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April 5, 2018

VIA ELECTRONIC FILING

Martha Lynn Jarvis
Chief Clerk
North Carolina Utilities Commission
430 N. Salisbury Street
Raleigh, North Carolina 27603

Re: Wilkinson Solar LLC; EMP-93, Sub 0

Dear Clerk Jarvis:

Enclosed are the pre-filed supplemental testimonies of Joe Von Wahlde, Paul Thienpont, and John Barefoot responding to matters raised at the Public Hearing held on March 19, 2018 in the above referenced docket.

Thank you for your assistance with this matter. Please let me know if you have any questions.

Sincerely,

/s/ Henry C. Campen

Enclosures

PPAB 4193811v1

PREFILED SUPPLEMENTAL TESTIMONY OF
JOE VON WAHLDE
ON BEHALF OF WILKINSON SOLAR LLC

NCUC DOCKET NO. EMP-93, SUB 0

INTRODUCTION

Q. PLEASE STATE YOUR NAME, TITLE AND BUSINESS ADDRESS.

A. My name is Joe von Wahlde. I am a Senior Consultant with Cardno, Inc. My business address is 11181 Marwill Avenue, Grand Haven, Michigan 49460.

Q. PLEASE DESCRIBE YOUR EDUCATION AND PROFESSIONAL BACKGROUND.

A. I hold a Bachelors of Science in Environmental Science, Biology, and Entomology from St. Norbert College and a Master of Science in Wildlife Management from Northern Michigan University. I am a Professional Wetlands Scientist with a PWS designation, which is a national certification from the Society of Wetland Scientists, and have 29 years of experience in this field.

Q. PLEASE SUMMARIZE YOUR CURRENT EMPLOYMENT RESPONSIBILITIES.

A. I have been a Senior Consultant with Cardno for more than twenty five years. In my role, I am responsible for state and federal surface resource regulatory permitting assistance to developers. I have conducted regulatory wetland delineations under the Northeast-northcentral, Midwest, and Atlantic Gulf Coastal Plain Regional Supplements under the 1987 United States Corps of Engineers Wetland Determination Manual. I am the Cardno Project Manager for the Wilkinson Solar Project (the "Project") and I have conducted a regulatory wetland delineation on the Project.

Q. HAVE YOU PREVIOUSLY TESTIFIED BEFORE THIS COMMISSION?

A. No.

Q. WHAT IS THE PURPOSE OF YOUR TESTIMONY?

A. The purpose of my testimony is to provide the Commission with information in response to allegations raised at the public hearing that Wilkinson had not coordinated with the United States Army Corps of Engineers (the "Corps") regarding wetland delineations of the Project.

Q. PLEASE DESCRIBE YOUR INVOLVEMENT WITH THE PROJECT.

A. Cardno was engaged by Invenergy in April of 2017 to perform a jurisdictional wetlands delineation for the Project. On April 10, 2017, my colleague John Lowenthal sent a letter, on which I was copied, requesting a pre-jurisdictional determination meeting with Bill Biddlecome, then Washington Field Office Regulatory Chief with the Corps, to discuss the methodology we proposed for the Project delineation for lands converted to agriculture over 50 years ago. **Supplemental Exhibit 1**. The letter is attached with a copy of the Project site boundary.

Q. WAS A METHODOLOGY AGREED TO AND A DELINEATION PERFORMED?

A. Yes. Cardno prepared a wetland delineation methodology specific to the Project which utilized methods presented in the Corps of Engineers 1987

Wetland Delineation Manual as well as the 2010 Atlantic and Gulf Coastal Plain Regional Supplement, which was agreed to by the Corps. A wetlands delineation, in accordance with the agreed upon methodology, was performed on the approximately 700 acre Project on May 16 and 17, 2017. On August 18, 2017, Invenergy requested that a second wetlands delineation be performed on approximately 200 acres south of Terra Ceia Road and provided a boundary for the delineation. **Supplemental Exhibit 2**. On December 6-8, 2017, this second wetlands delineation was performed on this additional acreage.

Q. ARE YOU FAMILIAR WITH THE SITE LAYOUT AMENDMENT FILED IN THE ABOVE-REFERENCED DOCKET ON NOVEMBER 29, 2017 (THE "AMENDMENT")?

A. Yes.

Q. DOES THE AREA COVERED IN THE SECOND WETLANDS DELINEATION COVER THE ACREAGE ADDED TO THE PROJECT IN THE AMENDMENT?

A. Yes.

Q. WHAT WERE THE RESULTS OF THE FIRST AND SECOND WETLANDS DELINEATIONS?

A. The wetlands delineations of the approximately 900 acres identified minimal jurisdictional areas within the Project.

Q. WHAT ADDITIONAL STEPS WERE TAKEN AFTER DETERMINING THE RESULTS OF THE WETLANDS DELINEATIONS?

A. The wetlands delineation report was provided to Invenergy.

Q. DID YOU IDENTIFY ANY NATURAL WATERCOURSES THAT WOULD BE SUBJECT TO THE TAR-PAMLICO BUFFER RULES?

A. Broad Creek Canal was the only natural waterway identified during the wetlands delineations. The canal is located offsite to the southeast. The Project is sited to be in compliance with the Tar-Pamlico Buffer Rules.

Q. DOES THIS CONCLUDE YOUR TESTIMONY?

A. Yes.

Cardno
Shaping the Future

April 10, 2017

Cardno GS, Inc.

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Hampton, VA 23666

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www.cardno.com

Bill Biddlecome
Washington Field Office Regulatory Chief
Army Corps of Engineers, Wilmington District
CESAW-RG-W
2407 West 5th Street
Washington, NC 27889

Subject: Wilkinson Solar, Invenergy LLC
Town of Pantego, Beaufort County, NC
Jurisdictional Wetland Delineation

Dear Mr Biddlecome:

Cardno as agent for Invenergy, is under contract to conduct a jurisdictional wetland delineation of an approximately 717 acre site in Beaufort County, NC and requests a pre-jurisdictional determination meeting to discuss the methodology to be utilized to delineate the project area. The project limits are illustrated on the attached exhibit and are primarily agricultural fields and support facilities.

As you know, the Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Atlantic and Gulf Coastal Plain (2010) identifies the delineation methodology for agricultural lands that are being converted to other uses as a "Difficult Wetland Situation". Cardno would like to discuss our proposed methodology and get any feedback from you and your staff ahead of time to allow the delineation effort to move forward as smoothly as possible.

We appreciate your time and attention to this effort and look forward to hearing back from you or one of your staff to schedule this meeting.

Sincerely,

John M. Lowenthal, PWS, PWD
Associate/Senior Biologist
Cardno
John.lowenthal@cardno-gs.com

Encl: Figure 1: Proposed Project Limits

cc: Andrea Giampoli, Invenergy
Joe von Wahlde, Cardno

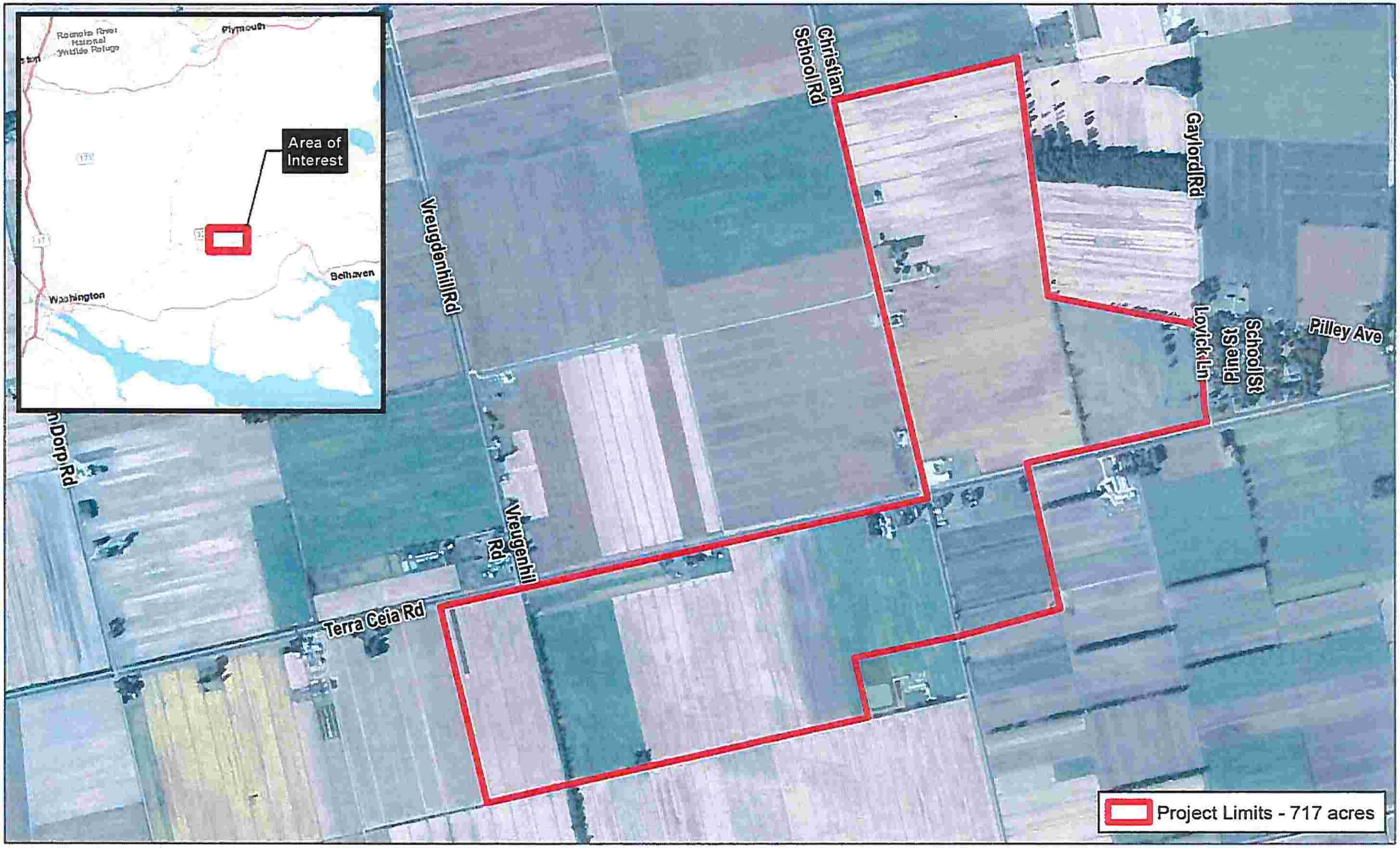

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Figure 1: Proposed Project Limits

Wilkinson Solar
Invenergy, LLC
Town of Pantego, Beaufort County, NC

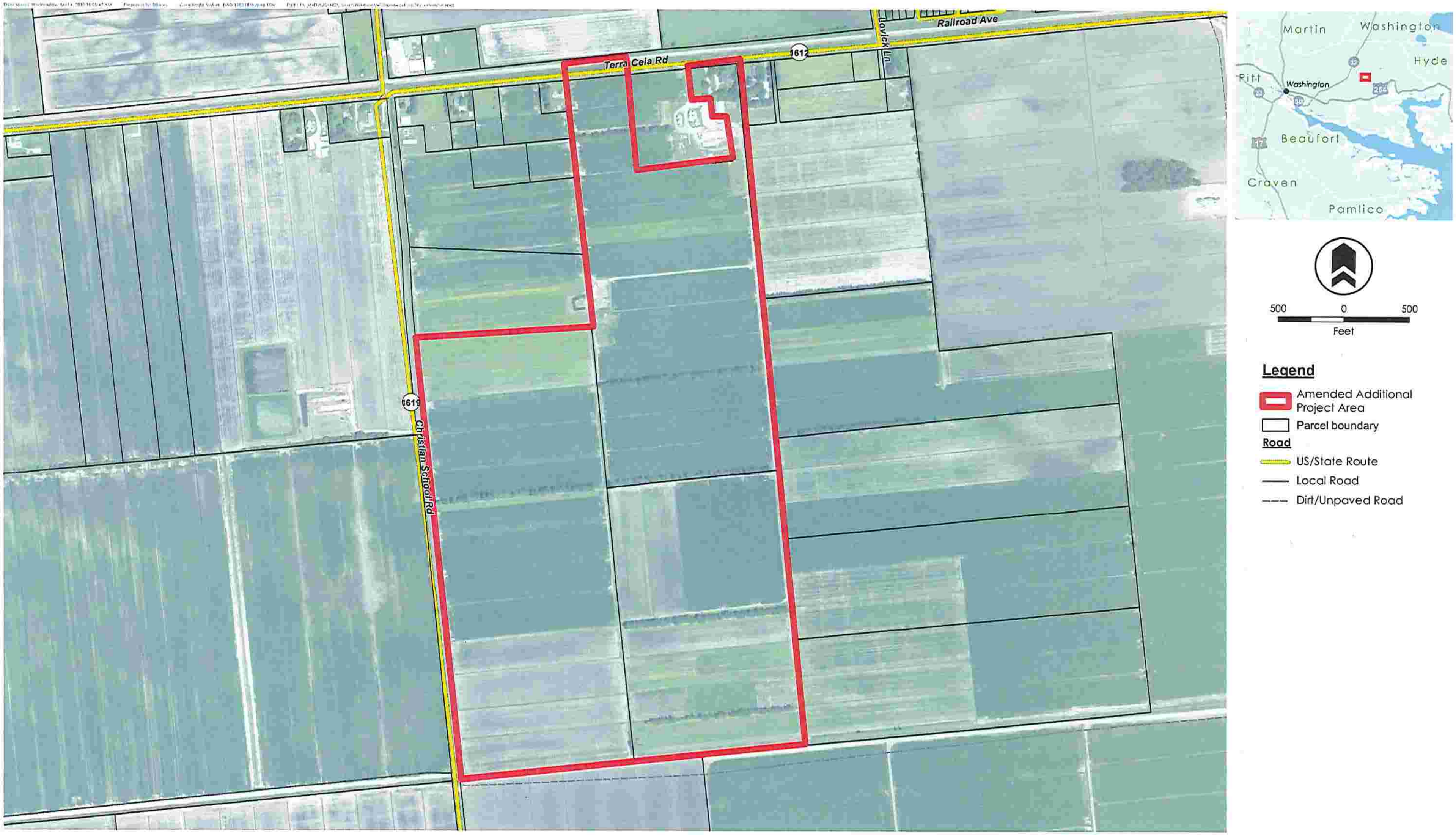
0.5 0.25 0 0.5 Miles

Cardno
Shaping the Future

Date: 4/6/2017 File Path: R:\Projects\16\16X\16X001M00_Invenergy_Master\16X001M02_168355400_Invenergy_WilkinsonSolar\GIS\MXD\Location map.mxd GIS Analyst: Rebecca Norris

Basemap: NCDOT GIS Unit, Sources: Esri, HERE, DeLorme, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), MapmyIndia, NGCC, © OpenStreetMap contributors, and the GIS User Community, Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Apr 05 2018 OFFICIAL COPY



Wilkinson Amended Application Exhibit A

Wilkinson Solar Energy Center | Beaufort County, North Carolina

Rev. 05
April 04, 2018

Invenergy

PREFILED SUPPLEMENTAL TESTIMONY OF
PAUL THIENPONT
ON BEHALF OF WILKINSON SOLAR LLC

NCUC DOCKET NO. EMP-93, SUB 0

INTRODUCTION

Q. PLEASE STATE YOUR NAME, TITLE AND BUSINESS ADDRESS.

A. My name is Paul Thienpont. I am a Manager, Renewable Engineering with Invenergy LLC. My business address is One South Wacker Drive, Suite 1800, Chicago, Illinois 60606.

Q. HAVE YOU PREVIOUSLY TESTIFIED BEFORE THIS COMMISSION?

A. Yes. I testified at the evidentiary hearing for the Wilkinson solar project (the "Project") CPCN application on May 22-23, 2017.

Q. HAS YOUR EDUCATIONAL AND PROFESSIONAL BACKGROUND CHANGED SINCE YOUR 2017 TESTIMONY?

A They have not.

Q. HAVE YOUR RESPONSIBILITIES WITH INVENERGY OR WITH RESPECT TO THE PROJECT CHANGED SINCE YOUR 2017 TESTIMONY?

A. They have not.

Q. ARE YOU FAMILIAR WITH THE SITE LAYOUT AMENDMENT FILED IN THE ABOVE-REFERENCED DOCKET ON NOVEMBER 29, 2017 (THE "AMENDMENT")?

A. Yes.

Q. HAVE YOU INSPECTED THE PROJECT SITE, INCLUDING THE AMENDMENT AREA?

A. Yes, I have been to Beaufort County and walked the site. I am well acquainted with the Amendment and how it fits on the site.

Q. WHAT IS THE PURPOSE OF YOUR TESTIMONY?

A. The purpose of my testimony is to provide the Commission with information in response to allegations raised at the public hearing on March 19, 2018, regarding health and safety concerns. However, it is my understanding that the North Carolina Department of Environmental Quality is the state environmental agency and that the State Clearinghouse has already reviewed and passed on the Amendment area. My testimony also provides information regarding the design of the Project to avoid wetlands, soil composition, and outreach to local Emergency Management Services ("EMS").

HAZARDOUS SUBSTANCES

Q. WHAT CONCERNS WERE RAISED AT THE PUBLIC HEARING ABOUT HAZARDOUS SUBSTANCES?

A. A few members of the public testified about their concerns over whether the solar panels contain Gen-X, perfluorinated alkylated substances ("PFAS"), and heavy metals.

Q. WHAT ARE GEN-X AND PFAS?

A. They are man-made chemicals that are used in certain manufacturing processes. Neither Gen-X nor PFAS are used in the production of any of the components that make up the solar panels planned for use for the Project. Attached as **Supplemental Exhibit 1** is a memorandum from

JinkoSolar, the manufacturer of the solar panels planned for use for the Project, confirming that these chemicals are not present in the solar panels.

Q. WHAT ABOUT HEAVY METALS?

A. As I testified at the CPCN application evidentiary hearing on May 22, 2017, the solar panels planned for use for the Project pass the EPA's Toxicity Characteristic Leaching Procedure ("TCLP") test, which classifies them as non-hazardous waste and allows for disposal in landfills.[1] The TCLP test report was admitted into evidence as Applicant Thienpont Exhibit Number 2.

FACILITY DESIGN

Q. HAVE JURISDICTIONAL WETLANDS DELINEATIONS BEEN DONE FOR THE PROJECT?

A. Yes. Cardno performed a jurisdictional wetlands delineation on the original Project site layout and a second delineation on the Amendment area.

Q. WHAT WAS DONE IN RESPONSE TO THE DELINEATIONS?

A. Invenergy took the results of the delineations into consideration during the engineering and design phase of development to help determine the Project layout. The Project has been designed to avoid impacts.

SOIL COMPOSITION

Q. MEMBERS OF THE PUBLIC EXPRESSED CONCERNS AT THE PUBLIC HEARING ABOUT THE AREA CONTAINING ORGANIC SOILS AND ABOUT COMBUSTIBILITY OF THOSE SOILS. HAS GEOTECHNICAL ENGINEERING FOR SOIL COMPOSITION BEEN DONE FOR THE PROJECT?

[1] See Transcript Vol. II at 75-76, 82, 204-06.

A. Yes, a geotechnical engineering study was done to determine soil composition. The geotechnical engineering firm has classified the soils at the site as Clayey Sand, Lean Clay with Sand, Silty Sand, and Poorly-graded Sand. For soils to be considered "combustible" they typically are comprised of organic compounds. The geotechnical engineering study has concluded that none of the soils sampled across the site are categorized as "organic".

<u>EMS OUTREACH</u>

Q. WILL WILKINSON COORDINATE WITH LOCAL EMS?

A. Yes. As I testified at the CPCN application evidentiary hearing on May 22, 2017, it is Invenergy's standard practice to coordinate with local EMS personnel, which typically consists of outreach to local law enforcement and local fire departments to inform them about the project. Invenergy's standard procedure is to start this coordination late in the development process, just prior to commencement of physical construction on the site.

Q. DOES THIS CONCLUDE YOUR TESTIMONY?

A. Yes.

JinKO Solar
Building Your Trust in Solar

April 4, 2018

Paul Thienpont
Manager, Renewable Engineering
Invenergy
One South Wacker Drive, Suite 1800, Chicago, IL 60606

RE: Jinko Solar Photovoltaic Modules and Dupont GenX chemical

Dear Mr. Paul Thienpont,

Jinko Solar, a solar panel manufacturer and part of the Jinko Solar Holding Co., Ltd. (NYSE: JKS), a vertically-integrated solar power solar photovoltaic module manufacturer, hereby confirms that neither the Gen X or PFAS chemical compounds are used in any of the materials used to manufacturer Jinko Solar photovoltaic modules. The Gen X and PFAS compound is not used in any of the Dupont supplied materials for the Jinko Solar photovoltaic module and the letter attached from Dupont can provide further confirmation.

We at Jinko Solar are committed to the highest standards of business ethics and always conduct business in accordance with applicable laws, rules and regulations. Jinko Solar's corporate governance policies are designed to protect the interests of its shareholders, and promote responsible business practices and corporate citizenship.

Sincerely,

Daniel Chang
Technical Director – North America
Jinko Solar U.S. Inc
595 Market St. ST 2200
San Francisco, CA 94105

JinKO Solar
Building Your Trust in Solar

Statement

DUPONT

WILMINGTON, Delaware, April 4, 2018 – As the industry leader in solar solutions that delivers proven power and lasting value for the solar industry, DuPont Photovoltaic Solutions does not use Gen X or PFAS compounds in the production or processing of Tedlar® polyvinyl fluoride films, which are widely used in backsheets for solar panels.

Teflon® PTFE is not sold into PV module applications. DuPont does not currently market or sell FEP for PV applications, and has not marketed or sold FEP in the past three years. JinkoSolar is only a customer for Tedlar®.

DuPont Photovoltaic Solutions (DPVS) is the leading supplier of specialty materials to the solar energy industry. Since 1975 more than half of the world's 900 million installed solar panels contain DuPont materials. The DPVS portfolio, including Solamet® photovoltaic metallization pastes and DuPont™ Tedlar® polyvinyl fluoride films, is the established benchmark of the industry, delivering lifelong value through proven performance, reliability, efficiency and best return on investment. To learn more, please visit http://photovoltaics.dupont.com.

# # #

Contact: Tara Stewart
302-650-3063
Tara.c.stewart@dupont.com

PREFILED SUPPLEMENTAL TESTIMONY OF
JOHN BAREFOOT
ON BEHALF OF WILKINSON SOLAR LLC

NCUC DOCKET NO. EMP-93, SUB 0

INTRODUCTION

Q. PLEASE STATE YOUR NAME, TITLE AND BUSINESS ADDRESS.

A. My name is John Barefoot. I am a Project Manager with Kimley Horn and Associates, Inc. My business address is 421 Fayetteville Street, Suite 600, Raleigh, North Carolina 27601.

Q. PLEASE DESCRIBE YOUR EDUCATION AND PROFESSIONAL BACKGROUND.

A. I hold a Bachelors of Science in Civil Engineering from North Carolina State University. I am a licensed North Carolina professional engineer with 8 years of experience. My areas of specialty are in land development, water resources, and hydrology.

Q. PLEASE SUMMARIZE YOUR CURRENT EMPLOYMENT RESPONSIBILITIES.

A. I am a project manager on multiple commercial, industrial, and utility scale solar projects.

Q. HAVE YOU PREVIOUSLY TESTIFIED BEFORE THIS COMMISSION?

A. No.

Q. WHAT IS THE PURPOSE OF YOUR TESTIMONY?

A. The purpose of my testimony is to provide the Commission with information in response to some of the stormwater runoff concerns that were raised by witnesses who testified at the public hearing.

Q. ARE YOU FAMILIAR WITH THE SITE LAYOUT AMENDMENT FILED IN THE ABOVE-REFERENCED DOCKET ON NOVEMBER 29, 2017 (THE "AMENDMENT")?

A. Yes, I am.

Q. HAVE YOU INSPECTED THE WILKINSON SOLAR PROJECT (THE "PROJECT") SITE?

A. Yes, I have been to Beaufort County and walked the Project site. I am well acquainted with the layout, including the amendment area.

Q. PLEASE DESCRIBE YOUR INVOLVEMENT WITH THE PROJECT.

A. Kimley-Horn was engaged by Invenergy in 2017 to prepare a preliminary review of stormwater requirements and anticipated stormwater management design for the Project. On June 19, 2017, I conducted a site visit on the original site layout, which included the Respess property and did not include the amendment area. On June 20, 2017, I prepared a memorandum detailing my review. **Supplemental Exhibit 1**.

Q. WAS YOUR MEMORANDUM LATER FILED WITH THE COMMISSION?

A. Yes, I understand that it was included as an attachment to an affidavit filed by April Montgomery in this docket on June 22, 2017.

Q. WHAT DID THE MEMORANDUM CONCLUDE?

A. The report concluded that: "Based on the site visit, NCDEQ's stormwater permitting requirements, and the anticipated stormwater design approach, Kimley Horn believes the proposed development's impact to existing drainage patterns and flows will be negligible, or more likely, the proposed solar use will provide a reduction in runoff from the site. In the event that the final design results in a different conclusion, additional measures can be implemented on the subject site to address stormwater concerns." Supplemental Exhibit 1, p. 4.

Q. ARE THE CONCLUSIONS REACHED IN YOUR JUNE MEMORANDUM RELEVANT TO THE AMENDMENT AREA?

A. Yes. The acreage added as part of the Amendment is identical in all material respects to the Respess acreage that was reviewed as part of the memorandum referenced above. The conclusion that the Project's impact to existing drainage patterns will be negligible, or even reduce runoff, is equally applicable to the amended site layout.

Q HAVE YOU REVIEWED THE STATE CLEARINGHOUSE COMMENTS ON THE AMENDMENT AREA?

A Yes, I have.

Q. DID THE AGENCIES RESPONDING TO THE CLEARINGHOUSE HAVE ANY COMMENTS WHICH WERE AT ODDS WITH YOUR CONCLUSIONS ABOUT STORMWATER MANAGEMENT AND RUNOFF POTENTIAL FROM THE AMENDMENT AREA?

A. No, and, in fact, the Clearinghouse concluded that the agency comments did not warrant any further review.

Q. DOES THIS CONCLUDE YOUR TESTIMONY?

A. Yes.

Kimley»Horn

MEMORANDUM

To: Ryan Van Portfliet, Invenergy, LLC

From: John Barefoot, P.E.

Date: June 20, 2017

Subject: Proposed Wilkinson Solar Facility
Washington, NC
Preliminary Stormwater Memo

This memorandum details a preliminary review of stormwater requirements, anticipated stormwater management design, and steps for future in-depth stormwater analysis in regards to the development of the proposed Wilkinson Solar Facility.

Project Understanding

The proposed Wilkinson Solar Facility is located on an ±717 acre site located at the intersection of Terra Ceia Road (SR 1612) and Christian School Road (SR 1619) to the east of the City of Washington in Beaufort County, North Carolina. The proposed site occupies land on eight separate parcels, some being north and some being south of Terra Ceia Road.

A site visit was conducted on 6/19/2017 by a Kimley-Horn representative to review the existing conditions of the proposed project area. The site's current use is cultivated farm land. The existing topography is very flat and drainage relief is provided by existing ditches which transverse the fields at regular intervals. These drainage ditches convey runoff out of the fields and into larger canals along the adjacent roads. The large canals route stormwater runoff into tributaries of the Pamlico Sound. While it was evident by swept vegetation that the canals have experienced large rain events in the past, they were heavily vegetated and stabilized at the time of the site visit. Images of the existing conditions taken at the subject site visit are included as Attachment A.

It is our understanding that the construction of the proposed solar facility will consist of the following:

- Ground-mounted arrays of photovoltaic panels arranged in rows and mounted on single-axis trackers;
- Inverters, combiners, and transformers;
- Substation and battery storage facility;
- Buried electrical conduits;
- Onsite unpaved access roads and interior access paths;
- Chain link security fencing located along the site perimeter; and
- Gravel-surfaced access driveways from the adjacent roadways

The proposed construction will require the disturbance of approximately 560 acres of land based on preliminary site layouts. This disturbed land currently does not appear to contain impervious area. It is anticipated that approximately three acres of impervious surface will be added to this area which include new access roads and equipment pads. This would be an impervious area increase of approximately 0.5%. The proposed solar panels on site are viewed as pervious as detailed in the following section.

Stormwater Management Rules and Regulations

The North Carolina Department of Environmental Quality (NCDEQ) has stormwater and erosion control permitting authority for the proposed project site. With the proposed site being located in a costal county and adding over 10,000 square feet of built upon area, it is anticipated that a stormwater permit will be required. To receive a stormwater permit, the site design will need to meet the requirements of the NCDEQ stormwater design manual, specifically the low density chapter and new Solar Farm chapter. Based on the preliminary site layout, it is anticipated the project will be considered low density by NCDEQ as it should meet the built upon area requirements and utilizes vegetative conveyances.

As mentioned above, a new Solar Farm chapter in the NCDEQ stormwater design manual was added in 2016 and last updated in April of 2017. This chapter gives specific guidance for solar sites. The NCDEQ stormwater manual list requirements for all accepted stormwater control measures and their design criteria which must be met in order to receive a stormwater permit through NCDEQ. In short, the new chapter explains that as long as the panels are disconnected they are not classified as built upon area and sheet flow should be maintained. NCDEQ defines disconnected as the width between the rows of panels being greater than or equal to the panel width. The chapter also contains other recommendations for design practices. The solar farm chapter of the NCDEQ stormwater design manual is included for reference as Attachment B.

This understanding is further reinforced by a report in the Journal of Hydrologic Engineering titled "Hydrologic Response of Solar Farms" dated May 2013. The conclusion of this report after various testing procedures were carried out is the addition of solar panels over a grassy field has very little effect on the volume of runoff, the peak discharge, and the time to peak. With each analysis, the runoff volume increased slightly but not enough to require storm-water management facilities. The Hydrologic Response of Solar Farms report is included for reference as Attachment C.

An erosion and sediment control permit will be needed as the site disturbs over one acre. The proposed temporary erosion control measures on site will need to be in compliance with the NCDEQ Sediment and Erosion Control Manual in order to receive an erosion and sediment control permit through NCDEQ.

If the proposed design impacts any wetlands or streams that may be present on site, permitting through the Army Corps of Engineers will be required.

Anticipated Stormwater Management Design

The goal for the proposed Wilkinson facility will be to maintain natural drainage patterns to the maximum extent possible. As with all development, grading construction activities are cost-adders to the facility, and thus, developers are incentivized to minimize the need for those activities in their designs. This approach pairs well with the low-density nature of solar facilities and with less grading comes less potential for erosion. Where an access road or path must cross a drainage ditch, an appropriately sized culvert will be placed to make the crossing. Due to the alignment of the solar panel rows not matching the alignment of existing ditches, panels will need to cross over existing ditches. This layout and approach has worked on other nearby solar sites in Shawboro and Beaufort, NC, that Kimley-Horn has designed recently. These sites were very similar to the proposed Wilkinson solar site as they also had 2-3 foot deep drainage ditches traversing relatively flat fields. The panels were able to cross the ditches without the need for grading or realignment. Please see image below for one example of this low-impact design. Please be aware that when rows of panels cross existing field ditches, there will likely be increased cost for long term ditch maintenance that should be taken into consideration by the owner/developer.

Recent Solar Facility Design, Shawboro, NC

During the civil design process, existing culverts, new culverts, and ditch cross sections within the project area will be checked to confirm they are adequately sized to convey runoff from their respective drainage areas.

Further, the current cultivated agricultural land use has a higher curve number than the managed open space that the site will be classified as under the proposed solar use. The curve number is a way to relate site rainfall to site runoff and is based on soils, plant cover, amount of impervious areas, interception, and surface storage. A higher curve number means more rainfall becomes runoff. In summary, the stabilized grassy meadow condition of the solar use is expected to retain more rainfall from becoming runoff than the currently planted crops. Additionally, in the current use, the site is tilled and disturbed typically on an annual basis which increases the potential for erosion and maintenance concerns. The proposed use once constructed is expected to remain stabilized over the life of the facility.

Steps for Future In-Depth Stormwater Analysis

To further confirm that the design approach described above will be sufficient and result in minimal impact to the existing drainage patterns, Invenergy can acquire topographical data from a field survey to include all culvert and ditch sizing. Kimley-Horn will use this data to ensure that existing and proposed site drainage features are adequately sized to convey design stormwater flows.

Other services that are recommended prior to civil design are as follows:

- Storm surge analysis due to proximity to coast line
- Flood elevation study to determine maximum water elevations on the project site
- Wetland and Stream delineation

Conclusions

Based on the site visit, NCDEQ's stormwater permitting requirements, and the anticipated stormwater design approach, Kimley Horn believes the proposed development's impact to existing drainage patterns and flows will be negligible, or more likely, the proposed solar use will provide a reduction in runoff from the site. In the event that the final design results in a different conclusion, additional measures can be implemented on the subject site to address stormwater concerns.

Attachment A - Site Photos

Photo 1: Looking east from Christian School Road at typical existing drainage ditches on parcels north of Terra Ceia Road.

Photo 2: Looking south from Terra Ceia Christian School Driveway at small canal that intercepts field drainage ditches.

Photo 3: Looking east from intersection of Terra Ceia Road and Christian School Road at large canal that intercepts small canals. All project drainage exits to this tributary.

Photo 4: Looking northwest from Terra Ceia Road at project area. Large canal in foreground.

Photo 5: Looking west from intersection of Terra Ceia Road and Lovich Lane at project area.

Photo 6: Looking south from Terra Ceia Road at typical existing drainage ditches on parcels south of Terra Ceia Road.

Photo 7: Looking southeast from Terra Ceia Road at project area.

Photo 8: Looking southwest from Terra Ceia Road at project area.

E-6. Solar Farms


Image SAS, Cary, NC

Design Objective

Solar farms consisting of large arrays of ground-mounted photovoltaic systems are becoming increasingly common in North Carolina. Responsible development of solar farms must balance the growth of this valuable industry with the need to protect our natural resources, including addressing issues related to stormwater runoff. Solar farms that use traditional elevated solar panels are unique because they contain an impervious surface (elevated solar panel) that often have a pervious surface (vegetation) underneath the panel. Stormwater management may be achieved in a cost-effective manner by disconnecting rows of solar panels and directing runoff over the vegetated areas between the rows.

Regulatory Requirements

Currently, the State allows solar panels associated with ground-mounted solar farms to be considered pervious if configured such that they promote sheet flow of stormwater from the panels and natural infiltration of stormwater into the ground beneath the panels. Other structures associated with the solar farm such as buildings, entrance roads, transformers, and footings would still be considered impervious.

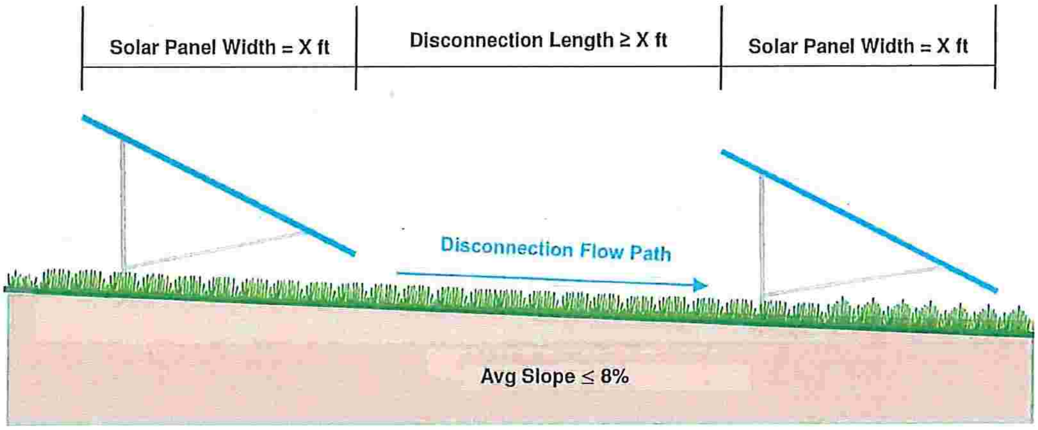
Important Links

N.C.G.S. 143-214.7(b2): "For purposes of implementing stormwater programs, 'built-upon area' means impervious surface and partially impervious surface to the extent that the partially impervious surface does not allow water to infiltrate through the surface and into the subsoil."

RECOMMENDATION 1: AVOID COMPACTION OF SUBSOIL
Subsoil compaction should be minimized during and after installation of solar arrays to allow the maximum amount of natural infiltration. If compaction occurs during construction, subsoil should be tilled and amended to return the soil to its pre-compaction condition.

RECOMMENDATION 2: DISCONNECT RUNOFF FROM SOLAR PANEL ARRAYS
Solar arrays should be designed and installed to allow growth of vegetation under and between the solar arrays. Rows of panels should be installed with sufficient distance between rows to allow for capture of rainfall from at least 1.0 inch of rain (Figure 1). Where installed on slopes greater than 8%, consider options for maintaining sheet flow and dissipating energy at the drip edge of each row of panels.

Figure 1: Disconnection of flow path between solar panels when average slope is less than 8%.



RECOMMENDATION 3: AVOID CONCENTRATION OF STORMWATER
Panels should be positioned to allow stormwater to run off their surfaces; however, collection and concentration of stormwater flow is to be avoided. Arrays should be installed on a uniform plane such that stormwater will sheet flow off the panels and remain unconcentrated. When considering a potential build site, it's a good idea to consider the slope of the land in the areas of the site where the solar arrays are most likely to be installed. Areas with steep slopes may not be suitable or may require considerable grading.

RECOMMENDATION 4: MINIMIZE USE OF HERBICIDES AND FERTILIZERS
Weed control and vegetation management is particularly important for ground-mounted solar systems. Overuse of herbicides and fertilizers can contribute to degraded water quality. Limit

the use of fertilizers to that necessary to maintain vegetation. Use mowing for vegetation control instead of herbicides.

RECOMMENDATION 5: PLANT MIX OF WARM- & COOL-SEASON GRASSES
Large solar arrays can have the effect of creating microclimates under the panels. To help account for this, plant a mixture of warm-season and cool-season grasses to account for differences in temperature and shading created from the installation of large solar arrays. In addition, use low-growing, low-maintenance grass mixtures. Planting mixtures can also include low-growing wildflowers such as white clover and other types of vegetation that can be attractive to pollinators. A win-win for the grass and the bees!

RECOMMENDATION 6: LIMIT VERTICAL CLEARANCE TO ≤ 10 FEET
Stormwater runoff falling from solar panels can cause scouring and erosion at the driplines. Limiting the lowest vertical clearance to no greater than 10 feet will help prevent erosion and scouring along the dripline.

Attachment C

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.** © *2013 American Society of Civil Engineers.*

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

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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)

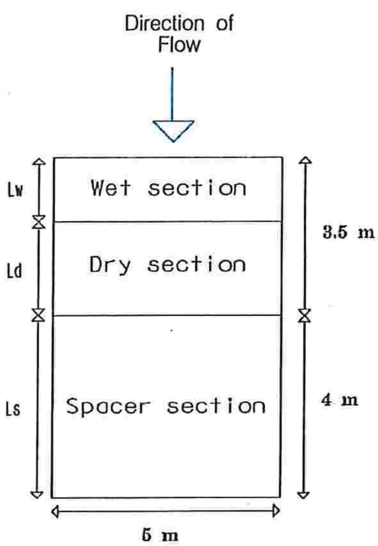

Fig. 2. Wet, dry, and spacer sections of a single cell with lengths *Lw*, *Ls*, and *Ld* with the solar panel covering the dry section

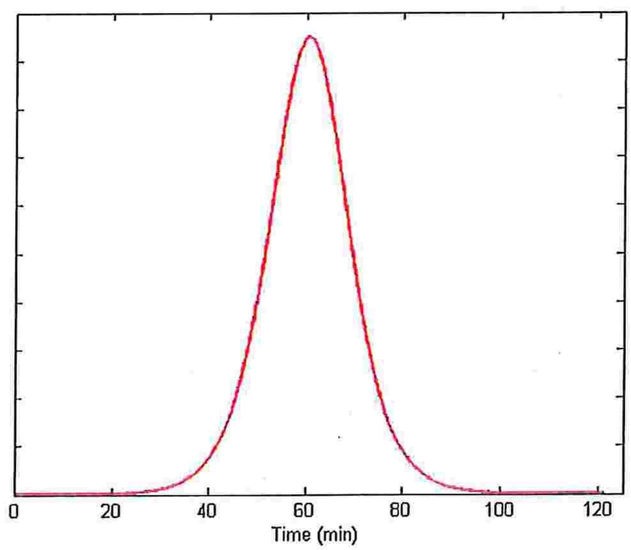

Fig. 3. Dimensionless hyetograph of 2-h Type II storm

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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

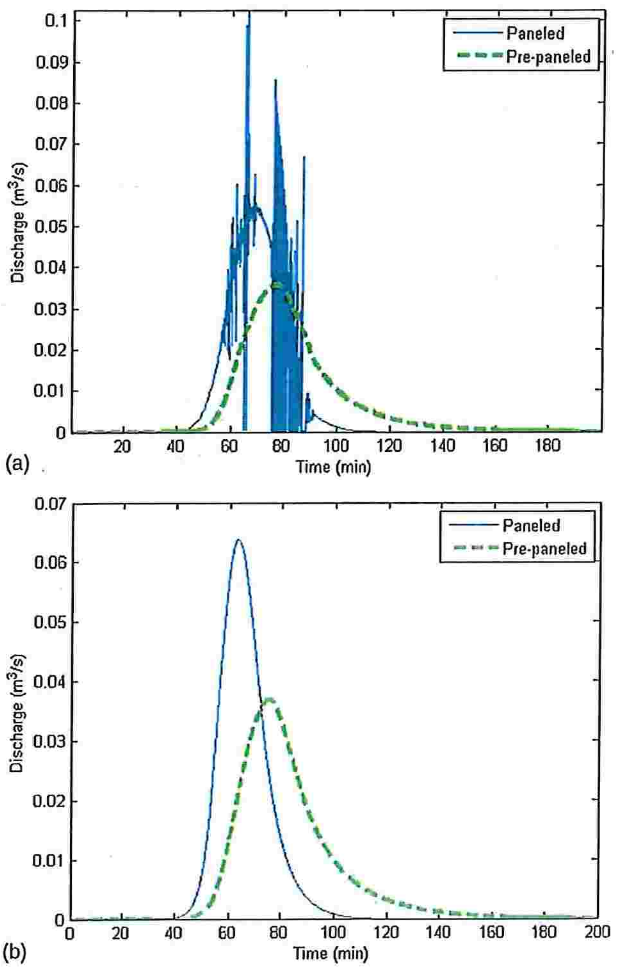

Fig. 4. Hydrograph with time increment of (a) 12 s; (b) 3 s with Manning's n for bare ground

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. 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

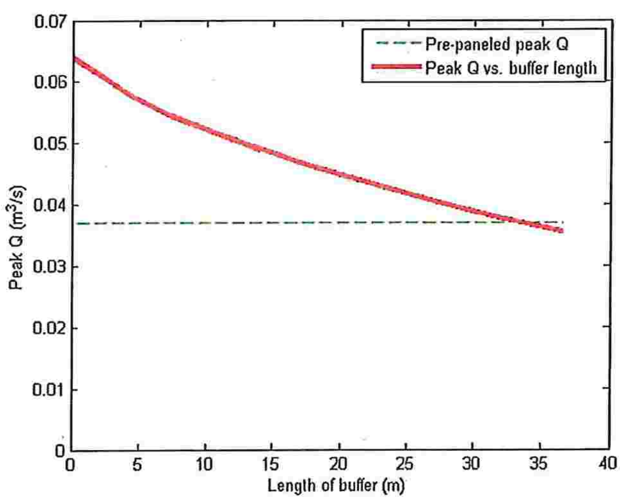

Fig. 6. Peak discharge over gravel compared with buffer length

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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