2-Dimensional Modelling to Simulate Stormwater Flows at Solar Voltaic Energy Sites

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Presentation Outline

1. Solar Farms
   - Stormwater Management Overview
   - Regulatory Considerations

2. Stormwater Modelling
   - Subcatchment-1D
   - 2D
   - Linked 1D-2D

3. Case Studies
   - Preliminary Site Assessment
   - Design
Solar Farms

- Large scale arrays of solar photovoltaic panels
- Ground mounted rectangular panels
- Fixed or tracking orientation
- Aligned in rows with controlled slopes to optimize output and minimize shading
- Access roads and electric switching equipment
- Located in rural areas
- Also completed landfills
Stormwater Management at Solar Farms

► Panels are impervious
► Stormwater falls directly to ground
► Site graded to maintain sheet flow
► $0 \leq \text{slope} \leq 5\%$ (vary depending on relation to the azimuth)
► Infiltration trenches for greater slopes
► Seeded with grass or other native vegetation
► Mowing 1 – 2 times per year
► Additional stormwater controls at perimeter
Stormwater Regulatory Considerations

► General development stormwater requirements
  • no net increase in site runoff,
  • no downstream impacts
► Maintain sheet flow
► New Jersey – state law exempts solar panels from zoning limitations on impervious cover, similar laws elsewhere

► State Guidelines (typical)
  • $0 \leq \text{slope} \leq 5\%$ (infiltration trenches for greater slopes)
  • Seeded with grass or other native vegetation
  • Mowing 1 – 2 times per year
  • Additional stormwater controls at perimeter

Credit: MDE
Stormwater Design Guidance
Runoff at Solar Farms?

Cook and McCuen (2013)

► Do panels increase runoff from site?
► Does drip at panel edge cause erosion?
► Used hydrologic model to assess ground slope, panel angle, storm duration, ground cover

► Conclusions
  ► Little impact on volume of runoff, time to peak or peak runoff
  ► Gravel or pavement increased volume and peak discharge
  ► Erosion from panel drip may be an issue
► No field verification published

Credit: Cook & McCuen 2013
Modelling Approaches

► Subcatchment-1D
  ► SWMM & variants
  ► Semi-distributed
  ► Generally accepted

► 2D
  ► Fully distributed
  ► Data & computationally intensive
  ► Required where flow paths are unknown, not 1D or change during event
  ► Can have 1D components in 2D domain

► Linked Model
  ► Use Subcatchment-1D to develop off site flows → boundary condition for 2D
  ► 2D domain focused on area of interest
## Comparison of Sub-catchment-1D and 2D Runoff Methods

<table>
<thead>
<tr>
<th>Component</th>
<th>Subcatchment-1D</th>
<th>2D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation</td>
<td>Time series</td>
<td>Time series</td>
</tr>
<tr>
<td>Runoff</td>
<td>Various hydrologic methods</td>
<td>Mass balance</td>
</tr>
<tr>
<td>Flow paths</td>
<td>Predefined by user</td>
<td>Model determines, may vary over simulation</td>
</tr>
<tr>
<td>Hydraulic Routing</td>
<td>Sub catchment → 1D conveyance structure</td>
<td>Cell → Cell</td>
</tr>
<tr>
<td>Input</td>
<td>Geometry, travel time, n-value, infiltration rates</td>
<td>Elevation, n-value, infiltration rates, boundary flows and water elevations</td>
</tr>
<tr>
<td>Output</td>
<td>Hydrograph, velocity and depth in conveyance structures</td>
<td>Hydrograph, velocity and depth time series</td>
</tr>
</tbody>
</table>
Linked Model Approach

Sub 1 → Stream @ A
Sub 2 & Sub 3 → Stream @ B
B inflow → 2D domain
Sub 4 → inflow 2D domain
Stream BC included in 2D domain
Proposed sites in west Texas

<table>
<thead>
<tr>
<th>Site</th>
<th>Size, ac</th>
<th>Flooding Issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2,607</td>
<td>55 sq. mi. upstream catchment, a draw along the site boundary</td>
</tr>
<tr>
<td>2</td>
<td>1,240</td>
<td>Major regional river, controlled dam upstream, 571 sq. mi. additional catchment</td>
</tr>
<tr>
<td>3</td>
<td>2,833</td>
<td>458 sq. mi upstream catchment, private dam, diversions to irrigation canals</td>
</tr>
</tbody>
</table>
Input parameters for models

<table>
<thead>
<tr>
<th>Software</th>
<th>Subcatchment</th>
<th>1D routing</th>
<th>2D</th>
</tr>
</thead>
<tbody>
<tr>
<td>HEC-HMS</td>
<td>HEC-HMS</td>
<td></td>
<td>FLO-2D</td>
</tr>
</tbody>
</table>

**Input parameters**
- Precipitation Area
- Time of concentration
- Curve number
- Channel length
- Channel slope
- Cross section
- Mannings n
- Precipitation Elevation
- n-value
- Curve number
- Boundary conditions
## Data sources for west Texas sites

<table>
<thead>
<tr>
<th>Data</th>
<th>Source</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation</td>
<td>Asquith and Roussel, 2004 Total depth from IDF</td>
<td>Varied by site Hyetograph from SCS Type II</td>
</tr>
<tr>
<td>Site Elevation</td>
<td>LiDAR</td>
<td>High quality</td>
</tr>
<tr>
<td>Regional Elevation</td>
<td>USGS</td>
<td>1/3 arc second, 10 × 10 m grid</td>
</tr>
<tr>
<td>Land use/land cover</td>
<td>National land cover Database</td>
<td>2006 data, 30 x 30 m pixel</td>
</tr>
<tr>
<td>Soils</td>
<td>USDA Web soil survey</td>
<td>Infiltration rates, particle size depth to water table hydrologic soil group</td>
</tr>
</tbody>
</table>
Timing of inflow hydrographs

- 24 hour storm across entire study area
- Long flow path delayed arrival of peak flow
- Hydrographs distributed along boundary of 2D domain
Map of maximum flood depths

Maximum flooding depths during 100 – year storm
Map of maximum surface velocities

Maximum velocities during 100 – year storm
Design of stormwater control measures

• Site location: Southwest Georgia
• 1,060 ac, 100 MW generation
• Straddles topographic divide of 3 drainages
• No off-site stormwater flows on to site
Sources of elevation data

Data from client blended with USGS data
Design of stormwater control measures

Design Criteria:
- Maximum slopes:
  - S-N 2%
  - E-W & N 2.5%
- Maximum depth 1 ft.
- Maximize use of grading to control stormwater
- Detention Ponds & Berms
- Georgia – 11 Standards
  - Reduce additional runoff
  - Runoff quality volume
Design of stormwater control measures

2-D Model
- 133,881 25 \times 25 \text{ ft cells}
- 7 culverts
- Berm along highway
- No inflows
- Elevation from DEM
- n-values & CNs from soils & land cover

Stormwater Accounting
- Drainage areas
- Cross sections
2D Modelling as Design Tool

Pre → Post Conditions Adjustments
- Forest land, shrubs & scrub → Grass cover (n & CN revised)
- Small increase in impervious area
- Detention pond outlets modeled as berms

Design Process
- Grading plan in Civil 3D
- Elevations → Revised 2D Model
- Meet criteria?
Example of pre- & post-development hydrographs for Drainage Area

Review for each model run (1, 50 & 100-year):
- Peak Flow
- Volume of runoff
Design of stormwater control measures

- Graphs of maximum depths 100-year storm
- Detention ponds required to reduce peak flows from some drainage areas
Design of stormwater control measures

Graphs of maximum velocities 100-year storm
Design of stormwater control measures

Georgia Stormwater Minimum Standard 2.1

.. is sized to capture and treat the prescribed water quality treatment volume, which is defined as the runoff volume resulting from the first 1.2 inches of rainfall from a site;

\[ WQ_v = \frac{1.2R_v A}{12} \]

Where:
- \( WQ_v \) = Water quality volume (ac-ft)
- \( R_v \) = 0.05 +0.009 (l) where (l) is Percent Impervious Cover (%)
- \( A \) = Drainage Area (ac)

Water quality treatment provided through a combination of storage ponds and overland flows through established vegetative areas below the solar panels.
Scour Analysis

Hydraulic Engineering Circular 18

D50 0.001 ft  Pier length 0.48 ft
D90 0.003 ft  Pier width 0.33
Pier shape square nose  Angle of attack 0 – 90 degrees
Bed Conditions clear scour

![Graph showing scour depth vs flow depth for different velocities.](image-url)
Design of stormwater control measures

Panels supported by driven piles. Depth = scour depth + structural depth
Summary

► 2D hydrologic models are appropriate for solar farm sites where sheet flow is maintained across the site.

► 2D models produce information regarding flow depths and velocities not available from subcatchment runoff models.

► Linked models are appropriate where large upgradient areas contribute stormwater flows to site.

► Linked models are useful for the design of stormwater control facilities at solar farms.

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