Table 6. Hydraulic modeling results for the existing condition model: 2- and 100-year flood events.

River Sta.	Reach	Profile	Q total (m^3/s)	Min Ch El (m)	W.S. Elev (m)	Vel (m/s)
Natural Drainage						
1	South	2-yr	2.37	90.91	91.17	1.36
2			2.37	92.03	92.34	1.48
3	West		2.40	108.28	108.68	1.64
4			2.40	113.17	113.61	1.75
5			2.40	117.43	117.87	1.70
6			2.40	116.12	118.05	0.15
7			5.42	117.39	117.98	2.08
8			5.42	123.33	123.69	1.55
9	East		0.02	116.74	116.81	0.61
10			0.02	121.39	121.44	0.49
11			0.02	120.32	121.45	0.003
12			0.02	114.27	121.45	0.00004
13			10.06	114.09	121.45	0.02
14			10.06	114.06	121.45	0.02
15	North		7.73	62.57	63.49	2.40
16			7.73	68.60	69.16	1.69
17			8.63	74.56	75.35	1.62
18			8.63	77.38	78.57	2.84
19			8.63	84.18	85.66	2.70

Table 6. Hydraulic modeling results for the existing condition model: 2- and 100-year flood events (continued).

River Sta.	Reach	Profile	Q total (m^3/s)	Min Ch El (m)	W.S. Elev (m)	Vel (m/s)
Natural Drainage						
1	South	100-yr	16.55	90.91	91.63	2.30
2	South	100-yr	16.55	92.03	92.87	2.31
3	West	100-yr	8.87	108.28	109.05	2.26
4	West	100-yr	8.87	113.17	114.04	2.40
5	West	100-yr	8.87	117.43	118.28	2.43
6	West	100-yr	8.87	116.12	118.64	0.38
7	West	100-yr	11.09	117.39	118.60	1.56
8	West	100-yr	11.09	123.22	123.84	1.85
9	East	100-yr	7.49	116.74	117.57	2.38
10	East	100-yr	7.49	121.39	122.16	2.32
11	East	100-yr	7.49	120.32	122.48	0.50
12	East	100-yr	7.49	114.27	122.50	0.01
13	East	100-yr	20.95	114.09	122.50	0.03
14	East	100-yr	20.95	114.06	122.50	0.04
15	North	100-yr	15.47	62.57	63.85	2.80
16	North	100-yr	15.47	68.60	69.34	1.94
17	North	100-yr	17.16	74.56	75.50	1.69
18	North	100-yr	17.16	77.38	79.08	3.33
19	North	100-yr	17.16	84.18	86.12	3.11

The computed maximum velocities produced along the studied natural drainage vary from 0.0004 to 2.84 m/s and from 0.01 to 3.33 m/s for the 2- and 100-year flood events, respectively.

Maximum backwater occurs at different sections. Sections 2, 5 and, 6 have 0.01, 0.01 and, 0.01 meters of backwater, respectively. Therefore, it complies with the Planning Regulation No. 13 of the PR Planning Board.

Proposed Condition Model

The existing condition model was modified to simulate the natural drainage conditions considering the proposed peak discharges computed with the HEC-HMS model. Computed water levels and velocities at each cross section along the ***Natural Drainage*** for the 2- and 100-year flood events are presented in Table 7. Figure 12, 13, 14, 19, 20 and, 21 shows the water surface profiles for the 2- and 100-year flood events for the ***Natural Drainage*** at ***North***, ***East***, ***West*** and, ***South***. HEC-RAS input and output data (geometry: ***PROPOSED***) are included in Appendix E.

Table 7. Hydraulic modeling results for the proposed condition model: 2- and 100-year flood events.

River Sta.	Reach	Profile	Q total (m^3/s)	Min Ch El (m)	W.S. Elev (m)	Vel (m/s)
Natural Drainage						
1	South	2-yr	2.42	90.91	91.17	1.36
2	South	2-yr	2.42	92.03	92.35	1.49
3	West	2-yr	2.44	108.28	108.68	1.64
4	West	2-yr	2.44	113.17	113.61	1.76
5	West	2-yr	2.44	117.43	117.88	1.70
6	West	2-yr	2.44	116.12	118.06	0.15
7	West	2-yr	5.47	117.39	117.98	2.08
8	West	2-yr	5.47	123.33	123.69	1.55
9	East	2-yr	0.02	116.74	116.81	0.61
10	East	2-yr	0.02	121.39	121.44	0.49
11	East	2-yr	0.02	120.32	121.45	0.003
12	East	2-yr	0.02	114.27	121.45	0.00004
13	East	2-yr	10.01	114.09	121.45	0.02
14	East	2-yr	10.01	114.06	121.45	0.02
15	North	2-yr	0.14	62.57	62.74	0.93
16	North	2-yr	0.14	68.60	68.71	0.74
17	North	2-yr	7.77	74.56	75.33	1.54
18	North	2-yr	7.77	77.38	78.50	2.79
19	North	2-yr	7.77	84.18	85.60	2.65

Table 7. Hydraulic modeling results for the proposed condition model: 2- and 100-year flood events (continued).

River Sta.	Reach	Profile	Q total	Min Ch El	W.S. Elev	Vel
			(m^3/s)	(m)	(m)	(m/s)
Natural Drainage						
1	South	100-yr	16.15	90.91	91.62	2.28
2			16.15	92.03	92.86	2.30
3	West		8.95	108.28	109.06	2.26
4			8.95	113.17	114.04	2.41
5			8.95	117.43	118.28	2.44
6			8.95	116.12	118.64	0.38
7			11.19	117.39	118.61	1.56
8			11.19	123.22	123.85	1.85
9	East		7.95	116.74	117.59	2.41
10			7.95	121.39	122.18	2.35
11			7.95	120.32	122.52	0.52
12			7.95	114.27	122.53	0.01
13			20.05	114.09	122.53	0.03
14			20.05	114.06	122.53	0.04
15	North		11.96	62.57	63.70	2.65
16			11.96	68.60	69.27	1.84
17			15.90	74.56	75.54	2.05
18			15.90	77.38	79.02	3.26
19			15.90	84.18	86.07	3.06

The computed maximum velocities produced along the studied natural drainage vary from 0.0004 to 2.79 m/s and 0.01 to 3.06 m/s for the 2- and 100-year flood events, respectively.

Maximum backwater occurs at different sections. Sections 3, 7, 8, 9, 10, 11, 12, 13, 14, 15 and, 17 have 0.01, 0.01, 0.01, 0.02, 0.02, 0.04, 0.03, 0.03, 0.03 and, 0.04 meters of backwater, respectively. Moreover, the computed levels at sections 15 to 19 are lower than the existing. Therefore, it complies with the Planning Regulation No. 13 of the PR Planning Board.

V. SEDIMENTATION ANALYSIS

Methodology

Sediment Yield

The sedimentation analysis was performed to determine the average sediment yield and the sediment load from the studied areas for the 2-, 10-, and 100-yr events. The soil erosion and sediments yield were estimated using the Modified Universal Soil Loss Equation (MUSLE) to calculate the sediment yield of a basin as a result of a specific storm event [Fifield, 2001]. The equation used was the following:

$$A = 95\ (V \times Qp)^{0.56*} \times K \times LS \times C \times P / At \qquad (2)$$

where *A* is the soil erosion calculated in tons/acre, *V* is the volume of runoff in acre-ft, *Qp* is the peak flow in cubic feet per second, *K* is the erosion factor, *LS* is the topographic factor, *C* is the cover and management factor, *P* is the erosion control practice factor, and *At* is the area of the basin.

The *K* factor used for the studied area was obtained from the USDA database for the Caribbean Area available in the RUSLE2 software version 1.26.6.4 (See Appendix F). The *LS* factor was obtained from tables [Fifield, 2001], using the slope and slope length for the analyzed areas for the existing and proposed conditions. The cover factor *C* used for the landfill areas was 1.0 for areas without any cover and 0.004 for areas with grass. The control practice management factor *P* used was 1.0 assuming no erosion management practices.

For the landfill area the erosion factor K was obtained using the soil erodibility nomograph developed by the USDA [2007]. The fill material in the landfill corresponds to AASHTO A-2-4. This material has a maximum of 35 percent of very fine material and an average of 65 sand percent [USDA, 2007]. A zero percent of organic matter was assumed; the soil structure was assumed as very fine granular and; permeability was assumed as very slow. Using these parameters, and the USDA erodibility nomograph, an erosion factor K of 0.36 was estimated for the landfill area (see Appendix F).

The sediment yield and total sediment load were calculated for all analyzed sub-basins described in the hydrologic analysis for the existing and proposed condition.

Pond Sedimentation Analysis

A pond sedimentation analysis was performed to evaluate the storage and sediment trap capacities in the existing and proposed retention ponds. This analysis was developed based on the existing and proposed ponds dimensions, fill material properties and peak flows. The 2-, 10-, and 100-yr rainfall events were evaluated.

As mentioned in the previous section, the fill material assumed for the landfill area was AASHTO A-2-4. The texture classification for this corresponds to sandy loam material. The average size average diameter corresponds to 0.5 to 0.25 mm (fine sand) and a settling velocity of 3.475 centimeters per second (0.03475 m/s) to 20°C [Fifield, 2001]. The sediment trap capacity was evaluated calculating the average upflow velocity within the existing and proposed ponds. The upflow velocity is defined as the flow average velocity from the inlet point to the outlet point within the retention structure. This velocity is directly proportional to the outflow controlled by the outlet structure. The upflow average velocity was calculated using the following equation:

$$v = Q / A \qquad (3)$$

where v is the average upflow velocity in the analyzed retention pond, Q is outflow from the pond, and A is the pond surface area. The peak outflows resulting from the retention analysis, shown in Tables 3 and 5, were used in this analysis for the existing and proposed conditions, respectively.

The average upflow velocities were calculated for the existing and proposed retention ponds. These were compared with the settling velocity determined for the fill material (0.03475 m/s). In addition, very fine sands, coarse silt and very fine silts were analyzed. The particles are trapped in the retention pond if the average upflow velocity is lower than its settling velocity. Appendix G includes the sedimentation analysis for the existing and proposed retention ponds.

Sediment Analysis Results

Sediment Yield

Using the MUSLE equation, the sediment yields were calculated for the analyzed basins for the existing and proposed condition for the 2-, 10-, and100-yr rainfall events. Appendix F includes the parameters used in MUSLE equation, the calculated sediment yield and the total sediment load for the existing and proposed conditions for each analyzed event.

Results shows that the sediment load is higher for the proposed condition compared to the existing condition. The sediment load is increased from 13,101 to 15,033 tons within the studied areas for the 2-yr event, from 24,100 to 27,231 tons for the 10-yr event, from 42,535 to 47,839 tons for the 100-yr for the analyzed basins.

The sediment yields for the existing condition within the landfill area varied from a minimum of 48.29 to a maximum of 403.35 ton/acre for the 2-yr event, a minimum of 91.92 to a maximum of 742.01 ton/acre for the 10-yr event and, a minimum of 165.48 to a maximum of 1,274.93 ton/acre for the 100-yr event. The minimum occurs at ***BASN*** area and the maximum occurs at the landfill area ***LW***.

For the proposed condition the sediment yield varied from a minimum of 45.47 to a maximum of 480.68 ton/acre for the 2-yr event, a minimum of 90.60 to a maximum of 875.08 ton/acre for the 10-yr event, a minimum of 167.51 to a maximum of 1,506.41 ton/acre for the 100-yr event. The minimum occurs at ***BASN*** area and the maximum occurs at the landfill area ***LW***.

Pond Sedimentation Analysis

For the existing condition the results shows that ponds ***South 1*** and ***South 2*** have the capacity to trap particles with a size higher than 0.2 mm (fine sands). Ponds ***North*** and ***West*** trap particles size higher than 0.09 mm (very fine sands) and, pond ***East*** trap particles with a size higher than 0.047 mm (coarse silt).

For the proposed condition the results shows that the ponds ***North***, ***West*** and ***South*** trap particles size higher than 0.09 mm (very fine sands), and pond ***East*** trap particles with a size higher than 0.047 mm (coarse silt).

The calculations for the pond sedimentation analysis are included in the Appendix G for the existing and proposed conditions.

VI. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. The results for the 2-, 10- and 100-yr events indicated that the existing ponds ***North***, ***South 1*** and ***South 2*** are flooded. For the 2-yr event ponds ***South 1*** and ***South 2*** are flooded 0.17 meter each one. For the 10-yr event ponds ***North***, ***South 1*** and ***South 2*** are flooded 0.06, 0.35 and 0.35 meter, respectively. For the 100-yr event the ponds ***North***, ***South 1*** and ***South 2*** are flooded 0.13, 0.60 and 0.60 meter, respectively.

2. The effective storage volume for ***Pond West*** and ***Pond East*** are controlled by the pond's dimensions and the topography. That is, when the structures are flooded the surrounding area operates as large storage volumes. These areas were established using the existing topographic survey and the USGS topographic maps. Figure 5

shows the location plan and the storage volume limits for the existing retention ponds.

3. The existing pond ***North***, ***South 1*** and ***South 2*** should be modified to comply with two purposes: 1) provide the minimum required storage capacity and; 2) to produce an outflow discharge equal or lower than the calculated for the existing condition.

4. The proposed ponds will reduce the peak flow discharge at the north and south limits. The peak flows are reduced from 249 ft^3/s to 5 ft^3/s for the 2-yr event and, from 546 ft^3/s to 423 ft^3/s for the 100-yr event, at the north limit (pond ***North***). The peak flow is reduced from 149 ft^3/s to 102 ft^3/s for the 2-yr event and, from 584 ft^3/s to 570 ft^3/s for the 100-yr event, at the south limit (pond ***South***). As noted, for both events the proposed discharge is lower than the existing. Therefore, both ponds complies with the Planning Regulation No. 3 of the PR Planning Board. Specifications of this structure are indicated in Figures 15 and 16.

5. For the landfill area the erosion factor K was obtained using the soil erodibility nomograph developed by the USDA [2007]. The fill material in the landfill corresponds to AASHTO A-2-4. This material has a maximum of 35 percent of very fine material and an average of 65 sand percent [USDA, 2007]. A zero percent of organic matter was assumed, structure was assumed as very fine granular and

permeability as very slow. Using these parameters and the USDA erodibility nomograph, an erosion factor K of 0.36 was estimated for the landfill area.

6. Results shows that the sediment load is higher for the proposed condition compared to the existing condition. The sediment load is increased from 13,101 to 15,033 tons for the 2-yr event, from 24,100 to 27,231 tons for the 10-yr event and, from 42,535 to 47,839 tons for the 100-yr, for the analyzed basins.

7. The sediment yields for the existing condition within the landfill area varied from a minimum of 48.29 to a maximum of 403.35 ton/acre for the 2-yr event, a minimum of 91.92 to a maximum of 742.01 ton/acre for the 10-yr event and, a minimum of 165.48 to a maximum of 1,274.93 ton/acre for the 100-yr event. The minimum value occurs at ***BASN*** area and the maximum occurs at the landfill area ***LW***.

8. For the proposed condition the sediment yield varied from a minimum of 45.47 to a maximum of 480.68 ton/acre for the 2-yr event, a minimum of 90.60 to a maximum of 875.08 ton/acre for the 10-yr event and, a minimum of 167.51 to a maximum of 1,506.41 ton/acre for the 100-yr event. The minimum occurs at the landfill area within the ***BASE*** area and the maximum occurs at the landfill area ***LW***.

9. For the existing condition the results shows that ponds ***South 1*** and ***South 2*** have the capacity to trap particles with a size higher than 0.2 mm (fine sands), pond

North and ***West*** trap particles size higher than 0.09 mm (very fine sands) and, pond ***East*** trap particles with a size higher than 0.047 mm (coarse silt).

10. For the proposed condition the results shows that ponds ***North***, ***West*** and ***South*** trap particles size higher than 0.09 mm (very fine sands) and, pond ***East*** trap particles with a size higher than 0.047 mm (coarse silt).

11. Based on the results of the flood profile analysis it is concluded that no backwater results from the proposed condition compared to the existing condition. Therefore, the proposed expansion to the existing landfill complies with the requirements of the Planning Regulation No. 13 of the PR Planning Board for rural areas (0.30 meter of maximum increase).

Recommendations

1. The recommended outlet structure for pond ***North*** consists of two weirs located at the north limit. The first weir has a length of 7.0 meters and an invert elevation of 73.00 m (msl). The second weir has a length of 12.0 meters and an invert elevation of 73.60 m (msl). Figure 22 shows the proposed outlet structure for pond ***North***.

2. The recommended outlet structure for pond ***South*** consists of two weirs located at the north limit. The first weir has a length of 6.5 meters and an invert elevation of

96.70 m (msl). The second weir has a length of 9.0 meters and an invert elevation of 97.70 m (msl). Figure 23 shows the proposed outlet structure for pond ***South***.

3. For the proposed condition, the depth of pond ***North*** was increased 1.0 meter. The ponds ***South 1*** and ***South 2*** were joined in one single pond named ***Pond South***. The outlet structures for the proposed modified structures are composed weirs. Figure 6 shows the proposed retention structures.

4. The results for the retention pond analysis for the proposed condition are shown in the Table 5. For the proposed condition a freeboard of 0.30 and 0.35 meter was calculated for the 100-yr event at ponds North and South, respectively.

5. The minimum required flow retention structures recommended should be as specified in Figures 15 and 16.

6. Dimensions of the proposed retention structures can be changed to fit the site civil design. However, minimum storage volume, outlet structure and, relative minimum invert elevations should be as recommended.

7. The recommended minimum storage volume includes at least 0.30 meter of freeboard.

8. All recommendations specified herein must be implemented to assure performance in accordance with the hydraulic design. Since the results of this study are based on free flow conditions through the recommended structures, proper cleaning and maintenance is required to assure this condition. The accumulation of debris can severely obstruct flow, producing backwater much higher than presented herein.

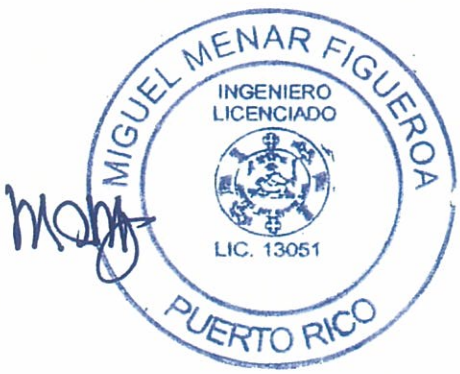
Study Limitations

All recommendations specified herein must be implemented to assure performance in accordance with the design. The results of this study are based on free flow conditions through the recommended hydraulic structures. Proper maintenance is required to assure this condition since, the accumulation of debris can severely obstruct flow, producing backwater much higher than presented herein. This analysis is based on the field data as submitted by Mr. Ricardo Flores Ortega, P.E., representative of RF Engineering, P.S.C. Inaccuracies in this data may total or partially invalidate the results and recommendations contained in this study.

VII. CERTIFICATION

I certify that the hydrologic-hydraulic study presented herein was performed by me and the information is true, correct, and complete as per my knowledge. I know and accept the consequences of include and submit incomplete, unfinished or false information in this document. To state this, I sign the present certification in *Canóvanas, Puerto Rico*, on October 23, 2008.

Respectfully submitted,



Miguel Menar Figueroa, MSCE, PE
PE License #13051

VIII. REFERENCES

Fifield, J. S., 2001. *Designing for Effective Sediment and Erosion Control on Construction Sites.* Santa Bárbara, California.

Natural Resources Conservation Service, 2007. Soil Data Mart Web site or the NRCS Web Soil Survey. [Online] Available: http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx

P.R. Planning Board, 2005a. *Reglamento sobre Áreas Especiales de Riesgo a Inundación.* Reglamento de Planificación Número 13. Estado Libre Asociado de Puerto Rico, Oficina del Gobernador. Sexta Revisión. 31 de diciembre de 2005.

P.R. Planning Board, 2005b. *Reglamento de Lotificación y Urbanización.* Reglamento de Planificación Número 3. Estado Libre Asociado de Puerto Rico, Oficina del Gobernador. Revisado 30 de junio de 2005.

Renard, K.G., 1997 Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). USDA Agricultural Handbook No. 703. US Department of Agriculture, Washington D.C.

U.S. Army Corps of Engineers, 2008. Hydrologic Modeling System (HEC-HMS). Hydrologic Engineering Center. Davis, California. Version 3.2. April 2008.

U.S. Army Corps of Engineers, 2008. *River Analysis System (HEC-RAS).* Hydrologic Engineering Center. Davis, California. Version 4.0. March 2008.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, Silver Spring, 2006. NOAA Atlas 14: Precipitation-Frequency Atlas of the United States, Volume 3 Version 3.0: Puerto Rico and the U.S. Virgin Islands. [Online] Available: http://hdsc.nws.noaa.gov/hdsc/pfds/pr/pr_pfds.html

U.S. Department of Agriculture, Natural Resources Conservation Service, 2007. National Soil Survey Handbook, title 430-VI. [Online] Available: http://soils.usda.gov/technical/handbook/.

United States Geological Survey, 1982. Topographic Quadrangle Maps. 1:20,000, 7.5 minutes.

FIGURES