Hydrologic Study: Stormwater Management

M Solar Generating, LLC
Manatí, Puerto Rico

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1. INTRODUCTION

M Solar Generating, LLC is planning the development of a photovoltaic farm to be located in the Municipality of Manatí, Puerto Rico, near PR-667. The proposed project has an area of 900 acres.

1.1 Project Description and Location

The project is proposed to be located in the eastern part of the Municipality of Manatí. The project is mostly bounded by undeveloped land with some areas of rural development. The project can be accessed through state road PR-667.

Appendix A shows a location map of the project.

1.2 Study Purpose

The purpose of the study is to generate hydrologic data to estimate the flows and to determine the storm-water management facilities required to manage the excess runoff produced by the proposed development, if any.

1.3 Scope of Work

The scope of work of the study is to generate hydrologic data required to estimate the peak flows and to determine the excess runoff produced by the project and by the developed areas. The following tasks were performed to complete the hydrologic analysis scope of work:

1. Watershed delineation and flow pattern determination for the watershed contributing to the study reach.
2. Determination of soil type and land cover for the delineated watersheds;
3. Determination and assignment of design storm precipitation values for all watersheds.
4. Curve Number estimation for each delineated watershed based on the soil type and land cover.
5. Determination of time of concentration for each watershed.

6. Development and construction of a hydrologic simulation model to determine the maximum flood flows generated by storm events with return periods of 2, 10, 25, and 100 years and 24 hour of duration for pre-developed and proposed condition.
7. Recommend the minimum storage volume required to manage the excess runoff in order to comply with local regulations and state laws.

1.4 Parties Involved and Authorization

M Solar Generating, LLC, through Environmental Resources Management, Inc. (ERM) has contracted PMG & Associates, LLC (PMG) to prepare a Hydrologic Study to evaluate the storm water runoff under pre-developed and post-developed conditions and to make recommendations to reduce the excess runoff generated by the proposed project.

2. DESCRIPTION OF STUDY AREA

2.1 Topography and Water Bodies

The project area is accessible by the PR-642 and is located in the karst region of the north of Puerto Rico. The topography is variable with elevations ranging from 190 to 40 meter above mean sea level characterized by “mogotes”, caves, sinkholes caused by water that dissolves limestone and increase groundwater routes. Drainage patterns discharge mainly into sinkholes.

The nearest water body to the project is the Río Grande de Manatí located approximately 500 meters to the east.

2.2 Previous Studies

No previous studies were found for the project area.

2.3 Flood Zone Classification

The project site is classified as Zone X in FEMA’s Flood Insurance Rate Map (FIRM) Panels #72000C0270J; November 18, 2009. Appendix B shows the Flood Prone Area Map.

2.4 Field Inspection

Field inspection within the project area showed that drainage patterns flow towards depressions, possibly sinkholes, and common to these areas. No surface water bodies were found within the project site. Field pictures can be found on Appendix C.

3. HYDROLOGIC ANALYSIS

The major driving forces for the rainfall-runoff process are the intensity and duration of storm events; followed by watershed characteristics that translate the rainfall input into an output hydrograph at the outlet of the basin. Size, slope, shape, soils, and storage capacity are all important parameters in watershed geomorphology. Land use and land cover parameters can significantly alter the natural hydrologic response through increases in impervious cover, altered slopes, and improved drainage channel networks.

A hydrologic analysis was conducted to establish the peak discharge and runoff volumes frequency relationships for floods of the selected recurrence intervals for the project area.

3.1 Hydrologic Analysis Methodology

Advances in computer methods combined with larger and more extensive data-monitoring efforts have allowed for the development and application of simulation models in hydrology. Such models incorporate various equations to describe hydrology transport process and account for water balances through time.

The hydrologic simulation was performed in accordance with the methods developed by the Soil Conservation Service. The hydrologic model used was ICPR Streamline Technologies. This computer program estimates the surface runoff resulting from any synthetic or natural rain storm. Rainfall is transformed to runoff via unit hydrograph methods. Discharge is computed at the outlet of each sub-area.

3.2 Watershed Description

Our study divides the project in 26 sub-basins. Only sub-basins that are being developed were included in the study. These sub-basins are shaped by “mogotes”, sinkholes, caves and other karst features. Based on field inspection and the topographic data available, each sub-basin flows to a depression, presumably a

sinkhole, which infiltrates into the groundwater system. The delineated basins are characterized to have steep slope along its boundaries defined by “mogotes” and a fairly flat slope on its center. Weighted average watershed slope varies from to 21.1% to 46 %. Appendix D shows the topographic plans available and Appendix E shows the watershed map and potential sinkholes location.

3.3 Design Storm and Rainfall Data

The precipitation for the 2, 10, 25, and 100 years return period and 24 hours durations, where obtained from Atlas 14 del Hydrometeorological Design Study Center at a latitude of 18.4333 and longitude of -66.4500 (See Appendix F). The values obtained are presented on Table 3.1. Rainfall temporal distributions were established according to the frequency distribution method.

Table 3.1. Rainfall average values for storms with different return periods and 24-hour duration.

Precipitation Depth corresponding to Tr and 24 hours (millimeters)					
2	**5**	**10**	**25**	**50**	**100**
50 %	20 %	10%	4%	2%	1%
5.08	6.73	8.07	9.92	11.41	12.95

3.4 Runoff Curve Number

The SCS method of runoff estimation involves the computation of a runoff Curve Number (CN). This number corresponds to hydrologic soil-cover relations and land uses. The major factors to determine CN are the hydrologic soil group, cover type, and antecedent moisture condition.

Values of CN were obtained from tables prepared by the SCS for the Caribbean area and were weighted according to the soil type and land use area percentage on each sub-basin. Soil characteristics of the study area were identified by means of soil maps. The United States Department of Agriculture Soil Conservation Service, in cooperation with the University of Puerto Rico has published soil maps

and classified the soils according to their hydrologic characteristics. The PRPB has digitized these maps. Land cover for the site was assigned based on data available from the U.S. Geological Survey published in 2003, aerial photography and site visit.

Runoff CN's were determined using the information provided in the Soil Map and Land Cover MAP together with the SCS tables. The combination of the soil and land cover map was achieved using GIS techniques.

Adjustments for sub-basins were minimal because the solar panels will maintain grass cover underneath, thus, the change corresponds to the reduction of the vegetation density.

3.4.1 Land Uses

Most of the project area is characterized by forest and grassland. Rural developed areas (low to medium density) can be found within the defined sub-basins. For the proposed condition, the land use for the solar panel area used in the hydrologic model corresponds to low density grassland, which will be found below each solar panel after the completion of the project construction. The land cover map for the pre-developed and developed condition is in the Appendix G.

3.4.2 Soil Type

Soil types within the basin are variable, the most common soil type found are Rock Outcrop-Tamana Complex with 1.55 km^2 and 12 to 20 percent slopes, Bayamon with 2 to 5% percent slopes (ByB) with an area of 0.91 km^2 and clay soil texture, Tamana (TaD2) with 0.15 km^2 and clay soil texture, and Toa (To) with an area of 0.01 km^2 and silty clay soil texture. The predominant hydrologic soil group is type D (1.71 km^2) and the followed the type B. Appendix G shows the soil map and hydrologic group distribution into the study basin.

Soil map data and land cover data were combined to obtain a CN. Once combined soil and land use properties were tabulated to obtain a weighted CN value for each sub-basin. Appendix I shows the CN calculation table.

3.5 Time of Concentration

The time of concentration was estimated for each basin using the commonly used method known as Lag Equation. This equation was developed by NRCS using 24 watersheds in United States. It provides reasonable results for watersheds with areas up to 19 mi^2. Lag method equation follows and the computed times are shown in Table 2.

$$T_c = [1.67 * L^{0.8}[(1000/CN) - 9]^{0.7}]/ (1900. S^{0.5})$$

where:

Tc = time of concentration (hr)

L = stream flow length (km)

H = difference in elevation, (m)

C= runoff coefficient

Hydrologic properties used to estimate the Tc for each basin is presented on Appendix I.

3.6 Hydrologic Simulation

The hydrologic simulation model used for this study was ICPR Streamline Technologies. The simulation model incorporates 16 sub-basins for the pre-developed condition. Their respective hydrologic properties are presented on Table 3.2.

The proposed conditions include the evaluation of runoff excess by the project area development with the solar panels. Table 3.3 shows their respective hydrologic properties for the proposed conditions.

The hydrologic simulation was also used to determine the increase in the volume of runoff generated by the proposed condition. This was calculated using the difference between the pre-developed and developed conditions.

Table 3.2. General hydrologic properties for the Sub-Basins for the Pre-Developed Condition.

	Properties				
Sub-Basin	**Area (acres)**	**Total Flow Length (m)**	**Average Watershed Slope (%)**	**Time of Concentration (min)**	**CN (AMC II)**
10	36.55	409	22.2	9.8	75.5
20	32.36	522	22.2	16.6	63.1
30	20.62	337	21.1	10.5	68.2
40	92.77	1057	18.7	18.7	74.0
50	11.06	211	30.3	6.5	65.5
60	4.66	120	30.3	5.0	65.2
70	13.9	203	34.2	5.0	74.5
80	12.09	65	27.6	5.0	77.5
90	61.65	1000	24.9	22.0	70
100	143.59	100	24.9	5.0	62.1
110	14.31	100	24.9	5.0	68.1
120	34.64	500	24.9	12.0	72.0
130	31.31	725	30.12	13.8	74
140	7.47	100	28.29	5	73.8
150	46.31	627	24.9	13.6	73.8
160	5.31	105	24.9	5	62
170	10.2	300	24.9	7.5	74.1
180	17.04	229	29.9	6.1	70.6
190	17.08	256	30.8	5.6	76.3
200	31.6	370	46.0	6.2	75.6
210	8.33	236	46.0	5	74.3
220	12.26	299	25.5	7.8	72.3
230	12.47	238	31.9	5.2	76.1
240	12.1	258	27.1	6.6	72.9
250	24.27	913	24.8	16.1	78.4
260	36.29	913	24.8	16	78.7

Table 3.3 General hydrologic properties for the Sub-Basins for the Developed Condition.

	Properties				
Sub-Basin	**Area (acres)**	**Total Flow Length (m)**	**Average Watershed Slope (%)**	**Time of Concentration (min)**	**CN (AMC II)**
10	36.55	409	22.2	9.5	76.3
20	32.36	522	22.2	15.5	65.7
30	20.62	337	21.1	10.3	69.0
40	92.77	1057	18.7	18.1	75.0
50	11.06	211	30.3	5.9	68.7
60	4.66	120	30.3	5.0	65.9
70	13.9	203	34.2	5.0	75.6
80	12.09	65	27.6	5.0	77.9
90	61.65	1000	24.9	22.0	70.0
100	143.59	100	24.9	5.0	64.9
110	14.31	100	24.9	5.0	71.1
120	34.64	500	24.9	11.4	73.6
130	31.31	725	30.12	13.3	75.3
140	7.47	100	28.29	5.0	75.0
150	46.31	627	24.9	13.2	75.0
160	5.31	105	24.9	5.0	66.5
170	10.2	300	24.9	7.2	75.4
180	17.04	229	29.9	5.8	71.9
190	17.08	256	30.8	5.5	76.9
200	31.6	370	46.0	6.2	76.0
210	8.33	236	46.0	5.0	75.5
220	12.26	299	25.5	7.4	73.9
230	12.47	238	31.9	5.1	76.9
240	12.1	258	27.1	6.3	74.4
250	24.27	913	24.8	16.0	78.6
260	36.29	913	24.8	14.9	80.9

3.6.1 Hydrologic Analysis Results

The SCS Dimensionless Unit Hydrograph Method was used to calculate the design discharge for the 2, 10, 25, and 100 years storm event with 24-hour duration. The SCS method uses the Lag time instead of the Tc. The Lag Time can be obtained by multiplying the Tc by 0.6.

Table 3.4 and Table 3.5 show the simulation results for pre-developed and developed hydrologic condition. The ICPR Streamline Technologies output report can be found on Appendix J.

Comparing both conditions (pre and post) it can be seen that there is an increase in runoff due to the proposed condition. Using the difference between hydrographs for pre-developed and developed conditions was estimated the approximate volume that would be needed for each sub-basin to mitigate the increased runoff. Table 3.6 shows the excess runoff volume generated by the proposed development.

Table 3.4. Hydrologic simulation results for existing condition.

Basin/Junction ID	Tr	100	25	10	2
	Area	Peak Discharge			
	(acres)	(cfs)			
Sub-Basin 10	36.55	209.59	184.44	164.05	114.63
Sub-Basin 20	32.36	125.76	117	85.05	46.95
Sub-Basin 30	20.62	104.47	88.7	76.01	47.11
Sub-Basin 40	92.77	408.46	355.58	312.19	210.39
Sub-Basin 50	11.06	63.74	53.45	45.21	26.97
Sub-Basin 60	4.66	29.02	24.29	20.51	12.17
Sub-Basin 70	13.9	98.68	86.83	76.93	53.37
Sub-Basin 80	12.09	88.65	79.05	70.96	51.28
Sub-Basin 90	61.65	241.4	205.89	177.22	111.49
Sub-Basin 100	143.59	84.55	69.39	57.44	31.81
Sub-Basin 110	14.31	93.34	79.48	68.22	42.76
Sub-Basin 120	34.64	176.87	152.95	133.44	87.4
Sub-Basin 130	31.31	155.32	135.54	119.31	80.31
Sub-Basin 140	7.47	52.6	46.13	40.74	27.98
Sub-Basin 150	46.31	230.25	200.89	176.81	119.08
Sub-Basin 160	5.31	31.21	25.59	21.17	11.7
Sub-Basin 170	10.2	230.23	201.7	178.07	121.65
Sub-Basin 180	17.04	108.73	93.68	81.35	52.88
Sub-Basin 190	17.08	120.11	106.56	95.2	67.75
Sub-Basin 200	31.6	214.88	189.89	169.01	118.74
Sub-Basin 210	8.33	59	51.87	45.91	31.76
Sub-Basin 220	12.26	73.63	63.88	55.88	37.34
Sub-Basin 230	12.47	89.08	78.91	70.38	49.8
Sub-Basin 240	12.1	78.06	68.09	59.85	40.4
Sub-Basin 250	24.27	118.72	105.69	94.91	68.02
Sub-Basin 260	36.29	178.78	159.34	143.23	102.95

Table 3.5 Hydrologic simulation results for developed condition

Basin/Junction ID	Tr	100	25	10	2
	Area	Peak Discharge			
	(acres)	(cfs)			
Sub-Basin 10	36.55	214.27	189.52	169	118.94
Sub-Basin 20	32.36	135.69	112.94	94.9	55.26
Sub-Basin 30	20.62	106.72	91.02	78.35	49.27
Sub-Basin 40	92.77	417.34	365.73	323.33	220.56
Sub-Basin 50	11.06	69.19	58.99	50.77	32.25
Sub-Basin 60	4.66	29.36	24.68	20.92	12.59
Sub-Basin 70	13.9	99.91	88.36	78.67	55.42
Sub-Basin 80	12.09	89	79.5	71.48	51.93
Sub-Basin 90	61.65	241.4	205.89	177.22	111.49
Sub-Basin 100	143.59	88.95	74.34	62.64	36.93
Sub-Basin 110	14.31	97.4	84.29	73.48	48.44
Sub-Basin 120	34.64	184.03	160.61	141.39	95.43
Sub-Basin 130	31.31	159.91	140.57	124.63	85.93
Sub-Basin 140	7.47	53.34	47.04	41.77	29.18
Sub-Basin 150	46.31	236.82	207.83	183.97	126.16
Sub-Basin 160	5.31	33.78	28.5	24.25	14.76
Sub-Basin 170	10.2	235.66	207.7	184.45	128.61
Sub-Basin 180	17.04	112.42	97.55	85.28	56.64
Sub-Basin 190	17.08	121.2	112.94	96.37	68.83
Sub-Basin 200	31.6	215.82	191.06	170.36	120.35
Sub-Basin 210	8.33	59.81	52.87	47.05	33.1
Sub-Basin 220	12.26	76.99	67.43	59.51	40.64
Sub-Basin 230	12.47	90.31	80.36	71.99	51.7
Sub-Basin 240	12.1	80.61	70.81	62.67	43.23
Sub-Basin 250	24.27	119.44	106.41	95.61	68.63
Sub-Basin 260	36.29	187.88	169.07	153.44	113.78

Table 3.6 Runoff volume for developed condition (storm 24 hr, Tr 100-yr)

Sub-Basin	Runoff Volume Pre-Developed	Runoff Volume Developed	Runoff Volume Increment
	m^3	m^3	m^3
Sub-Basin 10	36439.56	36867.76	428.20
Sub-Basin 20	26081.69	27423.15	1341.46
Sub-Basin 30	18281.86	18537.16	255.30
Sub-Basin 40	90427.19	91801.95	1374.76
Sub-Basin 50	9338.02	9891.68	553.65
Sub-Basin 60	3912.37	3963.98	51.60
Sub-Basin 70	13652.66	13878.46	225.80
Sub-Basin 80	12406.81	12476.86	70.05
Sub-Basin 90	56367.64	56367.64	0.00
Sub-Basin 100	11341.70	11986.92	645.21
Sub-Basin 110	12665.43	13325.01	659.58
Sub-Basin 120	32727.89	33559.40	831.51
Sub-Basin 130	30519.49	31123.16	603.67
Sub-Basin 140	7259.36	7392.35	132.99
Sub-Basin 150	45003.89	45828.31	824.43
Sub-Basin 160	4185.58	4567.05	381.47
Sub-Basin 170	35799.71	36505.25	705.55
Sub-Basin 180	15737.19	16073.63	336.44
Sub-Basin 190	17228.77	17378.39	149.63
Sub-Basin 200	31550.45	31736.06	185.62
Sub-Basin 210	8157.07	8304.83	147.76
Sub-Basin 220	11638.52	11932.42	293.90
Sub-Basin 230	12542.01	12687.85	145.83
Sub-Basin 240	11595.87	11866.68	270.80
Sub-Basin 250	25220.71	25291.69	70.99
Sub-Basin 260	37869.90	39007.21	1137.31

3.6.2 Storm water Management Requirements

As shown on Table 3.6 the M Solar Generating, LLC development, generate an increase in the peak flows. Local regulations and state laws require that for any development, the excess runoff produced must be managed before discharging

downstream into a neighboring property, in such a way that the peak outflow from the development is equal or below pre-developed flow conditions for all recurrences.

For the M Solar Generating, LLC all of the sub-basins delineated will discharge into an onsite depression within the project boundary itself. Therefore, no downstream discharge is expected.

Storm water management requirements will be based on the solar panel layout and the infiltration capacity of the depressions/sinkholes receiving the surface runoff. A surface drainage system can be used to direct the storm water runoff towards the depressions/sinkholes. Infiltration capacity will be required to determine the water spread and flooding depths expected during heavy rainfall events under pre-developed and post-developed conditions, which should be consider when determining the solar panel arrangement and height.

4. CONCLUSIONS AND RECOMMENDATIONS

After performing a hydrologic study for the M Solar Generating, LLC Project, the following conclusions and recommendations can be made:

- The proposed project is located in the northern karstic zone of Puerto Rico prone to sinkholes and underground cavities.

- Based on the site geology, its topography, and field visitation it can be concluded the all surface runoff generated from rainfall events flows towards low areas found in the field where sinkhole formations are found.

- A preliminary geologic assessment conducted by ERM estimates that approximately 34 sinkholes can be found within the project area.

- This study is an initial assessment of the hydrologic conditions found on the field to be used as a planning tool.

- Although the excess runoff produced by the project is relatively low, the storage requirements for each basin cannot be determined with accuracy without knowing the infiltration capacity of the sinkholes receiving the storm runoff. For planning purposes the values presented on The Table 3.6 can be used as a starting value. These values represent the most conservative approach by assuming a cero (0) infiltration capacity per sinkhole.

- Excess runoff resulting from the proposed development shall be managed inside the project site.

- Grass vegetation shall be maintained below solar panels. Exposed soils during plant operation may result in higher runoff rates transporting sediments that can reach the sinkholes and reduce their drainage capacity.

- During construction activities, a control of erosion and sedimentation plan shall be executed to protect the sinkholes from the sediments transported during rainfall events.

- The proposed storm water system should include bio-swales whenever possible. Bio-swales will serve as storm water filtration device.

- A buffer zone of 10 meters from all identified sinkholes is recommended to protect the sinkholes from sediment and other pollutants transported by storm runoff. The buffer zone boundary should include a grass fringe that will function as a filter for storm runoff discharging into the sinkholes.

5. LIMITATIONS OF STUDY

This study has been prepared according to accepted engineering practices. The conclusions and recommendations provided on this report are based on the data available at the time the study was completed. **It is the responsibility of the design engineer to follow all of the recommendations stated on this report**. Changes to the proposed site layout and\or any of the improvements recommended on this report should be consulted with the hydrologist preparing this document, as it could alter or invalidate some or all of the results presented herein. The results presented on this study shall be revised after the infiltration capacity of each sinkhole is determined.

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7. CERTIFICATION

I, Pedro M. García Campos, MSCE, PE, hereby certify that the calculations included on **Hydrologic & Hydraulic Study for the M Solar Generating, LLC Project**, in Manatí Puerto Rico were performed by me.

Related to this report, I certify that to the best of my knowledge, the information included on this document is truthful, correct, and complete.

Pedro M. García Campos, MSCE, PE

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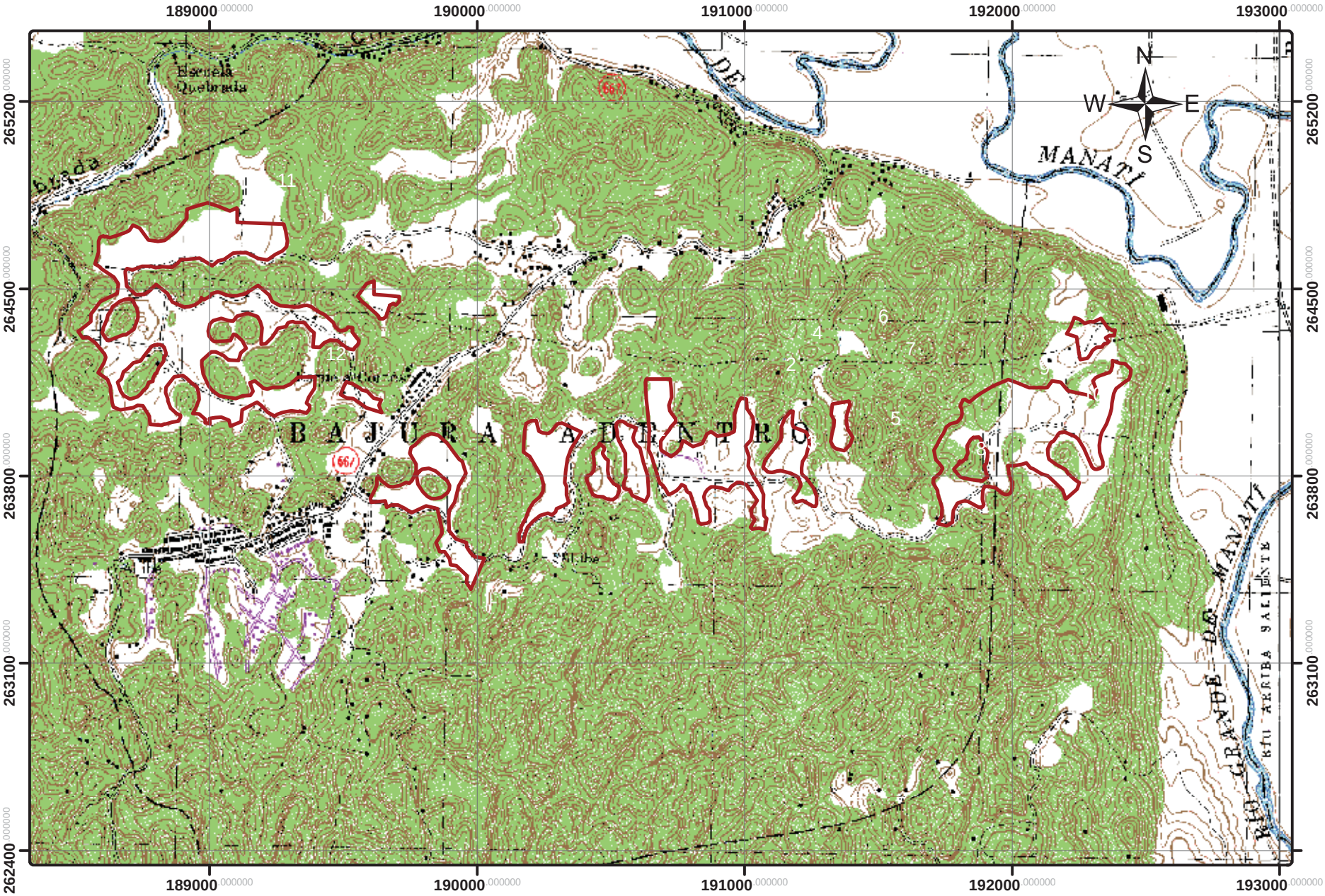
Appendix A: Location Map



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0 150 300 600 900 1,200 Meters

LOCATION MAP

M SOLAR GENERATING, LLC
PUERTO RICO

PMG

Appendix B: Flood Prone Area Map

ty map revision history prior to Commonwealth of Puerto Rico and mapping, refer to the Community Map History table located in the Flood dy report for this jurisdiction.

if flood insurance is available in this community, contact your Insurance e National Flood Insurance Program at 1-800-638-6620.

MAP SCALE
1:10,000

0.25 0 0.5 Kilometers

500 1,000 1,500 2,000 2,500 3,000 3,500 Feet

.5 0.125 0 0.25 Miles

NFIP

NATIONAL FLOOD INSURANCE PROGRAM

PANEL 0270J

FIRM

FLOOD INSURANCE RATE MAP

COMMONWEALTH OF PUERTO RICO AND MUNICIPALITIES

PANEL 270 OF 2160

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
PUERTO RICO	720000	0270	J

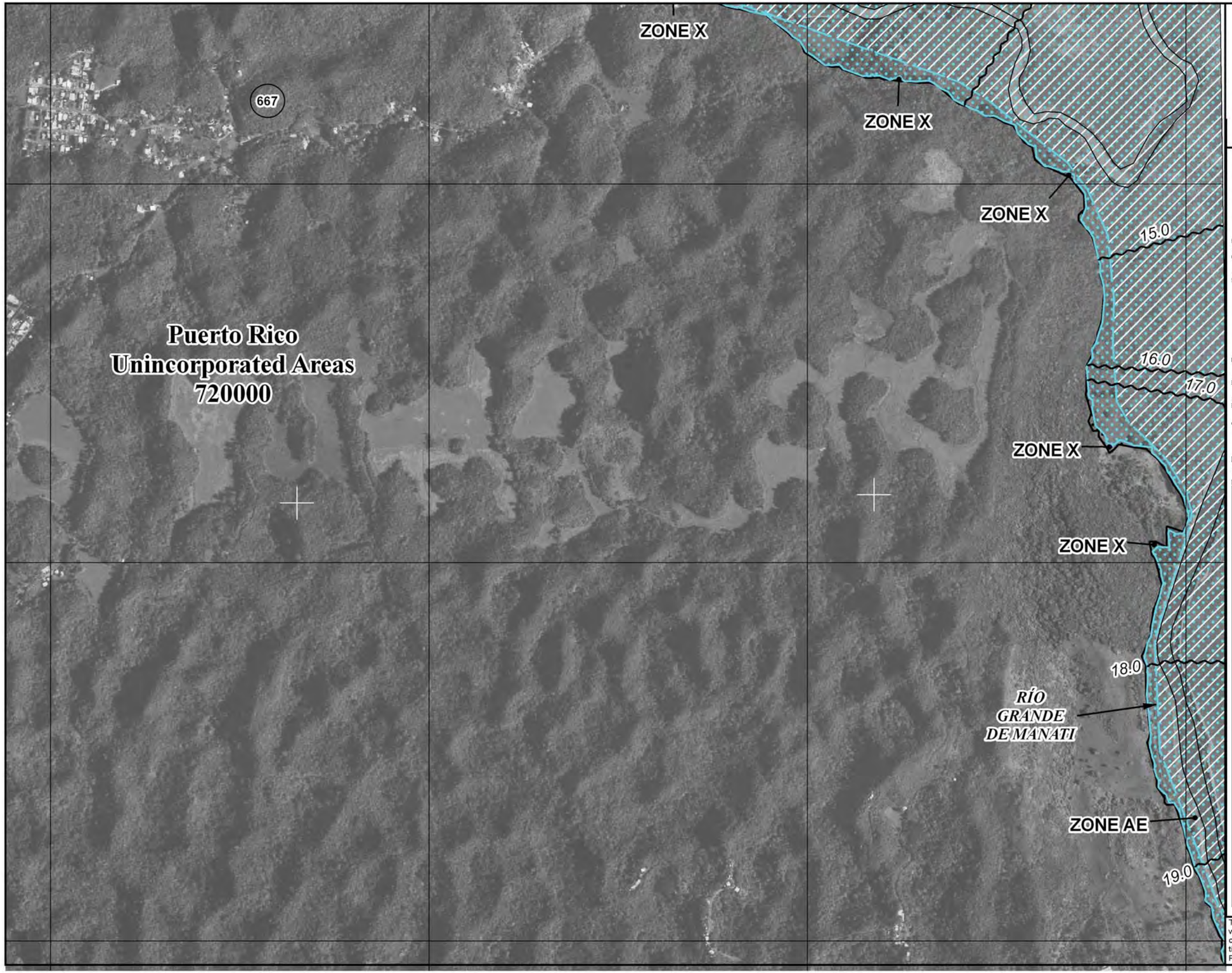
Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

MAP NUMBER
72000C0270J

MAP REVISED
NOVEMBER 18, 2009

Federal Emergency Management Agency

This is an official copy of a portion of the above referenced flood map. It was extracted using F-MIT On-Line. This map does not reflect changes or amendments which may have been made subsequent to the date on the title block. For the latest product information about National Flood Insurance Program flood maps check the FEMA Flood Map Store at www.msc.fema.gov



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MAP SCALE
1:10,000

0.25 0 0.5 Kilometers

500 1,000 1,500 2,000 2,500 3,000 3,500 Feet

5 0.125 0 0.25 Miles

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Appendix C: Field Pictures