DRAFT Annotated Bibliography on Solar Land Use Loading Rates

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TO: Urban Stormwater Workgroup

Cook, L.M. and R.H. McCuen. (2013). Hydrologic response of solar farms *J. Hydrol*. Eng. 18 536–41. https://doi.org/10.1061/(ASCE)HE.1943-5584.0000530

A model written in MATLAB was based on the creation of NRCS type II storms for precipitation inputs. A simple water balance for each land surface cell was used to allocate precipitation to storage or loss (runoff). Some modeling results suggest solar panels can increase erosion. The energy and velocity of water draining from the panels is higher, which could cause erosion in soil below the base of the panels, especially if the interspace is bare. Increases (up to 10 times) of kinetic energy were simulated, which could lead to erosion and the need for erosion control measures, but this modeling effort was not validated by field measurements. Field results indicated that the addition of solar panels over a grassy field does not change the volume of runoff, the peak discharge, nor time to peak.

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 pre-paneled 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 pre-paneled condition.

Liu, H., Wu, C., Yu, Y., Zhao, W., Liu, J., Yu, H., et al. (2023). Effect of solar farms on soil erosion in hilly environments: A modeling study from the perspective of hydrological connectivity. Water Resources Research, 59, e2023WR035067. https://doi. org/10.1029/2023WR035067

Results show that the Utility-Scale Solar Farms (USF) considerably increased runoff (99.18%–154.26%) during its operational period. USF also increased soil erosion rate (21.4%–74.84% and 25.35%–76.18%) and Hydrologic Conductivity (HC) (0.08%–0.26% and 0.47%–0.91%) throughout construction and operational periods, respectively. The highest erosion rates were detected in the installation zones and in the areas close to the river channel. The study concluded that there is support for the hypothesis that hydrologic conductivity (HC) is a critical indicator for sediment yield in a USF, and thus the long-term responses of soil erosion to USF installation and development can be explained in terms of HC.

Luis Mier-Valderrama, Julianna Leal, Humberto L. Perotto-Baldivieso, Brent Hedquist, Hector M. Menendez, Ambrose Anoruo, Benjamin L. Turner. (2024) Evaluating soil erosion and runoff dynamics in a humid subtropic, low stream order, southern plains watershed from cultivation and solar farm development. International Soil and Water Conservation Research, Volume 12, Issue 2, 2024, Pages 432-445, ISSN 2095-6339, https://doi.org/10.1016/j.iswcr.2023.09.004.

Experiments were conducted by varying precipitation depth, duration, and land uses: native vegetation pre-cultivation (control), cultivation (current), current conditions with 15% solar farm conversion (solar), and current conditions with 30% solar farm conversion (solar x2). Shifting to solar farming led to significant increases in cumulative sediment load (+12%–30%), with no significant differences in peak discharge rate changes (+0.38%–4%).

Mulla, D., Galzki, J., Hanson, A., & Simunek, J. (2024). Measuring and modeling soil moisture and runoff at solar farms using a disconnected impervious surface approach. Vadose Zone Journal, e20335. https://doi.org/10.1002/vzj2.20335

Predicted runoff depths were strongly affected by precipitation depth, soil texture, soil profile depth, and soil bulk density. Runoff depths across the five experimental sites averaged 13%, 25%, and 45% of the 2-, 10-, and 100-year design storm depths, clearly showing that these solar farms do not behave like impervious surfaces, but rather as disconnected impervious surfaces with substantial infiltration of runoff in the vegetated areas between and beneath solar arrays.

Lambert, Q., A. Bischoff, S. Cueff, A. Cluchier, R. Gros. (2021). Effects of solar park construction and solar panels on soil quality, microclimate, CO 2 effluxes, and vegetation under a Mediterranean climate. *Land Degradation and Development*, 2021, 32 (18), pp.5190-5202. https://doi.org/10.1002/ldr.4101

Soil levelling and vegetation removal during solar panel construction may have increased surface runoff and soil erosion. Low C and N content suggest that nutrient cycling was lower solar site soils compared to semi-natural conditions and that several solar farm soil functions (carbon sequestration, soil structure, biological processes) were hampered compared to semi-natural soils. There was also reduced water holding capacity.

The key processes involved in degradation of soil quality were soil tillage and partial topsoil removal increasing erosion (Quinton et al., 2010) and organic matter mineralization. Reduced organic matter content and increase of soil compaction decrease water holding capacity (Mujdeci et al., 2017) and soil stability (Simansky et al., 2013).

Yavari, R., D. Zaliwciw, R. Cibin, and L. McPhillips. (2022). Minimizing environmental impacts of solar farms: a review of current science on landscape hydrology and guidance on stormwater management. *Environ. Res.: Infrastruct. Sustain*. 2 032002. https://doi.org/10.1088/2634-4505/ac76dd

Research on a solar farm in Colorado, USA observed a greater coarse particle fraction on the solar farm as compared to an adjacent native grassland reference. The reason for the difference in particle size is likely the soil disturbance and vegetation removal during the construction phase of the solar farm, which causes erosion of the fine particles (Choi et al 2020a).

At a solar farms on reclaimed cropland with meadowgrasses, there were no significant differences in soil physical and chemical properties, as compared to a reference site (Armstrong et al 2016).

Unsaturated hydraulic conductivity was found to be higher beneath solar panels on a solar farm in Colorado than at the edge or interspace area between panels (see the schematic of example solar farm in figure 1). The reason for this difference may be the reduced exposure to maintenance activities beneath the panel, which could induce compaction.

At the time of the writing of this review, the evaluation of runoff generation has occurred only in published modeling-based studies. From this work, regardless of the orientation and tilt angles, runoff volume increases after solar panel installation. Impacts on peak flow are more variable, with the orientation of panels either increasing or decreasing peak flowrates. The results indicate that the panels also noticeably change the rain distribution onto the land surface.

Construction of solar farms can require substantial land manipulation. Thus, it is also important to consider this in erosion estimates, and manage this impact appropriately.

At the time of this review, the authors were unable to find any study that directly evaluated runoff generation on solar farms through field measurement. Thus, we are still lacking critical insight into whether solar farms change runoff generation, and whether existing site and stormwater management practices are adequate to prevent adverse impacts. As a result, existing hydrologic models of solar farms are largely uncalibrated. There is also a bias in the sort of sites being evaluated. In general, existing environmental research on solar farms has focused on more ideal sites, i.e. those on sites with lower slopes and well-draining soils. Thus, we are neglecting sites that could be more vulnerable to changes in hydrologic processes with solar farm development.