NC STATE UNIVERSITY

Project Part 2: Solar PV Design

Course: ECE 592: Utility Scale Solar PV Systems

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Content

1. North Carolina

1.1. Hydrology analysis

As shown in Figure 1, the site generally features a gentle slope. Topographical analysis indicates that there are localized low-lying areas within the site, particularly in Zones 1 and 2 of Figure 1, where stormwater may temporarily accumulate. However, considering the overall hydrological flow, it is expected that the stormwater will naturally drain toward the downstream area. Therefore, it is necessary to conduct a detailed analysis to identify zones requiring additional drainage infrastructure to minimize the risks of flooding and erosion. The overall risk score for the site is 13, which corresponds to a medium level of risk.

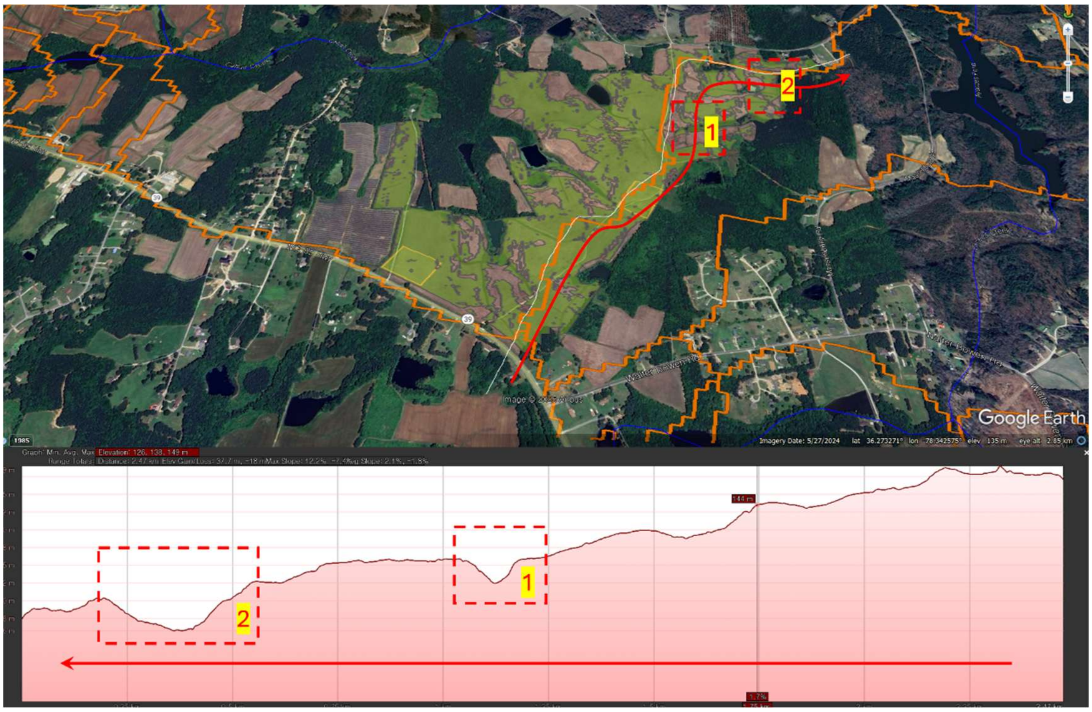

Figure 1. Hydrology Analysis, NC

1.2. PlantPredict Grading Analysis

Figures 2 and 3 present the results of the PlantPredict Grading Analysis. Due to an issue with image generation, only the Earthwork results image has been included in the report.

Figure 2 shows the results obtained by applying the Horizon tracker. A total earthwork volume of 265,766 bcm is required, consisting of 118,723 bcm of cut and 147,043 bcm of fill. The net earthwork volume amounts to 28,320 bcm (excess fill), with a cut/fill ratio of 0.807, indicating a fill-dominant condition. A total of 87.78 hectares (30.68%) of the area will be disturbed, with

40.77 ha designated for cut and 47 ha for fill. The maximum cut and fill depths are 3.61 m and 2.8 m, respectively, implying the need for substantial grading work. Therefore, significant cost and time would be required for site leveling under this scenario.

Figure 3 illustrates the results based on the XTR tracker. The total earthwork volume is significantly reduced to 13,914 bcm, with 5,271 bcm of cut and 8,644 bcm of fill. The net earthwork volume is 3,374 bcm, still indicating a fill-dominant condition, but the overall volume is substantially smaller compared to the first simulation. The cut/fill ratio is 0.61, reflecting a lower proportion of cuts. The disturbed area is also reduced to 34.25 ha (11.97%), with 28.16 ha for cut and 6.09 ha for fill. Maximum cut and fill depths are limited to 1.16 m and 1.23 m, respectively, requiring only shallow grading operations.

In conclusion, the XTR tracker demonstrates approximately 95% reduction in earthwork volume and about 60% reduction in disturbed areas compared to the Horizon tracker, offering substantial cost savings and reduced environmental impacts. Therefore, selecting the XTR tracker would be more cost-effective and suitable for sustainable site development.

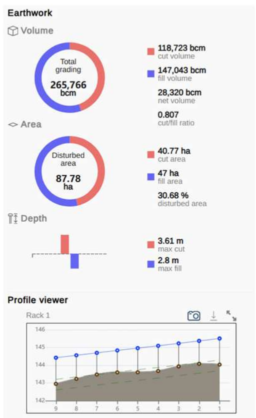

Figure 2. PlantPredict grading assessment for NC, Horizon tracker

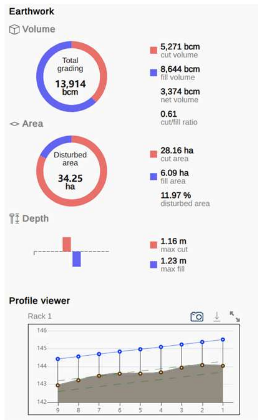

Figure 3. PlantPredict grading assessment for NC, XTR tracker

1.3. Reserve Area analysis

Figures 4 and 5 present the results of the reserve area analysis. Since the target sites are located at considerable distances from each other, substations have been positioned adjacent to the nearest TL for each site. A total of two substation areas have been designated.

In addition, three laydown areas have been selected to facilitate construction, material handling, and efficient BESS operation. These locations have been strategically distributed to ensure convenience and operational efficiency.

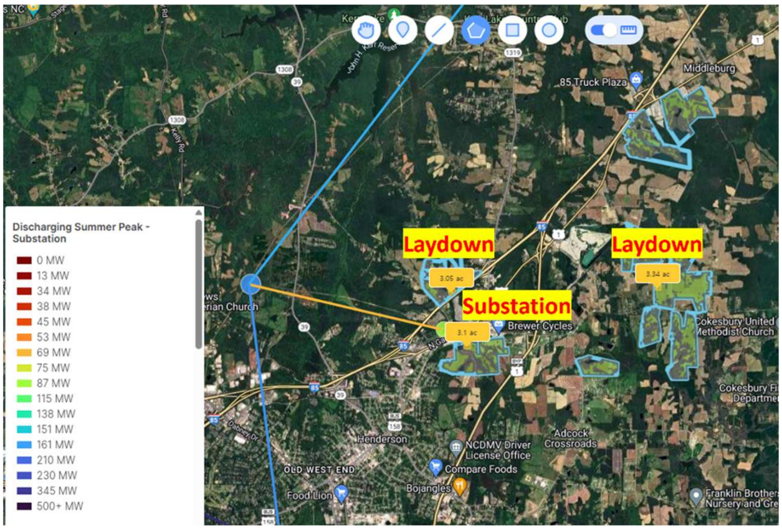

Figure 4. Reserve area analysis, NC 1

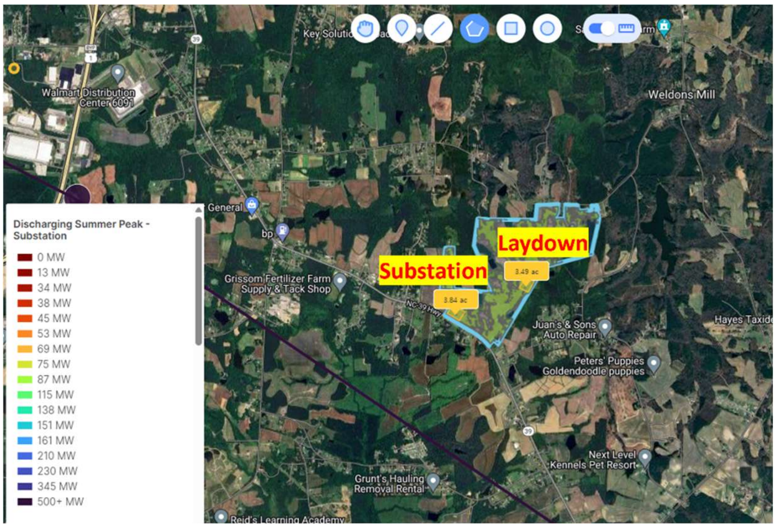

Figure 5. Reserve area analysis, NC 2

1.4. Hail Risk evaluation (Selection of PV Module)

The site has a 50-year recurrence interval (RI) for hailstones with a diameter of 45 mm, as shown in Figure 6. This indicates a high frequency of hail events. The analysis of Potential Maximum Loss (PML) reveals that for 2.2 mm glass, the lowest loss occurs at up to a 75-degree tilt, while for 3.2 mm glass, similar performance is maintained up to a 50-degree tilt. Given the hail risk at the North Carolina (NC) project site, a more durable PV module using 3.2 mm glass has been selected. The chosen PV module is the **LONGi LR5-72HBD 550M G2**.

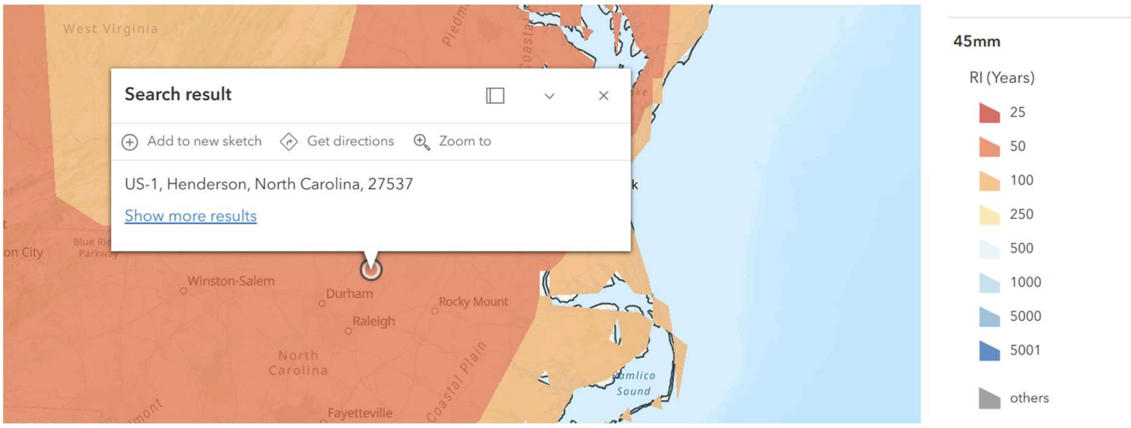

Figure 6. Hail Risk evaluation, NC

1.5. String Sizing

The string sizing analysis for the site is summarized in Table 1. The System Advisor Model (SAM) calculated the optimal string length as 28 modules, while both the Advanced Method in Voltage Pro and PV Tools (using the P99.5 percentile approach) calculated a string length of 29 modules. This discrepancy can be attributed to the use of more detailed climate data (spanning over 25 years) and probabilistic methodologies by Voltage Pro and PV Tools, which allow for a more optimized design. In contrast, SAM adopts a conservative, traditional approach, recommending slightly shorter string lengths. Given the long-term system operation and potential module degradation, the string sizing approach based on Voltage Pro and PV Tools (P99.5) appears to be a more reliable and robust design method.

Table 1. String Sizing, NC

Category	**SAM**	**Voltage Pro Advanced method**	**PVTools P99.5**
String Length	28	29	29

1.6. Selection of Tracker

Approximately 50% of the project site consists of slopes greater than 6%, and some areas contain bedrock (see Figure 7). When compared to the Horizon tracker, the XTR tracker can reduce cut-and-fill requirements by up to 73%, which significantly shortens construction timelines and reduces land preparation costs. Therefore, the XTR -0.75 tracker is considered the most suitable option for this project site.

Figure 7. Slope analysis, NC

2. Texas

2.1. Hydrology analysis

As shown in Figure 8, the Texas (TX) project site is located on a sloped terrain, which increases the risk of erosion and drainage issues due to higher runoff velocity during rainfall events. Stormwater runoff from the upstream highland area is expected to flow downstream along the anticipated water path, potentially forming high flow velocities due to the slope. Considering the surrounding topography, there is a possibility of flooding and soil erosion in areas where drainage converges. Therefore, appropriate drainage design is essential.

Compared to the California (CA) site, the TX site has a relatively gentler slope. However, it receives a large volume of inflow from a broader watershed area, making the drainage system even more critical. Thus, a comprehensive drainage system, including erosion control measures and the design of a retention basin, should be established. The overall risk score is evaluated at 16 points, which corresponds to a medium level of risk.

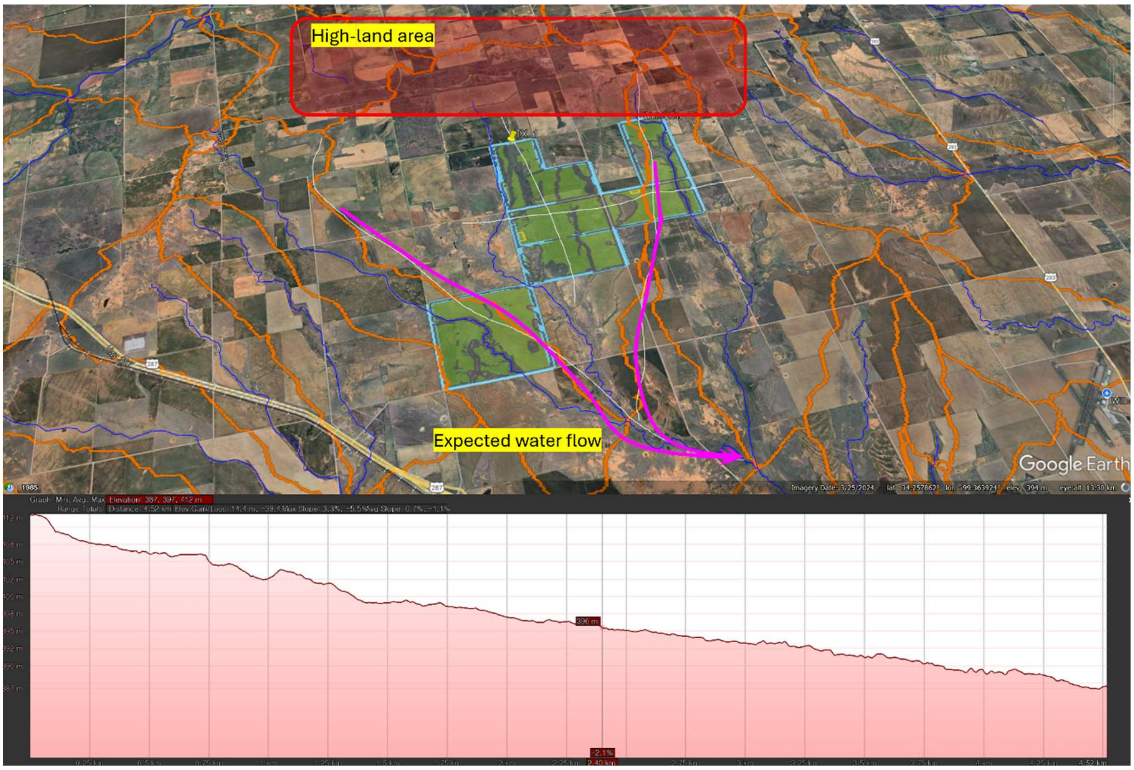

Figure 8. Hydrology Analysis, TX

2.2. PlantPredict Grading Analysis

Figure 9 shows the result of applying the Horizon tracker to the site, requiring a total earthwork volume of 43,346 bcm. The cut volume is 19,736 bcm, and the fill volume is 23,611 bcm, indicating a fill-dominant condition with a net earthwork volume of 3,876 bcm. The total disturbed area spans 47.05 hectares (approximately 9.88%), impacting a significant portion of the site. The maximum cut and fill depths are 1.89 m and 1.81 m, respectively, suggesting that deep grading operations would be necessary in some areas.

Figure 10 presents the result of applying the XTR tracker, showing a substantial reduction in earthwork. The total earthwork volume is reduced to 3,893 bcm, representing over 90% savings. The cut and fill volumes are 1,206 bcm and 2,688 bcm, respectively. The disturbed area also drastically decreases to 4.66 hectares (0.98%), with maximum cut and fill depths of 0.65 m and 1.19 m, indicating only shallow grading is required.

In conclusion, applying the Horizon tracker to the site would require large-scale earthwork and extensive site disturbance, whereas the XTR tracker significantly reduces earthwork volume by approximately 90%, minimizes disturbed area by over 80%, and lowers maximum cut and fill depths. These improvements enhance both cost-effectiveness and environmental sustainability. Therefore, the XTR tracker is considered a much more suitable option for construction and operation at the Vernon site.

Figure 9. PlantPredict grading assessment for TX, Horizon tracker

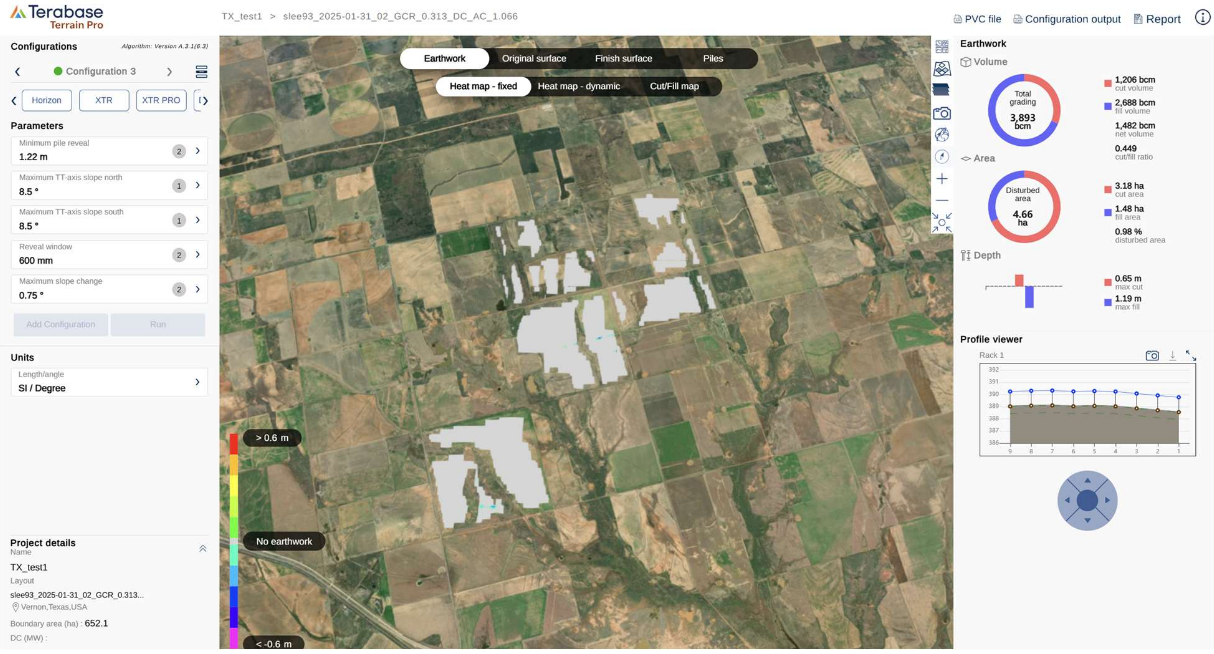

Figure10. PlantPredict grading assessment for TX, XTR tracker

2.3. Reserve Area analysis

Figure 11 presents the results of the reserve area analysis for the site. As the site is located adjacent to a TL with a capacity of over 500 kW, the substation area has been placed near the TL to ensure a convenient grid connection. Additionally, laydown areas have been strategically located near existing roads to facilitate easy access for construction, material handling, and transportation.

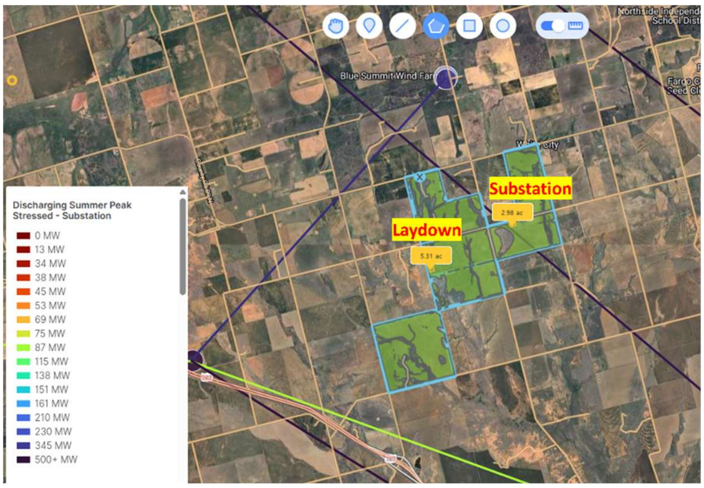

Figure 11. Reserve area analysis, TX

2.4. Hail Risk evaluation (Selection of PV Module)

The TX project site has a 50-year recurrence interval (RI) for 45 mm hailstones, as indicated in Figure 12, suggesting a high frequency of hail events. According to the Potential Maximum Loss (PML) analysis, 2.2 mm glass performs best up to a 75-degree tilt, while 3.2 mm glass maintains similar performance up to a 50-degree tilt. Therefore, in consideration of hail risks, a more durable 3.2 mm glass has been selected for the site. The chosen PV module is LONGi LR5-72HBD 550M G2.

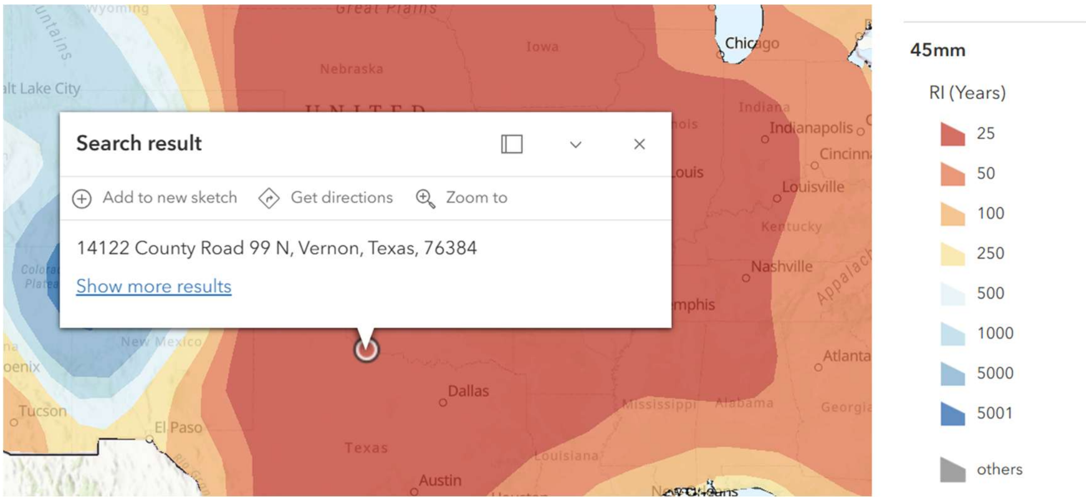

Figure 12. Hail Risk evaluation, TX

2.5. String Sizing

The string sizing results for the TX site are summarized in Table 2. Similar to the analysis conducted for the NC site, the System Advisor Model (SAM) recommends a string length of 28 modules, whereas both Voltage Pro (Advanced Method) and PV Tools (P99.5) suggest 29 modules. This outcome is again attributed to the probabilistic approach (P99.5 percentile) and long-term climate data used by Voltage Pro and PV Tools, allowing for a more optimized design. Their methodology permits longer string lengths by accounting for actual climate conditions and module degradation, offering reliable long-term operational efficiency in TX as well.

Table 2. String Sizing, TX

Category	**SAM**	**Voltage Pro**	**PVTools**
		Advanced method	**P99.5**
String Length	28	29	29

2.6. Selection of Tracker

The proportion of the site with slopes greater than 6% is relatively low (see Figure 13). Therefore, the NX Horizon (Standard) tracker is considered the most suitable option for this project site.

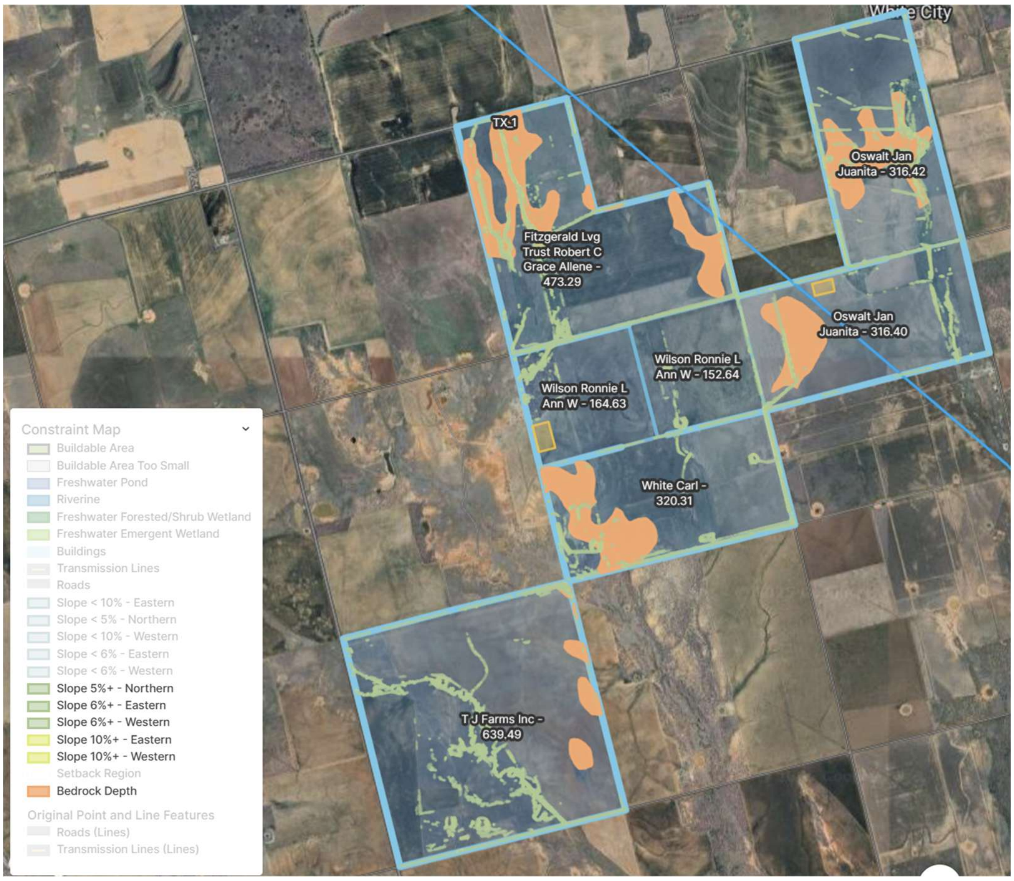

Figure 13. Slope analysis, TX

3. California

3.1. Hydrology analysis

The California (CA) project site is located on steep terrain, as shown in Figure 14. This topography significantly increases the potential for erosion and soil runoff due to rapid water flow during rainfall events. Strong flow velocities are likely to form along the expected water flow paths, and the risk of drainage and erosion issues may intensify during heavy rainfall due to the site's terrain characteristics.

Given the region's arid climate, vegetation is sparse, which likely reduces the soil's resistance to erosion. Without a properly designed drainage system, sediment transport and increased runoff velocity could negatively impact downstream areas. To mitigate these risks, it is essential to implement erosion control measures, retention basins, energy dissipation structures, and improve the overall drainage infrastructure. The overall risk score is 20 points, which corresponds to a high risk level.

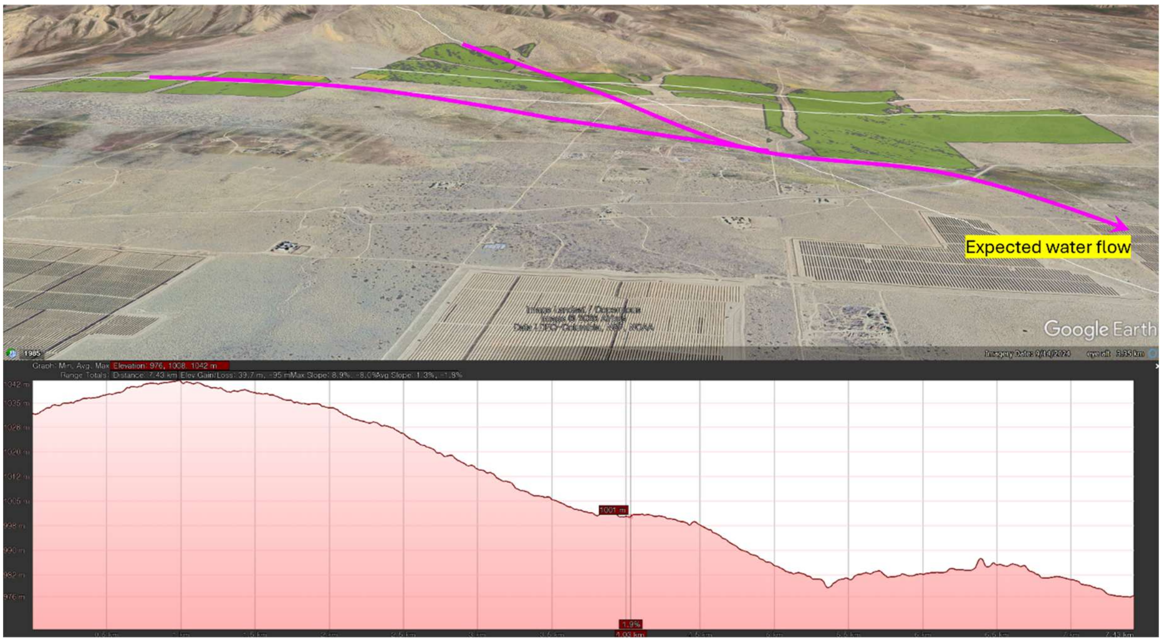

Figure 14. Hydrology Analysis, CA

3.2. PlantPredict Grading Analysis

Figure 15 illustrates the grading analysis when applying the Horizon tracker. A total earthwork volume of 46,544 bcm is required, disturbing approximately 35.13 hectares (about 9.72%) of land. This site involves substantial fill work (29,933 bcm) compared to cut (16,612 bcm), with a maximum cut depth of 1.51 m and a maximum fill height of 1.24 m, indicating the need for extensive earthmoving operations.

In contrast, Figure 16 shows the scenario using the XTR tracker, where the total earthwork volume is significantly reduced to 5,989 bcm, and the disturbed area is only 17.12 hectares (4.74%). The cut and fill volumes are nearly balanced (3,001 bcm and 2,989 bcm, respectively), with a maximum cut depth of 0.69 m and a maximum fill height of 1.12 m. Compared to the Horizon tracker, this reflects much shallower and balanced grading, demonstrating the XTR tracker's superior terrain adaptability. This approach is expected to reduce construction costs and environmental impact.

In conclusion, while the Horizon tracker demands significant earthwork, the XTR tracker provides an 87% reduction in earthwork volume and less than half the land disturbance, offering a more efficient and sustainable solution.

Figure 15. PlantPredict grading assessment for California, Horizon tracker

Figure 16. PlantPredict grading assessment for California, XTR tracker

3.3. Reserve Area analysis

Figure 17 presents the results of the reserve area analysis. The substation and access road are located in proximity to each other, allowing for the efficient placement of the substation and laydown area in adjacent zones, optimizing land use and operational convenience.

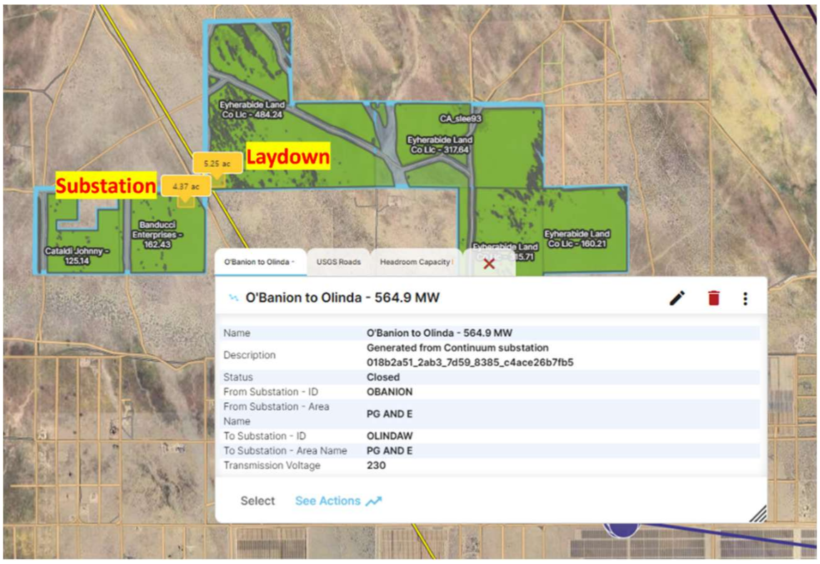

Figure 13. Reserve area analysis, California

3.4. Hail Risk evaluation (Selection of PV Module)

The CA project site has a recurrence interval (RI) of 5,000 years for hailstones of 45 mm diameter, as shown in Figure 18. This indicates a very low frequency of hail events. Therefore, it is considered appropriate to use PV modules with 2.2 mm glass, which have relatively lower durability. The PML (Potential Maximum Loss) analysis shows consistent performance between 30° and 75° tilt angles. The selected PV module is Trina Solar TSM-NEG19RC 605W.

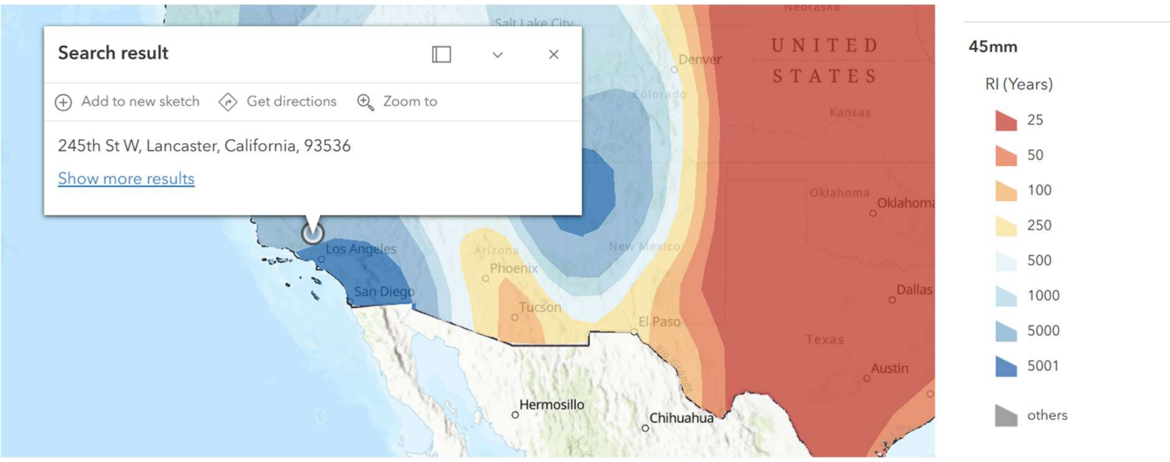

Figure 18. Hail Risk evaluation, CA

3.5. String Sizing

As shown in Table 3, the calculated string lengths for the CA site are as follows: 29 modules (SAM), 30 modules (Voltage Pro), and 31 modules (PV Tools, P99.5). Compared to other states, the CA site allows for relatively longer string lengths. This is likely due to California's climate characteristics, particularly high temperatures and solar irradiance distribution.

SAM provides a conservative estimate, while Voltage Pro offers optimized values by incorporating long-term weather data and module degradation. PV Tools suggests the longest string length to maximize operational efficiency. Considering all factors, Voltage Pro's recommendation of 30 modules is deemed the most appropriate, as it maintains the inverter's optimal operating range while avoiding excessive risk.

Table 3. String Sizing

Category	**SAM**	**Voltage Pro**	**PVTools**
		Advanced method	**P99.5**
String Length	29	30	31

3.6. Selection of Tracker

The CA site is relatively flat, with a slope of less than 5% (see Figure 19). Therefore, the NX Horizon (Standard) tracker is considered the most suitable option for this location.

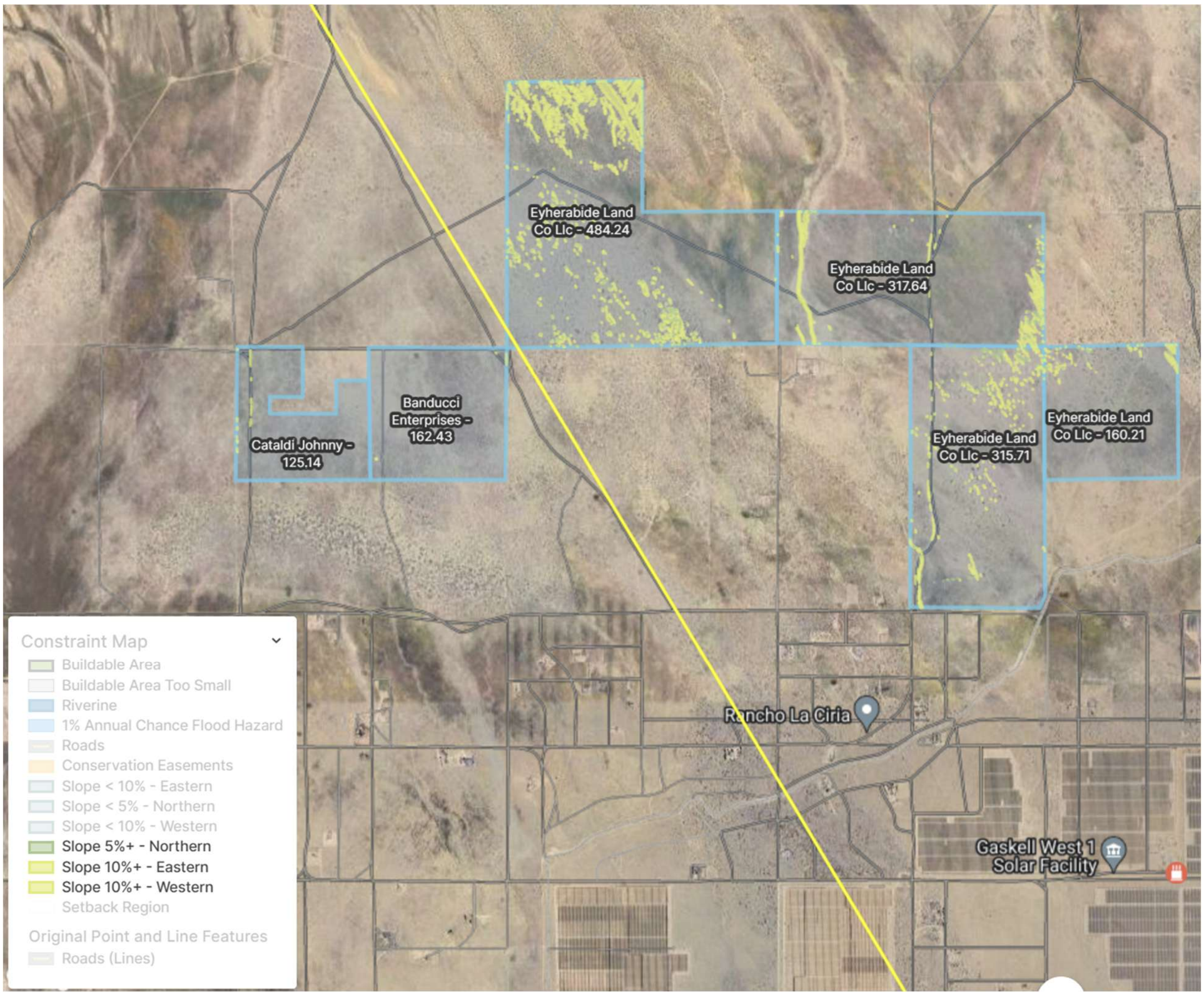

Figure 19. Slope analysis, IL

4. Illinois

4.1. Hydrology analysis

The Illinois (IL) project site is located in the upstream area, as shown in Figure 20, and features generally flat terrain, which suggests that the overall hydrological risk is relatively low. Rainwater is expected to flow along the anticipated drainage paths, and the lack of steep slopes means that the risk of erosion caused by increased flow velocity is limited.

Although the site lies adjacent to the boundary between high and low elevation areas (marked in red in Figure 20), the primary runoff paths are clearly defined. As long as the drainage system remains intact, the potential for flooding or uncontrolled runoff is minimal. However, there is a possibility of water stagnation in localized low-lying areas, which warrants additional drainage analysis near those boundary zones. Based on these considerations, the overall risk score is assessed at 10 points, indicating a Low to Medium level of hydrological risk.

Figure 20. Hydrology Analysis, IL

4.2. PlantPredict Grading Analysis

Figure 21 presents the grading analysis results for the IL site using the Horizon tracker. The total earthwork volume required is 8,719 bcm (cut: 3,290 bcm; fill: 5,430 bcm), and grading operations would disturb approximately 6.47 hectares (about 2.36%) of the site. While the terrain is relatively flat, with a maximum cut depth of 0.8 m and maximum fill depth of 0.78 m, a certain amount of earthwork is still required due to the fixed mounting system of the tracker. This is necessary to ensure proper leveling and alignment of the tracker system with the terrain.

Figure 22 shows the results using the XTR tracker, which drastically reduces the total earthwork to just 63 bcm, with minimal disturbance to only 1.15 hectares (about 0.42%) of the site. The maximum cut and fill depths are only 0.07 m and 0.02 m, respectively, indicating that most of the site can be utilized in its natural condition.

In conclusion, while the Horizon tracker demands significant grading and earthwork, the XTR tracker, with its terrain-adaptive design, offers a 99% reduction in both earthwork volume and disturbed area. Therefore, the XTR tracker is considered a significantly more cost-effective and environmentally sustainable alternative.

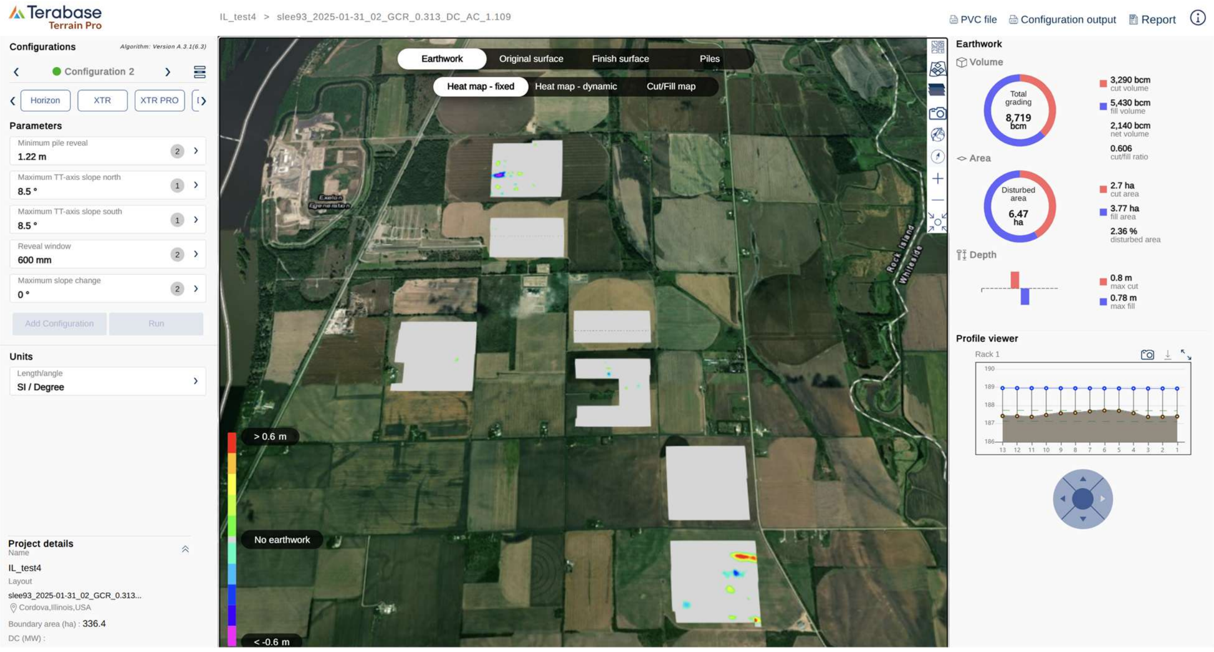

Figure 21. PlantPredict grading assessment for Illinois, Horizon tracker

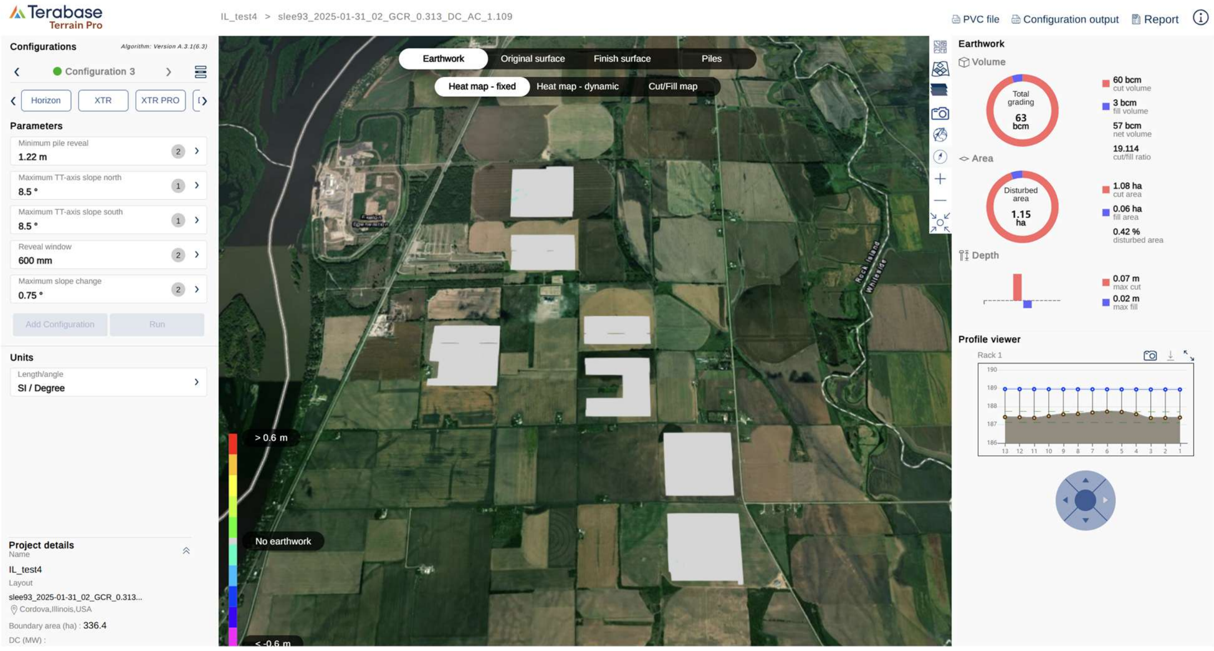

Figure 22. PlantPredict grading assessment for Illinois, XTR tracker

4.3. Reserve Area analysis

Figure 23 shows the reserve area analysis for the IL project site. The substation is strategically placed adjacent to the transmission line (TL) with the largest capacity, while the laydown area is positioned near an access road and centrally within the project boundary to facilitate efficient construction and operations.

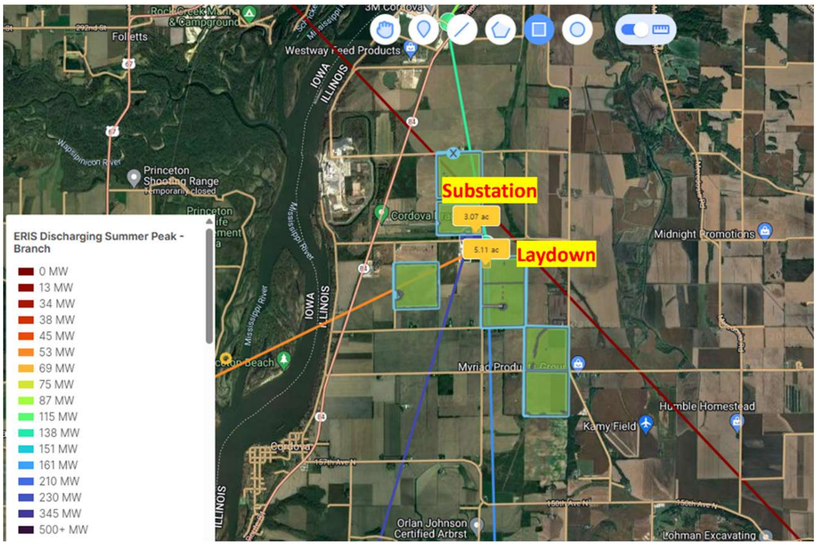

Figure 23. Reserve area analysis, Illinois

4.4. Hail Risk evaluation (Selection of PV Module)

The site has a 50-year recurrence interval (RI) for 45 mm hailstones, as shown in Figure 24, indicating a relatively high frequency of hail events. PML (Potential Maximum Loss) analysis shows that 2.2 mm glass provides the lowest loss up to a 75-degree tilt, while 3.2 mm glass performs similarly up to a 50-degree tilt. To account for hail risk, a more durable 3.2 mm glass module has been selected for this site. The chosen PV module is the LONGi LR5-72HBD 550M G2.

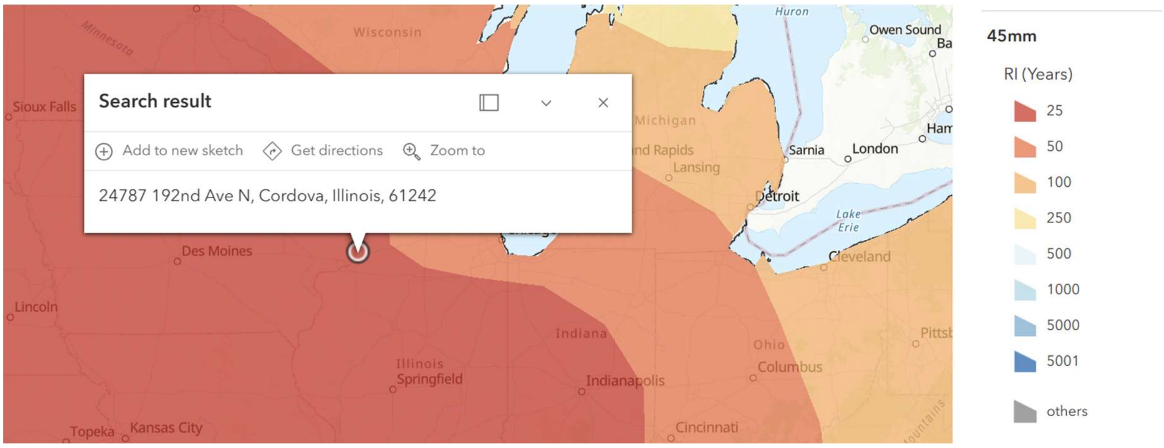

Figure 24. Hail Risk evaluation, IL

4.5. String Sizing

For the IL site, as shown in Table 4, SAM recommends a string length of 26 modules, while both Voltage Pro (Advanced Method) and PV Tools (P99.5) recommend 28 modules. This difference is due to the probabilistic approach of Voltage Pro and PV Tools, which leverage long-term climate data and module degradation to offer a more optimized string size. While SAM follows a conservative design methodology, Voltage Pro and PV Tools provide more realistic estimates based on actual site conditions, supporting long-term operational efficiency.

Table 4. String Sizing, IL

Category	**SAM**	**Voltage Pro**	**PVTools**
		Advanced method	**P99.5**
String Length	26	28	28

4.6. String Sizing

The IL site is confirmed to have relatively flat terrain with slopes less than 5% (see Figure 25). Therefore, the NX Horizon (Standard) tracker is considered the most suitable tracking system for this location.

Figure 25. Slope analysis, IL

5. Illinois (additional)

5.1. Geotechnical/ Hydrology analysis

1) Geotechnical

Table 5. Geotechnical analysis, IL-additional

Category	Score	Content
Subsoil Structure	Medium (15)	• Seasonal fluctuations and perched water conditions have been identified as potential concerns.
Topsoil Quality	Medium (15)	• Fine-grained cohesive materials (clay) • High moisture sensitivity • Potential instability in wet conditions
Sungrow Pile Testing Results	Low (5)	• Embedment Depths: 7–11 ft • Axial Uplift Capacity: 1,150–10,000+ lbs (at ¼-inch displacement) • Lateral Load Resistance: 750–5,000+ lbs (at 1-inch displacement) • Compression Load Resistance: Up to 15,000 lbs • Pile Drivability: Generally good
Corrosion Analysis	Medium (15)	• pH Levels: 7.46–9.21 • Soluble Sulfates: Up to 7,042 mg/kg • Soluble Chlorides: Avg. 181 mg/kg • Electrical Resistivity: 536–3,484 ohm-cm
Soil Stability	High (25)	• Moisture-sensitive • Requiring additional stability measures
Groundwater Influence	High (25)	• May increase excavation difficulties
Frost Heave Potential	High (25)	• Contains frost-susceptible materials
Excavation Hazards	Medium (15)	• May cause sloughing and instability
Drainage and Erosion	Medium (15)	• Existing drainage system must be maintained

2) Hydrology Analysis

Table 6. Hydrology analysis, IL-additional

Category	Score	Content
Water depth	Medium (15)	• localized deep inundation in certain areas, but generally manageable
Velocities	Medium (15)	• localized high velocities could contribute to erosion but overall controlled
Scour	Low to Medium (10)	• manageable in most areas, but potential for erosion in channels
Identify Area of Hydrological Influence (Watershed)	Medium (15)	• hydrological influence is well defined, but poor drainage may contribute to increased runoff

5.2. Reserve Area analysis

Figure 26 presents the results of the reserve area analysis for the project site. The substation is positioned adjacent to the transmission line (TL), while the laydown area is located near the access road and close to other usable parcels of the site. This layout supports operational efficiency and construction accessibility.

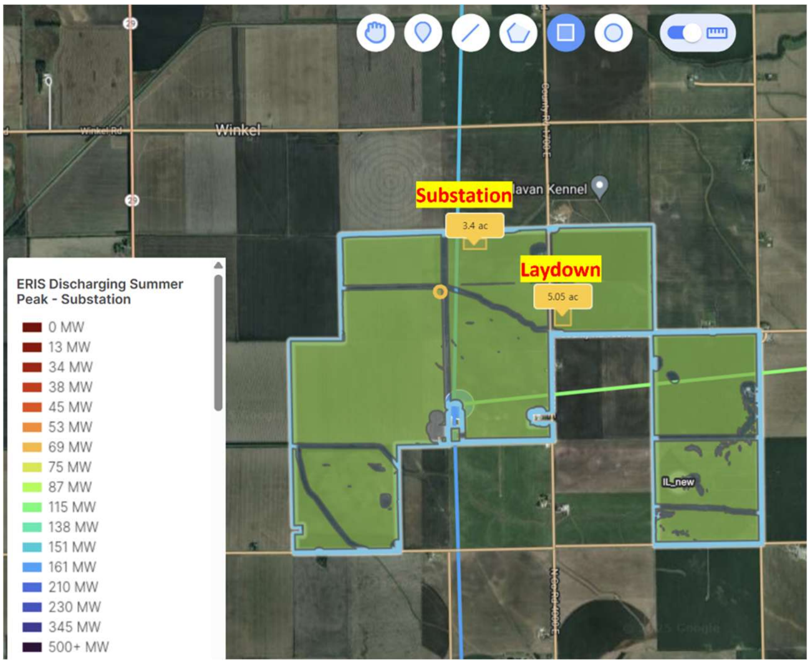

Figure 26. Reserve area analysis, Illinois (additional)

5.3. Hail Risk evaluation (Selection of PV Module)

The site has a 50-year recurrence interval (RI) for hailstones with a diameter of 45 mm, as shown in Figure 27, indicating a high frequency of hail events. According to the Potential Maximum Loss (PML) analysis, 2.2 mm glass provides the lowest loss up to a 75-degree tilt, while 3.2 mm glass maintains similar performance up to a 50-degree tilt. Therefore, for the IL site, as with the NC site, a more durable 3.2 mm glass was selected to mitigate hail-related risks. The selected PV module is the LONGi LR5-72HBD 550M G2.

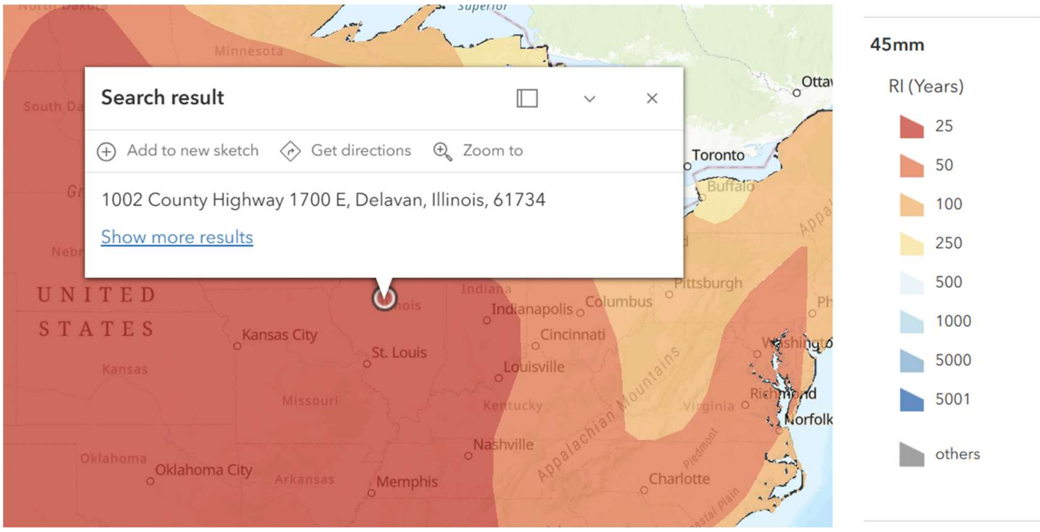

Figure 27. Hail Risk evaluation, IL (additional)

5.4. String Sizing

For the given IL site, SAM recommends a string length of 27 modules, while both Voltage Pro (Advanced Method) and PV Tools (P99.5) recommend 28 modules, as shown in Table 7. This result stems from the probabilistic P99.5 approach and the use of long-term climate data by Voltage Pro and PV Tools, providing more optimized string length estimates. While SAM follows a conservative design methodology, Voltage Pro and PV Tools account for actual climate conditions and potential module degradation, allowing for longer string lengths. This approach ensures long-term operational efficiency, similar to the outcomes observed for the TX project site.

Table 7. String Sizing, IL-additional

Category	**SAM**	**Voltage Pro**	**PVTools**
		Advanced method	**P99.5**
String Length	27	28	28