction of CN directly corresponds to a reduction of run-off. Therefore, by vegetating the land from crop field to a native meadow, the project will reduce the runoff compared to the existing condition. Refer to **Attachment 5 – Runoff Erosion Diagram** for visual representation.

Construction Best Management Practices

The above sections discuss the stormwater impacts from an existing to proposed condition. However, construction management is equally as important. Prior to construction, a Soil Erosion and Sediment Control Plan will be prepared for the project and will conform with Randolph County and the Illinois Environmental Protection Agency (IEPA) requirements. BMPs will be utilized during construction and permanent final vegetation to control runoff and sediment on site throughout the life of the project. These construction BMPs may consist of, but not be limited to:

- Silt Fence – Silt fence is a synthetic permeable mesh fabric, typically incorporating wooden support stakes at interval sufficient to support the fence, water and sediment retained by the fence. Silt fence is also available with wire mesh backing. The fence is designed to retain sediment-laden water to allow settlement of suspended soils before filtering through the mesh fabric for discharge downstream. Silt fence shall be located to capture overland, low-velocity sheet flow. It shall be installed at the downstream location of all site runoff.

- Filter Sock – Filter sock is a sock filled with biodegradable compost material that is locked in place with wooden stakes downslope of the filter sock. Similar to silt fence, filter sock is designed to retain sediment-laden water to allow settlement of suspended soils before filtering through the compost material for discharge downstream.

- Construction Entrance/Exit – All access points from the public street into the construction site shall include a construction entrance/exit composed of coarse stone to the dimensions shown on the Final Construction Drawings. The rough texture of the stone helps to remove clumps of soil adhering to construction vehicle tires through the action of vibration and jarring over the rough surface and the friction of the stone matrix against soils attached to vehicle tires.

- Concrete Washout Area – The concrete washout area is used to contain concrete and liquids when the concrete mixers and trucks are rinsed out after delivery. It is an onsite designated cleaning area. The washout facility consolidates solids for easier disposal and prevents runoff of liquids.

- Erosion Control Blanket – A temporary degradable rolled erosion control product composed of processed natural or polymer fibers mechanically, structurally, or chemically bound together to form a continuous matrix to provide erosion control and facilitate vegetation establishment.

- Silt Fence Rock Outlets – Rock Outlets contain median sized rip rap with thicker stone on the upstream side and smaller stone on the downstream side. These are located at potential concentrated outfalls from the site where silt fence design capacity is exceeded. The thicker rip rap provides stabilization for larger flow events and the stone filters the sediment-laden water before runoff leaves the site.

These BMPs, conforming to the Randolph County requirements and the Illinois Environmental Protection Agency (IEPA) requirements, are anticipated to limit sediment transport, slow runoff velocities, prevent erosion, and protect nearby wetlands and streams. Minimizing sediment that enters surface water bodies reduces the risk of transporting pollutants, leading to an increase in the quality of surface waters on site and on the surrounding properties. Wetlands present within the project area will be protected with BMPs to limit potential impacts and to preserve the wetland quality.

BMPs will be implemented prior to commencement of construction and remain in place until vegetation is reestablished. Some of these BMPs may remain in place to further mitigate the construction runoff conditions. General recommendation to establish vegetation throughout construction include:

- **Pre-seeding**: Pre-seeding the project prior to any construction activities. By pre-seeding the project prior to construction, this allows growth and vegetation to establish in areas where grading and stripping will not occur.
- **Topsoil**: Any areas that are stripped and graded, it is recommended to replace with topsoil. The contractor shall follow site specific Geotech recommendations for topsoil. Topsoil preservation efforts and best practices shall be carried out in accordance with the Agricultural Impact Mitigation Agreement (AIMA). Generally, it is recommended that any exposed areas be respread with a minimum of 4” of topsoil to ensure vegetation will grow.

If pollinator seed mixes are being utilized, a minimum respread of 6” of topsoil is recommended.

- **Seeding**: Immediately after grading and topsoil respread, it is recommended that seeding occurs.
    - **Temporary Seeding**: Per the IEPA Notice of Intent permit, within 7 days after construction activity ceases on any particular area, all disturbed ground where there will be construction longer than 14 days must be seeded with fast-germinating temporary seed. Hydromulch or matting may be necessary to protect the seed from erosion/washout. Contractor shall implement as needed to obtain stabilization.
    - **Permanent Seeding** – All areas at final grade must be seeded within 14 days after completion of the major construction activity. Hydromulch or matting may be necessary to protect the seed from erosion/washout. Contractor shall implement as needed to obtain stabilization.

The above are general recommendations to ensure the project will be setup for success. R3 Gateway LLC will obtain final design documents to meet all Authorities Having Jurisdiction (AHJ) requirements prior to constructing.

Permanent Stormwater Measures

As described above, the proposed solar site is not anticipated to increase runoff from the pre-development condition by changing the land cover from crop to meadow. A full hydrology report and study will be prepared to analyze this further during Final Engineering. Revegetation of disturbed and existing soils to allow suitable groundcover will reduce the post-development runoff. Permanent vegetation establishment will likely further reduce any dust and sediment loss inherent to the tilling operations utilized in the existing agricultural use. The requirement for permanent stormwater BMPs will be reassessed after final hydrology and stormwater reports and will meet all requirements of Randolph County and the IEPA requirements.

Executive Summary

The R3 Gateway LLC Facility will maintain or improve the existing stormwater runoff characteristics and will avoid negative impacts on local groundwater and surface waterbodies. By restoring currently farmed land to a meadow, the overall runoff potential of the site will decrease. A combination of revegetation and permanent BMPs, if determined necessary during final engineering, will be utilized to mitigate increased runoff from the addition of aggregate access roads, substation, and inverter pads. During the construction phase, temporary BMPs will be implemented until revegetation can be fully established.

Attachments

- Attachment 1 - NRCS Hydric Soil Rating Map
- Attachment 2 - NRCS Hydrologic Soil Group Map
- Attachment 3 – Hydrologic Soil-Cover Complexes
- Attachment 4 – Hydrologic Response of Solar Farms
- Attachment 5 – Runoff Erosion Diagram

ATTACHMENT 1 – NRCS HYDRIC SOIL RATING MAP

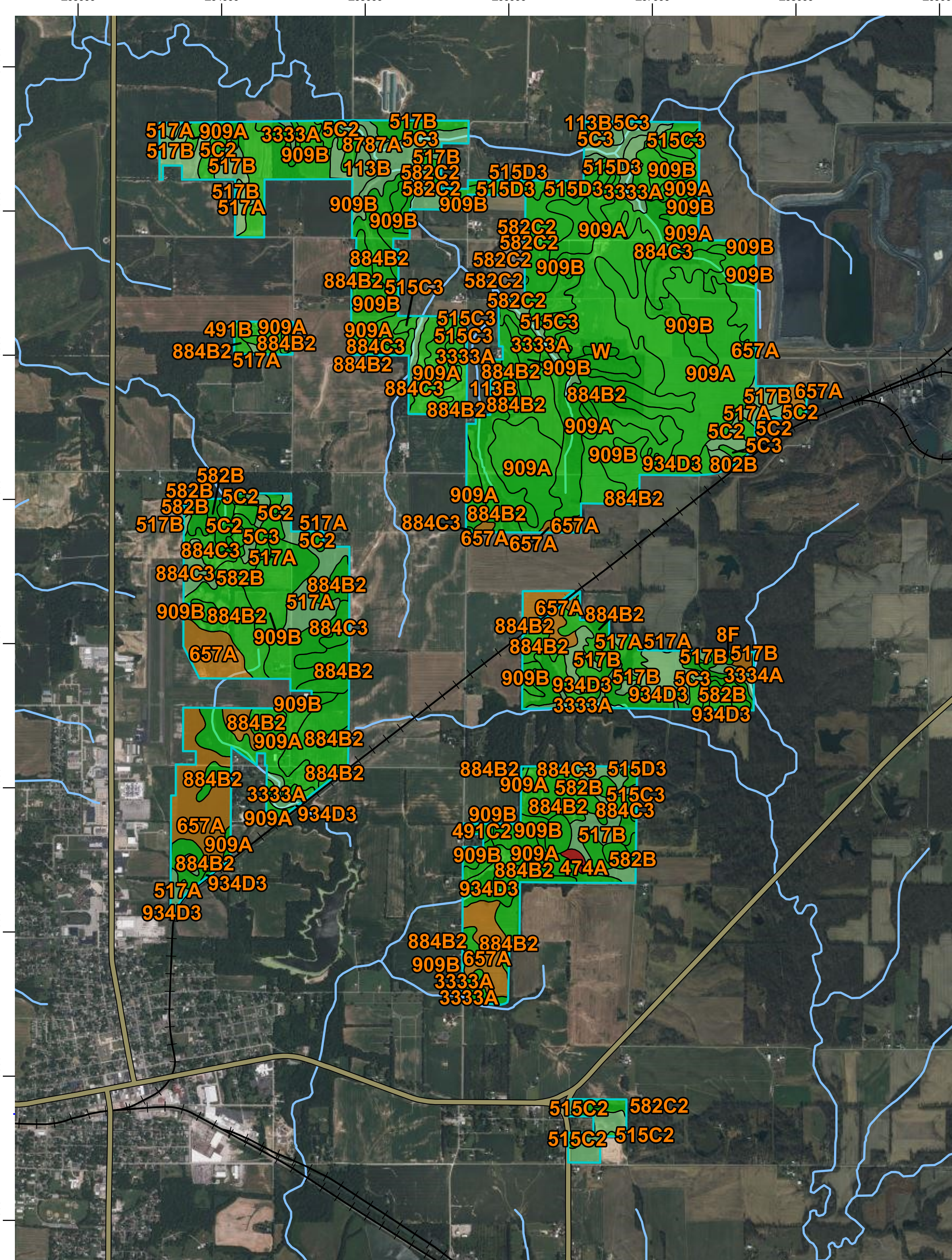
Hydric Rating by Map Unit—Randolph County, Illinois
(Project Boundary)

89° 42' 40" W | 89° 38' 10" W

263000 264000 265000 266000 267000 268000 269000

38° 11' 23" N | 38° 11' 23" N

4230000 4229000 4228000 4227000 4226000 4225000 4224000 4223000 4222000



38° 6' 41" N | 38° 6' 41" N

263000 264000 265000 266000 267000 268000

89° 42' 40" W | 89° 38' 10" W

Map Scale: 1:42,400 if printed on A portrait (8.5" x 11") sheet.

Meters: 0 500 1000 2000 3000

Feet: 0 2000 4000 8000 12000

N

Map projection: Web Mercator Corner coordinates: WGS84 Edge tics: UTM Zone 16N WGS84

MAP LEGEND

Area of Interest (AOI)

Area of Interest (AOI)

Soils

Soil Rating Polygons

Hydric (100%)

Hydric (66 to 99%)

Hydric (33 to 65%)

Hydric (1 to 32%)

Not Hydric (0%)

Not rated or not available

Soil Rating Lines

Hydric (100%)

Hydric (66 to 99%)

Hydric (33 to 65%)

Hydric (1 to 32%)

Not Hydric (0%)

Not rated or not available

Soil Rating Points

Hydric (100%)

Hydric (66 to 99%)

Hydric (33 to 65%)

Hydric (1 to 32%)

Not Hydric (0%)

Not rated or not available

Water Features

Streams and Canals

Transportation

Rails

Interstate Highways

US Routes

Major Roads

Local Roads

Background

Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:12,000.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL:
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Randolph County, Illinois
Survey Area Data: Version 20, Sep 1, 2025

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Jul 14, 2020—Apr 19, 2021

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Hydric Rating by Map Unit

Map unit symbol	Map unit name	Rating	Acres in AOI	Percent of AOI
5C2	Blair silt loam, 5 to 10 percent slopes, eroded	0	57.8	2.2%
5C3	Blair silty clay loam, 5 to 10 percent slopes, severely eroded	0	46.3	1.8%
8F	Hickory silt loam, 18 to 35 percent slopes	0	7.8	0.3%
113B	Oconee silt loam, 2 to 5 percent slopes	10	31.1	1.2%
474A	Piasa silt loam, 0 to 2 percent slopes	100	3.9	0.1%
491B	Ruma silt loam, 2 to 5 percent slopes	0	2.9	0.1%
491C2	Ruma silt loam, 5 to 10 percent slopes, eroded	0	3.9	0.2%
515C2	Bunkum silt loam, 5 to 10 percent slopes, eroded	0	14.5	0.6%
515C3	Bunkum silty clay loam, 5 to 10 percent slopes, severely eroded	0	64.0	2.5%
515D3	Bunkum silty clay loam, 10 to 18 percent slopes, severely eroded	0	9.1	0.4%
517A	Marine silt loam, 0 to 2 percent slopes	5	89.1	3.5%
517B	Marine silt loam, 2 to 5 percent slopes	5	143.5	5.6%
582B	Homen silt loam, 2 to 5 percent slopes	0	34.8	1.3%
582C2	Homen silt loam, 5 to 10 percent slopes, eroded	0	31.9	1.2%
657A	Burksville silt loam, 0 to 2 percent slopes	90	174.6	6.8%
802B	Orthents, loamy, undulating	0	0.8	0.0%
884B2	Bunkum-Coulterville silt loams, 2 to 5 percent slopes, eroded	0	526.7	20.4%

Map unit symbol	Map unit name	Rating	Acres in AOI	Percent of AOI
884C3	Bunkum-Coulterville silty clay loams, 5 to 10 percent slopes, severely eroded	0	100.3	3.9%
909A	Coulterville-Oconee silt loams, 0 to 2 percent slopes	0	458.0	17.7%
909B	Coulterville-Oconee silt loams, 2 to 5 percent slopes	0	532.6	20.6%
934D3	Blair-Grantfork silt loams, 10 to 18 percent slopes, severely eroded	0	97.0	3.8%
3333A	Wakeland silt loam, 0 to 2 percent slopes, frequently flooded	5	121.8	4.7%
3334A	Birds silt loam, 0 to 2 percent slopes, frequently flooded	90	3.5	0.1%
8787A	Banlic silt loam, 0 to 2 percent slopes, occasionally flooded	10	23.1	0.9%
W	Water	0	3.8	0.1%
Totals for Area of Interest			**2,582.9**	**100.0%**

Description

This rating indicates the percentage of map units that meets the criteria for hydric soils. Map units are composed of one or more map unit components or soil types, each of which is rated as hydric soil or not hydric. Map units that are made up dominantly of hydric soils may have small areas of minor nonhydric components in the higher positions on the landform, and map units that are made up dominantly of nonhydric soils may have small areas of minor hydric components in the lower positions on the landform. Each map unit is rated based on its respective components and the percentage of each component within the map unit.

The thematic map is color coded based on the composition of hydric components. The five color classes are separated as 100 percent hydric components, 66 to 99 percent hydric components, 33 to 65 percent hydric components, 1 to 32 percent hydric components, and less than one percent hydric components.

In Web Soil Survey, the Summary by Map Unit table that is displayed below the map pane contains a column named 'Rating'. In this column the percentage of each map unit that is classified as hydric is displayed.

Hydric soils are defined by the National Technical Committee for Hydric Soils (NTCHS) as soils that formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part (Federal Register, 1994). Under natural conditions, these soils are either saturated or inundated long enough during the growing season to support the growth and reproduction of hydrophytic vegetation.

The NTCHS definition identifies general soil properties that are associated with wetness. In order to determine whether a specific soil is a hydric soil or nonhydric soil, however, more specific information, such as information about the depth and duration of the water table, is needed. Thus, criteria that identify those estimated soil properties unique to hydric soils have been established (Federal Register, 2002). These criteria are used to identify map unit components that normally are associated with wetlands. The criteria used are selected estimated soil properties that are described in "Soil Taxonomy" (Soil Survey Staff, 1999) and "Keys to Soil Taxonomy" (Soil Survey Staff, 2006) and in the "Soil Survey Manual" (Soil Survey Division Staff, 1993).

If soils are wet enough for a long enough period of time to be considered hydric, they should exhibit certain properties that can be easily observed in the field. These visible properties are indicators of hydric soils. The indicators used to make onsite determinations of hydric soils are specified in "Field Indicators of Hydric Soils in the United States" (Hurt and Vasilas, 2006).

References:

Federal Register. July 13, 1994. Changes in hydric soils of the United States.

Federal Register. September 18, 2002. Hydric soils of the United States.

Hurt, G.W., and L.M. Vasilas, editors. Version 6.0, 2006. Field indicators of hydric soils in the United States.

Soil Survey Division Staff. 1993. Soil survey manual. Soil Conservation Service. U.S. Department of Agriculture Handbook 18.

Soil Survey Staff. 1999. Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys. 2nd edition. Natural Resources Conservation Service. U.S. Department of Agriculture Handbook 436.

Soil Survey Staff. 2006. Keys to soil taxonomy. 10th edition. U.S. Department of Agriculture, Natural Resources Conservation Service.

Rating Options

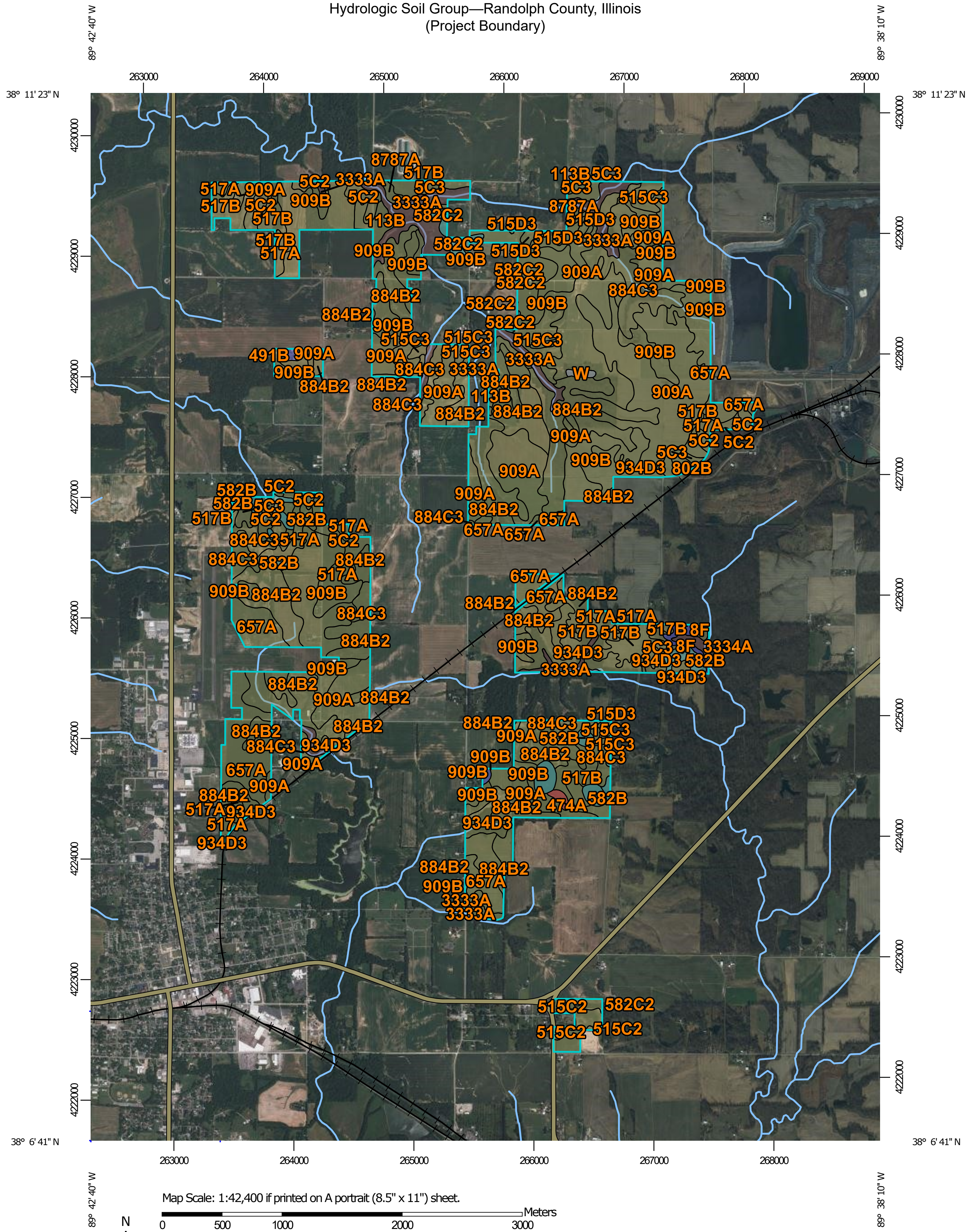
Aggregation Method: Percent Present

Component Percent Cutoff: None Specified

Tie-break Rule: Lower

ATTACHMENT 2 – NRCS HYDROLOGIC SOIL GROUP MAP

Hydrologic Soil Group—Randolph County, Illinois
(Project Boundary)



Map Scale: 1:42,400 if printed on A portrait (8.5" x 11") sheet.

N

Meters: 0, 500, 1000, 2000, 3000

Feet: 0, 2000, 4000, 8000, 12000

Map projection: Web Mercator Corner coordinates: WGS84 Edge tics: UTM Zone 16N WGS84

MAP LEGEND

Area of Interest (AOI)

Area of Interest (AOI)

Soils

Soil Rating Polygons

- A
- A/D
- B
- B/D
- C
- C/D
- D
- Not rated or not available

Soil Rating Lines

- A
- A/D
- B
- B/D
- C
- C/D
- D
- Not rated or not available

Soil Rating Points

- A
- A/D
- B
- B/D
- C
- C/D
- D
- Not rated or not available

Water Features

- Streams and Canals

Transportation

- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background

- Aerial Photography

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The soil surveys that comprise your AOI were mapped at 1:12,000.

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Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

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The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Hydrologic Soil Group

Map unit symbol	Map unit name	Rating	Acres in AOI	Percent of AOI
5C2	Blair silt loam, 5 to 10 percent slopes, eroded	C/D	57.8	2.2%
5C3	Blair silty clay loam, 5 to 10 percent slopes, severely eroded	C/D	46.3	1.8%
8F	Hickory silt loam, 18 to 35 percent slopes	B	7.8	0.3%
113B	Oconee silt loam, 2 to 5 percent slopes	C/D	31.1	1.2%
474A	Piasa silt loam, 0 to 2 percent slopes	D	3.9	0.1%
491B	Ruma silt loam, 2 to 5 percent slopes	B	2.9	0.1%
491C2	Ruma silt loam, 5 to 10 percent slopes, eroded	B	3.9	0.2%
515C2	Bunkum silt loam, 5 to 10 percent slopes, eroded	C/D	14.5	0.6%
515C3	Bunkum silty clay loam, 5 to 10 percent slopes, severely eroded	C/D	64.0	2.5%
515D3	Bunkum silty clay loam, 10 to 18 percent slopes, severely eroded	C/D	9.1	0.4%
517A	Marine silt loam, 0 to 2 percent slopes	C/D	89.1	3.5%
517B	Marine silt loam, 2 to 5 percent slopes	C/D	143.5	5.6%
582B	Homen silt loam, 2 to 5 percent slopes	C	34.8	1.3%
582C2	Homen silt loam, 5 to 10 percent slopes, eroded	C	31.9	1.2%
657A	Burksville silt loam, 0 to 2 percent slopes	C/D	174.6	6.8%
802B	Orthents, loamy, undulating	C	0.8	0.0%
884B2	Bunkum-Coulterville silt loams, 2 to 5 percent slopes, eroded	C/D	526.7	20.4%

Map unit symbol	Map unit name	Rating	Acres in AOI	Percent of AOI
884C3	Bunkum-Coulterville silty clay loams, 5 to 10 percent slopes, severely eroded	C/D	100.3	3.9%
909A	Coulterville-Oconee silt loams, 0 to 2 percent slopes	C/D	458.0	17.7%
909B	Coulterville-Oconee silt loams, 2 to 5 percent slopes	C/D	532.6	20.6%
934D3	Blair-Grantfork silt loams, 10 to 18 percent slopes, severely eroded	C/D	97.0	3.8%
3333A	Wakeland silt loam, 0 to 2 percent slopes, frequently flooded	B/D	121.8	4.7%
3334A	Birds silt loam, 0 to 2 percent slopes, frequently flooded	C/D	3.5	0.1%
8787A	Banlic silt loam, 0 to 2 percent slopes, occasionally flooded	C/D	23.1	0.9%
W	Water		3.8	0.1%
Totals for Area of Interest			**2,582.9**	**100.0%**

Description

Hydrologic soil groups are based on estimates of runoff potential. Soils are assigned to one of four groups according to the rate of water infiltration when the soils are not protected by vegetation, are thoroughly wet, and receive precipitation from long-duration storms.

The soils in the United States are assigned to four groups (A, B, C, and D) and three dual classes (A/D, B/D, and C/D). The groups are defined as follows:

Group A. Soils having a high infiltration rate (low runoff potential) when thoroughly wet. These consist mainly of deep, well drained to excessively drained sands or gravelly sands. These soils have a high rate of water transmission.

Group B. Soils having a moderate infiltration rate when thoroughly wet. These consist chiefly of moderately deep or deep, moderately well drained or well drained soils that have moderately fine texture to moderately coarse texture. These soils have a moderate rate of water transmission.

Group C. Soils having a slow infiltration rate when thoroughly wet. These consist chiefly of soils having a layer that impedes the downward movement of water or soils of moderately fine texture or fine texture. These soils have a slow rate of water transmission.

Group D. Soils having a very slow infiltration rate (high runoff potential) when thoroughly wet. These consist chiefly of clays that have a high shrink-swell potential, soils that have a high water table, soils that have a claypan or clay layer at or near the surface, and soils that are shallow over nearly impervious material. These soils have a very slow rate of water transmission.

If a soil is assigned to a dual hydrologic group (A/D, B/D, or C/D), the first letter is for drained areas and the second is for undrained areas. Only the soils that in their natural condition are in group D are assigned to dual classes.

Rating Options

Aggregation Method: Dominant Condition

Component Percent Cutoff: None Specified

Tie-break Rule: Higher

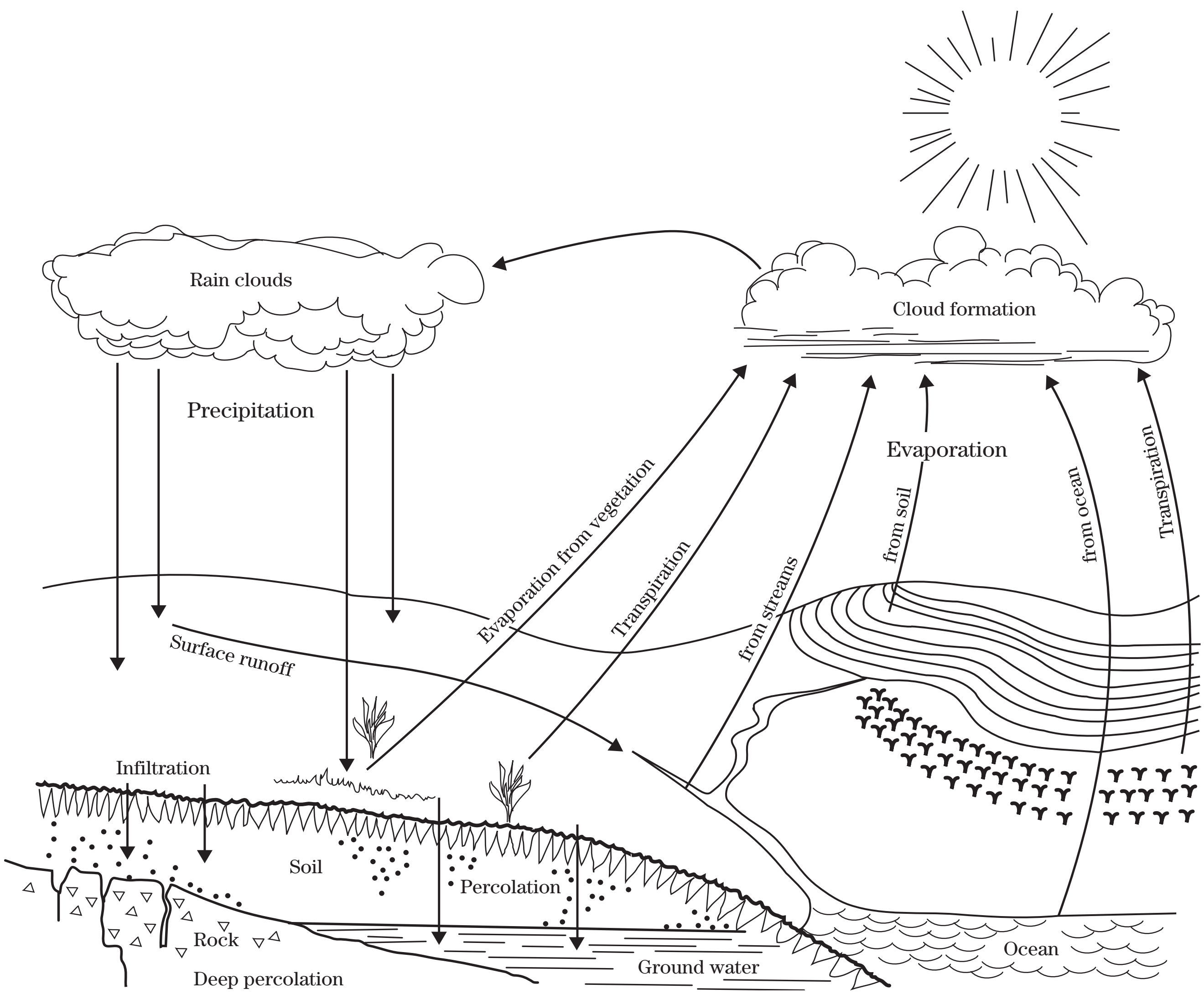
ATTACHMENT 3 – HYDROLOGIC SOIL-COVER COMPLEXES BY USDA, NRCS

United States
Department of
Agriculture

**Natural
Resources
Conservation
Service**

Part 630 Hydrology
National Engineering Handbook

Chapter 9 Hydrologic Soil-Cover Complexes



Issued July 2004

Acknowledgments

Chapter 9 was originally prepared by **Victor Mockus**, retired hydraulic engineer, USDA Soil Conservation Service, and was published in 1964. It was reprinted with minor revisions in 1969. This version was prepared by the Natural Resources Conservation Service (NRCS)/Agricultural Research Service (ARS) Curve Number Work Group and **Helen Fox Moody**, hydraulic engineer, NRCS, Beltsville, Maryland. Members of the NRCS/ARS Curve Number Work Group are:

Natural Resources Conservation Service
Donald E. Woodward (retired)
Robert D. Nielsen, soil scientist, Lincoln, Nebraska
Robert Kluth (retired)
Arlis Plummer, hydraulic engineer, Lincoln, Nebraska
Joe Van Mullem (retired)
Gary Conaway (retired)

Agricultural Research Service
William J. Gburek, hydrologist, University Park, Pennsylvania
Keith Cooley (retired)
Allen T. Hjelmfelt, Jr. (retired)
Virginia A. Ferreira (retired)

University of Arizona
Richard H. Hawkins, Ph.D., professor, Tucson, Arizona

Chapter 9 Hydrologic Soil-Cover Complexes

Contents:

Examples

Chapter 9 Hydrologic Soil-Cover Complexes

630.0900 General

A combination of a hydrologic soil group (soil) and a land use and treatment class (cover) is a hydrologic soil-cover complex. This chapter gives tables and graphs of runoff curve numbers (CNs) assigned to such complexes. This CN indicates the runoff potential of a complex during periods when the soil is not frozen. A higher CN indicates a higher runoff potential and specifies which runoff curve of appendix A or figure 10–2 in National Engineering Handbook, part 630 (NEH 630), chapter 10, is to be used in estimating runoff for the complex. Applications and further description of CNs are given in NEH 630, chapters 10 and 12.

630.0901 Determinations of complexes and curve numbers

(a) Agricultural land

Complexes and assigned CNs for combinations of soil groups of NEH 630, chapter 7 and land use and treatment classes of NEH 630, chapter 8 are given in table 9–1. Also given are some complexes that make applications of the table more direct. Impervious and water surfaces, which are not listed, are always assigned a CN of 98.

(1) Assignment of CNs to complexes

Table 9–1 was developed as follows:

- The data literature was searched for watersheds in single complexes (one soil group and one cover); watersheds were found for most of the listed complexes.
- An average CN for each watershed was obtained using rainfall-runoff data for storms producing the annual floods. The watersheds were generally less than 1 square mile in size, the number of watersheds for a complex varied, and the storms were of 1 day or less duration.
- The CNs of watersheds in the same complex were averaged and all CNs for a cover were plotted. A curve for each cover was drawn with greater weight given to CNs based on data from more than one watershed, and each curve was extended as far as necessary to provide CNs for ungaged complexes. All but the last three lines of CN entries in table 9–1 are taken from these curves.
- For the complexes in the last three lines of table 9–1, the proportions of different covers were estimated and the weighted CNs computed from previously derived CNs.

Table 9–1 has not been significantly changed since its construction in 1954 although CNs for crop residue cover treatment has been added. Supplementary tables for special regions have been developed and are shown later in this chapter.

(2) Use of table 9–1

Chapters 7 and 8 of NEH 630 describe how soils and covers of watersheds or other land areas are classified in the field. After the classification is completed, CNs are read from table 9–1 and applied as described in chapter 10. Because the principal use of CNs is for estimating runoff from rainfall, the examples of applications are given in chapter 10.

Table 9–1 Runoff curve numbers for agricultural lands [1/]

Cover description			CN for hydrologic soil group			
cover type	treatment [2/]	hydrologic condition [3/]	A	B	C	D
Fallow	Bare Soil	---	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C & T)	Poor	66	74	80	82
		Good	62	71	78	81
	C & T + CR	Poor	65	73	79	81
		Good	61	70	77	80
Small grain	SR	Poor	65	76	84	88
		Good	63	75	83	87
	SR + CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C + CR	Poor	62	73	81	84
		Good	60	72	80	83
	C & T	Poor	61	72	79	82
		Good	59	70	78	81
	C & T + CR	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded or broadcast legumes or rotation meadow	SR	Poor	66	77	85	89
		Good	58	72	81	85
	C	Poor	64	75	83	85
		Good	55	69	78	83
	C & T	Poor	63	73	80	83
		Good	51	67	76	80

See footnotes at end of table.

Table 9–1 Runoff curve numbers for agricultural lands [1/] — Continued

Cover description: cover type	treatment [2/]	hydrologic condition [3/]	CN for hydrologic soil group: A	B	C	D
Pasture, grassland, or range-continuous forage for grazing [4/]		Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
Meadow-continuous grass, protected from grazing and generally mowed for hay		Good	30	58	71	78
Brush-brush-forbs-grass mixture with brush the major element [5/]		Poor	48	67	77	83
		Fair	35	56	70	77
		Good	30 [6/]	48	65	73
Woods-grass combination (orchard or tree farm) [7/]		Poor	57	73	82	86
		Fair	43	65	76	82
		Good	32	58	72	79
Woods [8/]		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	30	55	70	77
Farmstead--buildings, lanes, driveways, and surrounding lots		---	59	74	82	86
Roads (including right-of-way):						
Dirt		---	72	82	87	89
Gravel		---	76	85	89	91

1/ Average runoff condition, and I_a=0.2s.

2/ Crop residue cover applies only if residue is on at least 5 percent of the surface throughout the year.

3/ Hydrologic condition is based on combinations of factors that affect infiltration and runoff, including (a) density and canopy of vegetative areas, (b) amount of year-round cover, (c) amount of grass or close-seeded legumes, (d) percent of residue cover on the land surface (good $\geq$20%), and (e) degree of surface toughness.
Poor: Factors impair infiltration and tend to increase runoff.
Good: Factors encourage average and better then average infiltration and tend to decrease runoff.
For conservation tillage poor hydrologic condition, 5 to 20 percent of the surface is covered with residue (less than 750 pounds per acre for row crops or 300 pounds per acre for small grain).
For conservation tillage good hydrologic condition, more than 20 percent of the surface is covered with residue (greater than 750 pounds per acre for row crops or 300 pounds per acre for small grain).

4/ Poor: < 50% ground cover or heavily grazed with no mulch.
Fair: 50 to 75% ground cover and not heavily grazed.
Good: > 75% ground cover and lightly or only occasionally grazed.

5/ Poor: < 50% ground cover.
Fair: 50 to 75% ground cover.
Good: > 75% ground cover.

6/ If actual curve number is less than 30, use CN = 30 for runoff computation.

7/ CNs shown were computed for areas with 50 percent woods and 50 percent grass (pasture) cover. Other combinations of conditions may be computed from the CNs for woods and pasture.

8/ Poor: Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: Woods are grazed, but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

(b) National and commercial forest: forest-range

(1) Forest-range in Western United States

In the forest-range regions of the Western United States, soil group, cover type, and cover density are the principal factors used in estimating CNs. Figures 9–1 and 9–2 show the relationships between these factors and CNs for soil-cover complexes used to date. The figures are based on information in table 2–1, part 2, of the USDA Forest Service's Handbook on Methods of Hydrologic Analysis (USDA 1959b). The amount of litter is taken into account when estimating the density of cover.

Present hydrologic conditions are determined from existing surveys or by reconnaissance, and future conditions from the estimate of cover and density changes resulting from proper use and treatment. Table 9–2 lists CNs for arid and semiarid rangelands. It is used like table 9–1.

Figure 9–1 Estimating runoff curve numbers of forest-range complexes in Western United States: herbaceous and oak-aspen complexes

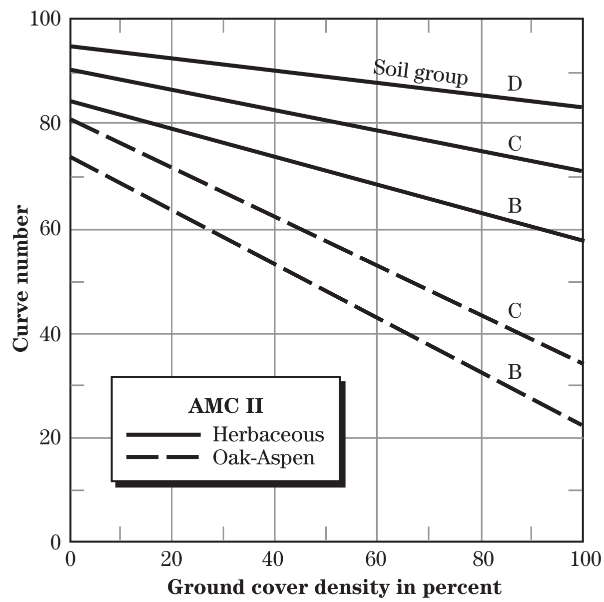


Figure 9–2 Estimating runoff curve numbers of forest-range complexes in Western United States: juniper-grass and sage-grass complexes

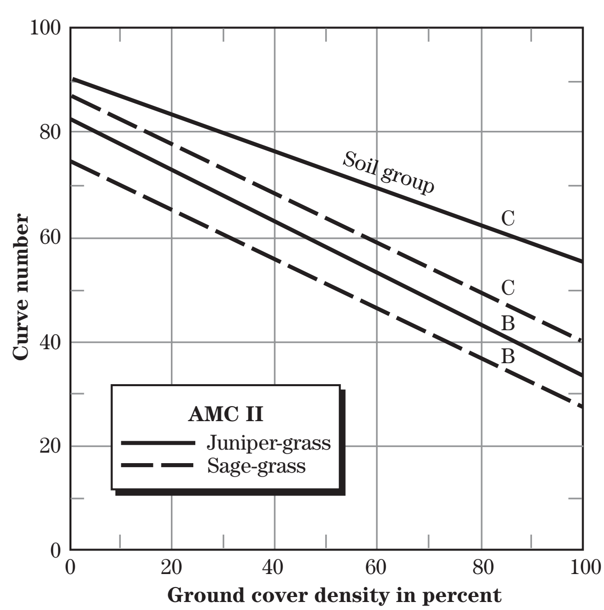


Table 9–2 Runoff curve numbers for arid and semiarid rangelands [1/]

Cover description		Hydrologic soil group			
cover type	hydrologic condition [2/]	A [3/]	B	C	D
Herbaceous—mixture of grass, weeds and low-growing brush, with brush the minor element	Poor		80	87	93
	Fair		71	81	89
	Good		62	74	85
Oak-aspen—mountain brush mixture of oak brush, aspen, mountain mahogany, bitter brush, maple, and other brush	Poor		66	74	79
	Fair		48	57	63
	Good		30	41	48
Pinyon-juniper—pinyon, juniper, or both; grass understory	Poor		75	85	89
	Fair		58	73	80
	Good		41	61	71
Sage-grass—sage with an understory of grass	Poor		67	80	85
	Fair		51	63	70
	Good		35	47	55
Desert shrub—major plants include saltbush, greasewood, creosotebush, blackbrush, bursage, paloverde, mesquite, and cactus	Poor	63	77	85	88
	Fair	55	72	81	86
	Good	49	68	79	84

1/ Average runoff condition, and I_a = 0.2s. For range in humid regions, use table 9–1.

2/ Poor: <30% ground cover (litter, grass, and brush overstory).
Fair: 30 to 70% ground cover.
Good: >70% ground cover.

3/ Curve numbers for group A have been developed only for desert shrub.

(2) Supplementary tables of CNs

Tables 9–3 and 9–4 are supplements to table 9–1 and are used in the same way. Table 9–3 gives CNs for selected covers in Puerto Rico. The CNs were obtained using a relation between storm and annual data and the annual rainfall-runoff data for experimental plots at Mayaguez, Puerto Rico.

Table 9–4 gives CNs for sugarcane complexes in Hawaii. The CNs are tentative estimates now undergoing study.

Table 9–3 Runoff curve numbers for hydrologic soil-cover complexes in Puerto Rico [1/]

Cover description — cover type and hydrologic condition	CN for hydrologic soil group A	B	C	D
Fallow	77	86	91	93
Grass (bunchgrass or poor stand of sod)	51	70	80	84
Coffee (no ground cover, no terraces)	48	68	79	83
(with ground cover and terraces)	22	52	68	75
Minor crops (garden or truck crops)	45	66	77	83
Tropical kudzu	19	50	67	74
Sugarcane: (trash burned, straight-row)	43	65	77	82
(trash mulch, straight-row)	45	66	77	83
(in holes, on contour)	24	53	69	76
(in furrows, on contour)	32	58	72	79

1/ Average runoff condition, and $I_a = 0.2S$.

Table 9–4 Runoff curve numbers; tentative estimates for sugarcane hydrologic soil-cover complexes in Hawaii [1/]

Cover and treatment [2/]	------- Hydrologic soil group ------- A	B	C	D
Sugarcane:				
Limited cover, straight row	67	78	85	89
Partial cover, straight row	49	69	79	84
Complete cover, straight row	39	61	74	80
Limited cover, contoured	65	75	82	86
Partial cover, contoured	25	59	75	83
Complete cover, contoured	6	35	70	79

1/ Average runoff condition and $I_a = 0.2S$.

2/ Degrees of cover:
Limited cover—Cane newly planted, or ratooned cane with a limited root system; canopy over less than half the field area.
Partial cover—Cane in the transition period between limited and complete cover; canopy over half to nearly the entire field area.
Complete cover—Cane from the stage of growth when full canopy is provided to the stage at harvest.
Straight-row planting is up and down hill or cross-slope on slopes greater than 2 percent.
Contoured planting is the usual contouring or cross-slope planting on slopes less than 2 percent.

(c) Urban and residential land

Several factors, such as the percentage of impervious area and the means of conveying runoff from impervious areas to the drainage system, should be considered in computing CNs for urban areas (Rawls et al., 1981). For example, do the impervious areas connect directly to the drainage system, or do they outlet onto lawns or other pervious areas where infiltration can occur?

The urban and residential CNs given in table 9–5 were developed for typical land use relationships based on specific assumed percentages of impervious area. These CN values were developed on the assumptions that

- pervious urban areas are equivalent to pasture in good hydrologic condition,
- impervious areas have a CN of 98 and are directly connected to the drainage system, and
- the cover types listed have assumed percentages of impervious area as shown in table 9–5.

Sheet flow is flow over plane surfaces that usually occurs in the headwater of streams immediately after the rainfall's impact. Sheet flow has very shallow flow depths of 0.05 to 0.1 foot, with laminar flow characteristics of parallel or nearly parallel flowlines and a maximum flow length of 100 feet.

Shallow concentrated flow occurs downstream from sheet flow and upstream from flow in a defined channel. In shallow concentrated flow, the water flows in nonparallel flow paths, and flow depths range from 0.1 foot to as much as 0.5 foot.

In concentrated flow the water follows definite channels that are a discernable feature on the ground surface. See NEH 630, Chapter 15, Time of Concentration, for more information on these flow types.

(1) Connected impervious areas

An impervious area is considered connected if runoff from it flows directly into the drainage system. It is also considered connected if runoff from it occurs as shallow concentrated flow that runs over a pervious area and then into a drainage system.

If all of the impervious area is directly connected to the drainage system, but the impervious area percentages in table 9–5 or the pervious land use assumptions are not applicable, use equation 9–1 or figure 9–3 to compute a composite CN.

$$CN_c = CN_p + \left(\frac{P_{imp}}{100}\right)\left(98 - CN_p\right) \qquad [9\text{–}1]$$

where:
CN_c = composite runoff curve number
CN_p = pervious runoff curve number
P_{imp} = percent imperviousness.

Figure 9–3 Composite CN with connected impervious area

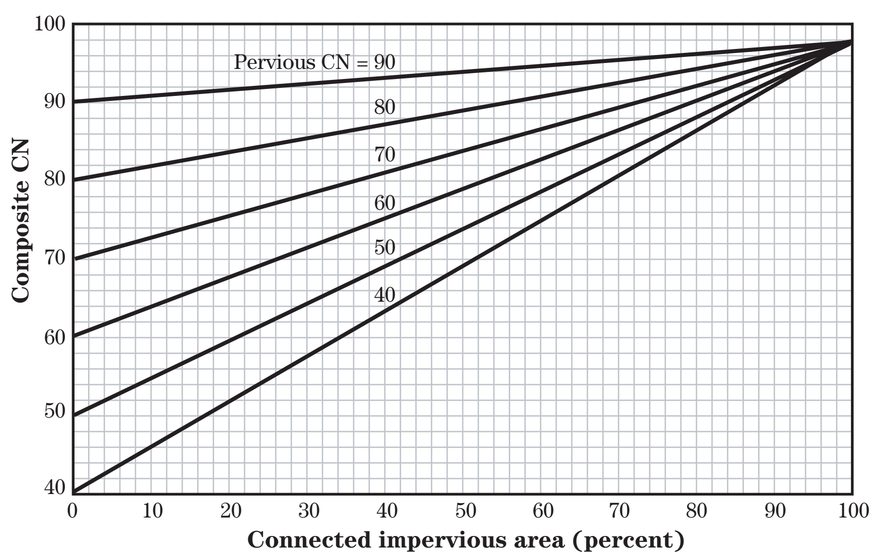


Table 9–5 Runoff curve numbers for urban areas [1/]

Cover description cover type and hydrologic condition	Average percent impervious area [2/]	- - CN for hydrologic soil group - - A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.) [3/]					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only) [4/]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation)		77	86	91	94

1/ Average runoff condition, and $I_a = 0.2S$.

2/ The average percent impervious area shown was used to develop the composite CNs. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition.

3/ CNs shown are equivalent to those of pasture. Composite CNs may be computed for other combinations of open space type.

4/ Composite CNs for natural desert landscaping should be computed using figures 9–3 or 9–4 based on the impervious area percentage (CN=98) and the pervious area CN. The pervious area CNs are assumed equivalent to desert shrub in poor hydrologic condition.

Example 9–1 Calculation of composite urban residential CN with different percentage of impervious area than that assumed in table 9–5

Given: Table 9–5 gives a CN of 70 for a ½-acre lot in HSG B with an assumed impervious area of 25 percent. The pervious area CN is 61.

Problem: Find the CN to be used if the lot has 20 percent impervious area.

Solution: **Method 1**—Solve equation 9–1 with CN_p, the pervious runoff curve number, equal to 61 and P_{imp}, the percent imperviousness, equal to 20:

$$CN_c = 61 + \left(\frac{20}{100}\right)(98 - 61)$$

$$CN_c = 61 + (.20)(37)$$

$$CN_c = 61 + 7.4$$

$$CN_c = 68.4 \text{ round to } 68$$

The CN difference between 70 in table 9–5 and 68 reflects the difference in percent impervious area.

Method 2—Enter figure 9–3 with the percentage of impervious area equal to 20 and move up to a point a little above the curve representing a pervious curve number of 60 to find the point for a pervious CN of 61. Read the Composite CN of 68 on the left axis.

The CN difference between 70 in table 9–5 and 68 reflects the difference in percent impervious area.

Example 9–2 Calculation of a composite urban residential CN with different CN for the pervious area than that assumed in table 9–5

Given: Table 9–5 gives a CN of 70 for a ½-acre lot in HSG B with an assumed impervious area of 25 percent. The pervious area CN is 61.

Problem: Find the CN to be used if the lot's pervious area has a CN of 69, indicating fair condition instead of good condition.

Solution: **Method 1—**Solve equation 9–1 with CN_p, the pervious runoff curve number, equal to 69 and P_{imp}, the percent imperviousness, equal to 25:

$$CN_c = 69 + \left(\frac{25}{100}\right)(98 - 69)$$

$$CN_c = 69 + (.25)(29)$$

$$CN_c = 69 + 7.25$$

$$CN_c = 76.25 \text{ round to } 76$$

The CN difference between 70 in table 9–5 and 76 reflects the difference in the pervious area CN.

Method 2—Enter figure 9–3 with the percentage of impervious area equal to 25 and move up to a point a little below the curve representing a pervious curve number of 70 to find the point for a pervious CN of 69. Read the Composite CN of 76 on the left axis.

The CN difference between 70 in table 9–5 and 76 reflects the difference in the pervious area CN.

(2) Unconnected impervious areas

If runoff from impervious areas occurs over a pervious area as sheet flow prior to entering the drainage system, the impervious area is unconnected. To determine CN when all or part of the impervious area is not directly connected to the drainage system:

- use equation 9–2 or figure 9–4 if the total impervious area is less than 30 percent of the total area or
- use equation 9–1 or figure 9–3 if the total impervious area is equal to or greater than 30 percent of the total area, because the absorptive capacity of the remaining pervious areas will not significantly affect runoff.

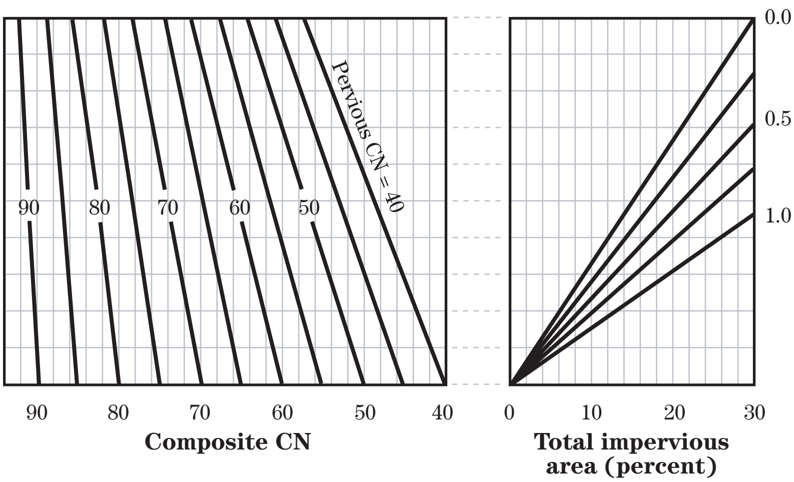
$$CN_c = CN_p + \left(\frac{P_{imp}}{100}\right)\left(98 - CN_p\right)\left(1 - .05R\right) \quad [9\text{–}2]$$

where:

CN_c = composite runoff curve number
CN_p = pervious runoff curve number
P_{imp} = percent imperviousness
R = ratio of unconnected impervious area to total impervious area

When impervious area is less than 30 percent, obtain the composite CN by entering the right half of figure 9–4 with the percentage of total impervious area and the ratio of total unconnected impervious area to total impervious area. Then move left to the appropriate pervious CN and read down to find the composite CN.

Figure 9–4 Composite CN with unconnected impervious areas and total impervious area less than 30%



Example 9–3 Determine the composite CN with unconnected impervious areas and total impervious area less than 30%

Given: A ½-acre lot in HSG B has an assumed impervious area of 20 percent, 75 percent of which is unconnected. The pervious area CN is 61.

Problem: Find the CN to be used for the lot.

Solution: **Method 1—**Solve equation 9–2 with CN_p, the pervious runoff curve number, equal to 61; P_{imp}, the percent impervious area, equal to 20; and R, the ratio of unconnected impervious area to total impervious area, equal to 0.75:

$$CN_c = 61 + \left(\frac{20}{100}\right)(98-61)\left(1-0.5(0.75)\right)$$

$$CN_c = 61 + (.20)(37)(1-0.375)$$

$$CN_c = 61 + (.20)(37)(0.625)$$

$$CN_c = 61 + 4.62$$

$$CN_c = 65.62 \text{ round to } 66$$

Method 2—Enter the right half of figure 9–4 with the percentage of impervious area equal to 20 and move up to the 0.75 line for the ratio of unconnected impervious area to total impervious area. Then move to the left part of the figure, left to the appropriate pervious CN 61, and read down to find the composite CN 66.

The CN considering all the impervious areas to be connected as in example 9–1 is 68. Example 9–3 shows that if 75 percent of the impervious area is unconnected, the CN is reduced to 66.

630.0902 References

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ATTACHMENT 4 – HYDROLOGIC RESPONSE OF SOLAR FARMS

Hydrologic Response of Solar Farms

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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. Although 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.

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.

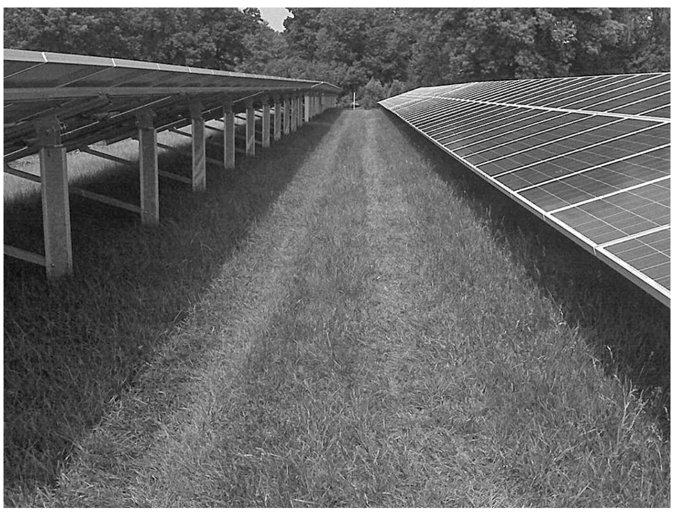

Fig. 1. Maintenance or "spacer" section between two rows of solar panels (photo by John E. Showler, reprinted with permission)

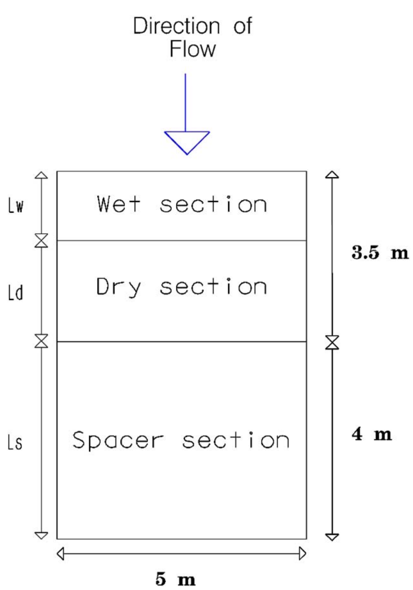

Fig. 2. Wet, dry, and spacer sections of a single cell with lengths *Lw*, *Ls*, and *Ld* with the solar panel covering the dry section

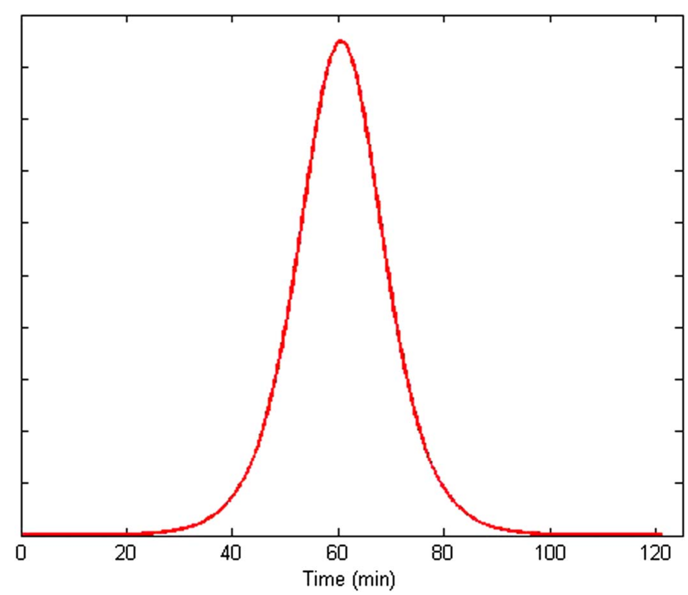

Fig. 3. Dimensionless hyetograph of 2-h Type II storm

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

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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.

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

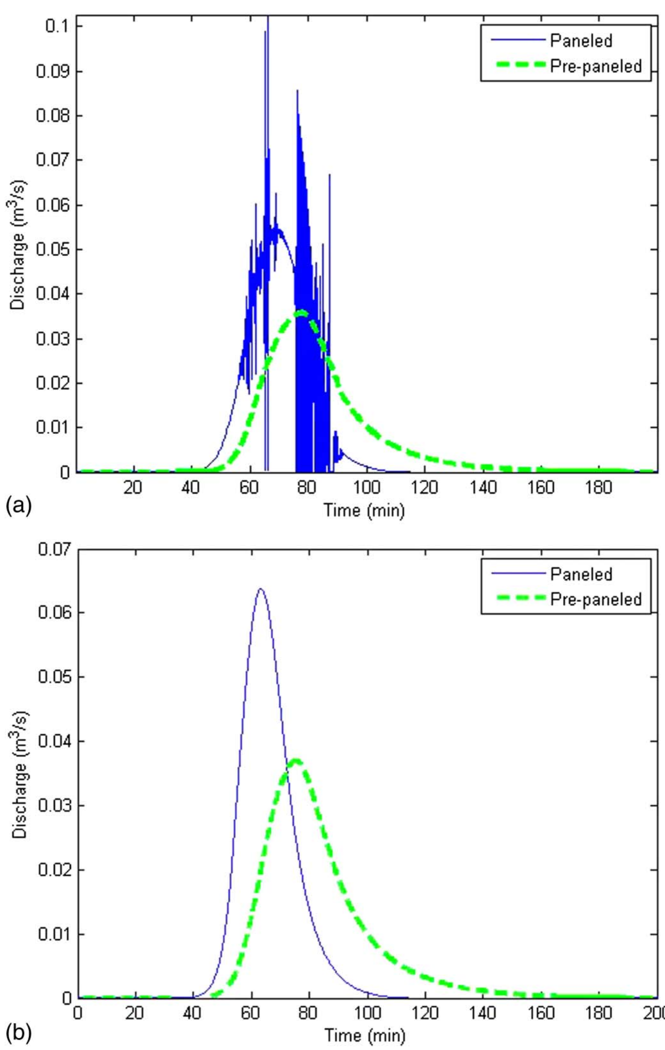

Fig. 4. Hydrograph with time increment of (a) 12 s; (b) 3 s with Manning's n for bare ground

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)

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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

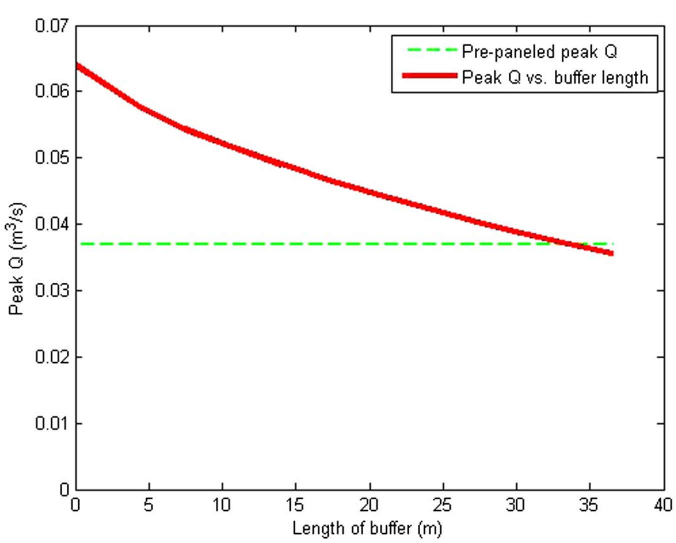

Fig. 6. Peak discharge over gravel compared with buffer length

runoff was calculated using Manning's equation, and the velocity of falling rainwater was calculated using the following:

$$V_t = 120\, d_r^{0.35} \tag{1}$$

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

$$K_e = 916 + 330 \log_{10} i \tag{2}$$

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.

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

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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.

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ATTACHMENT 5 – RUNOFF EROSION DIAGRAM

SOLAR FARMS REDUCE RUNOFF THROUGH LANDCOVER CONVERSION

Kimley»Horn

AGRICULTURAL FIELDS (BEFORE) VS. SOLAR FIELD (AFTER)