Figure 1 - USGS quadrangle for the study site. Note dates of topography data and revision.

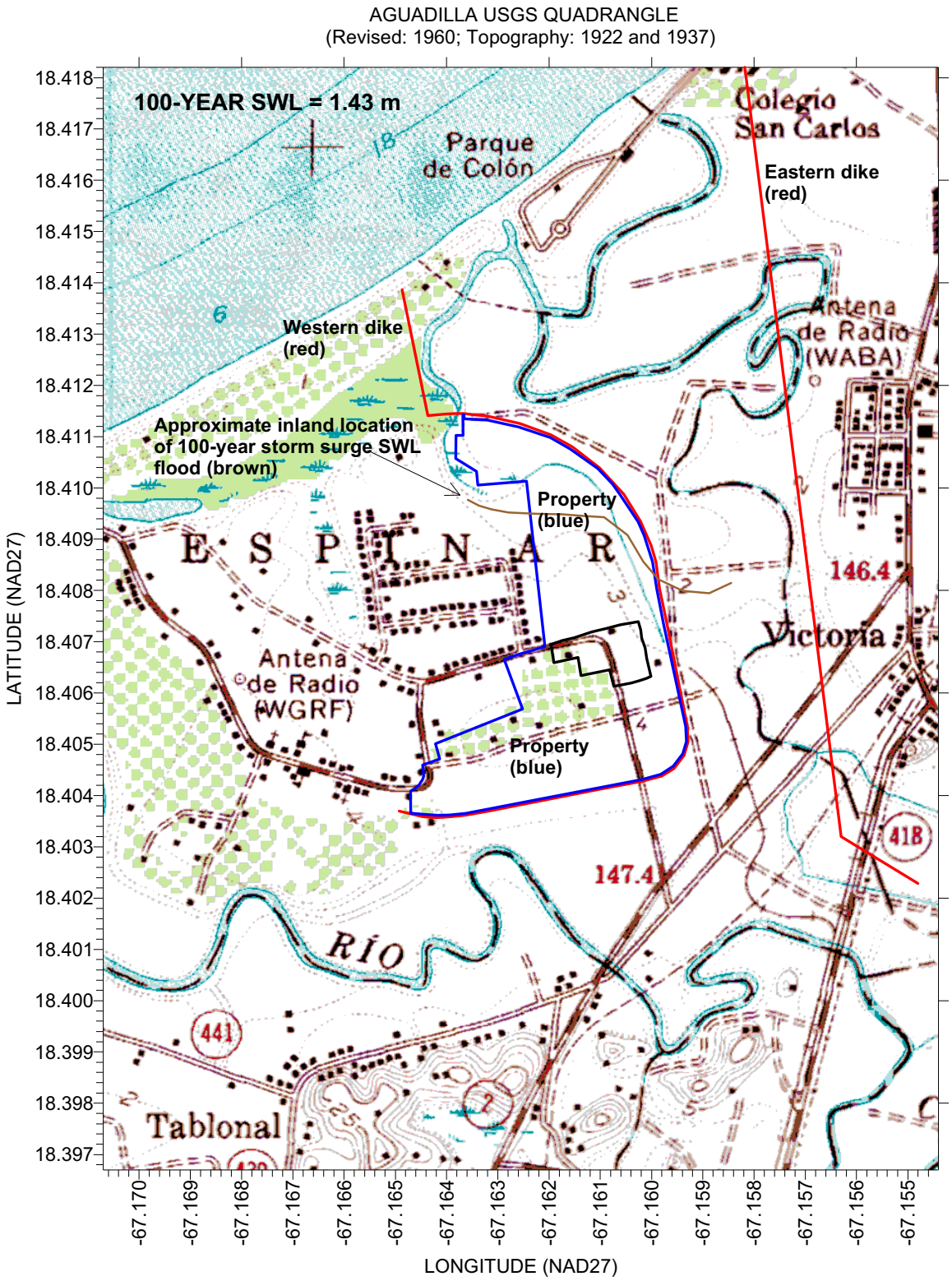


Figure 2 - Zoom in of the are where the complex is to be built. Also shown are the proposed dikes, the periphery of the complex, and the approximate inland penetration of the 100-year stillwater elevation.

Insurance Study done by Mercado for the federal Emergency Management Agency, also known as FEMA (Mercado, 1009, 1994). The SWL is the water elevation, relative to Mean Sea Level (MSL), that would be measured inside a flooded (closed) building where the influence of the high frequency waves has been filtered out but storm surge water still leaks in through gaps. The waves propagate on top of the SWL. It is important to notice that the Base Flood Elevation (BFE) for the study site in the VE zone is 2.3 m. This is higher than the SWL because, by definition, the BFE is the elevation of the crest of the highest waves that can propagate over the 100-year SWL at the site (see Figure 3). Its determination is based on the following equation (FEMA, 2000):

$$BFE\ (above\ MSL) = SWL + 0.7H$$

where H is the wave height of the maximum wave that can propagate over the study site. In this case SWL equals the 100-year storm surge elevation above MSL. The above formula assumes that near shore the water wave profile becomes asymmetrical relative to the SWL such that the elevation of the crest of the wave above the SWL is 0.7 of the wave height H (under normal conditions the elevation of the crest above the SWL is 0.5H). It is now also assumed that the maximum wave height equals 0.78 times the (total) local water depth, d. Therefore, the BFE is given by

$$BFE = SWL + (0.7)(0.78)d$$

Recall that in general (see Figure 3),

$$d = h + SWL.$$

where h = water depth relative to MSL.

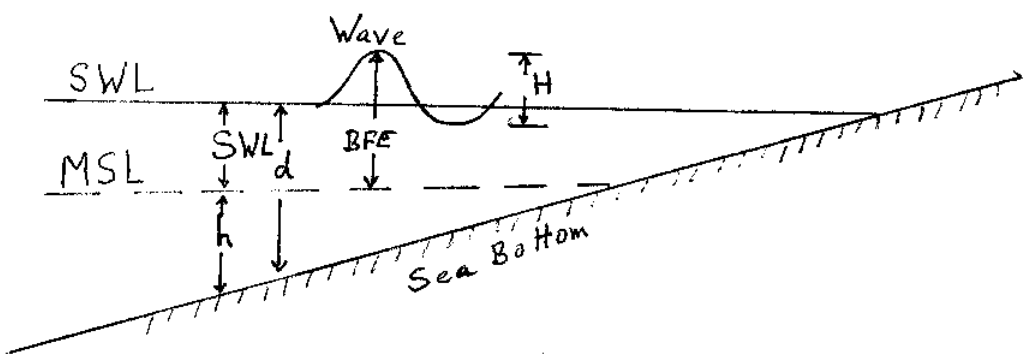


Figure 3 - Sketch showing the relationship between Mean Sea level, Stillwater Level (or Elevation), wave height, and Base Flood Elevation.

Therefore, the above equation can be rewritten as

$$BFE = SWL + 0.55\ SWL + 0.55\ h = (1.55)\ SWL + 0.55h.$$

But right at the MSL shoreline $h = 0$ (by definition). Therefore, right at the shoreline

$$BFE = 1.55\ SWL.$$

Using as SWL the value found by Mercado (1990, 1994), of 1.43 m, we get for the BFE at the study site the approximate value of BFE = 2.22 m, which is close to the value of 2.3 m listed in the FIRM.

Figure 2 shows that since the 1.43 m contour crosses the northern part of the complex, this northern part is potentially floodable by the 100-year coastal flood, or storm surge. This is assuming that the present topography is the same as the one shown in the USGS Aguadilla quadrangle, which is topography from the years 1922 and 1937. Therefore, all that the developers have to do to take the property above the 100-year storm surge is raise the topography of the complex above the elevation of 1.43 m above MSL. But the problem does not lie with coastal flooding, but with riverine flooding.

Figure 4 shows that, as is known, the entire complex is situated in an area floodable by the 100-year flood, but from the discussion above we can conclude that it is riverine flood which dominates all over the property. Note that, as expected, the entire property lies much inland of the inland boundary of the ocean wave VE Zone (which is the area where waves with heights of 3 or more feet can propagate). The inland boundary of the ocean VE Zone is shown as a white line paralleling the line representing the shoreline in Figure 4. The figure shows gutter lines (lines indicate changes in zones, and are solid lines extending across the entire 100-year flood plain) with flood elevations starting at 2.8 m (close to the mouth of Caño Madre Vieja) increasing to above 6 m above MSL as we move upstream the river discharge. It is obvious that this is not storm surge flooding.

We have seen (see Figure 2) that a fraction of the proposed complex can be flooded by the 100-year storm surge SWL, and that this can happen even if the dikes are constructed since the ocean water can move inland just west of the western dike. Again, this is as long as the topography on the USGS quadrangle has not changed. This is corroborated by Figure 5, which shows a geo-referenced scanned image of the Hurricane Storm Tide Atlas for the study site. The figure shows a reference point, number 40 – located right at the entrance of Caño Madre Vieja, at which the storm surge computer model has given as the SWL elevations for the category 1, 3, and 5 storm surges the values of 1.3, 2.1, and 2.9 m above MSL. The value for the Category 1 storm surge is close to the 100-year coastal SWL and its inland boundary does coincide closely with the 1.43 m contour line drawn in Figure 2, corroborating what we stated above about the fact that raising the property elevation above 1.43 m will take it above the 100-year ocean SWL. Figure 5 also shows that the entire property is floodable by the expected storm surge from a direct hit by a Category 5 hurricane. But Figure 4 shows that even then the 100-year river discharge will dominate over the Category 5 SWL.

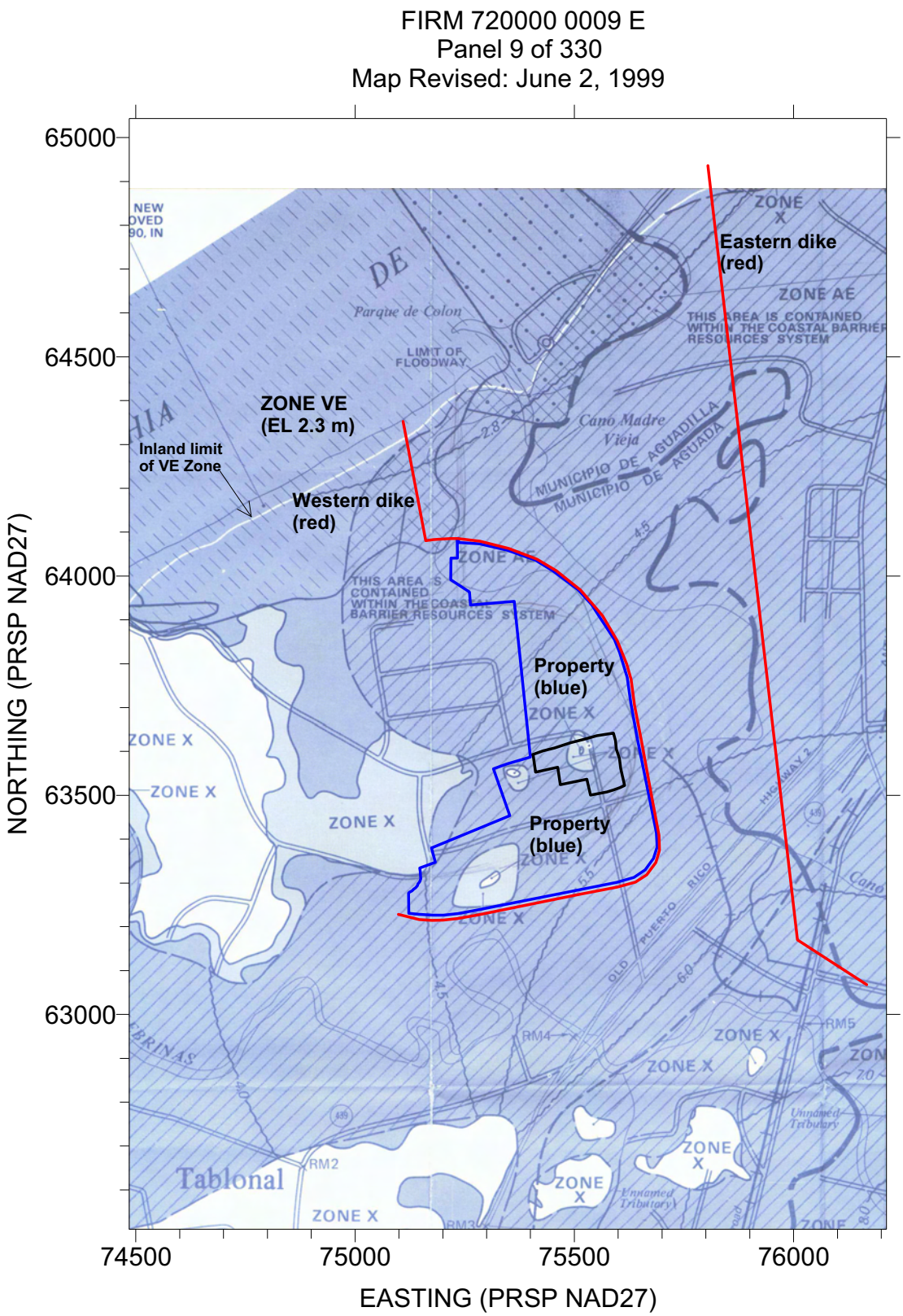


Figure 4 - Scanned map of the FIRM used in this study. Overlaid over the image are the proposed dikes and the periphery of the proposed complex.

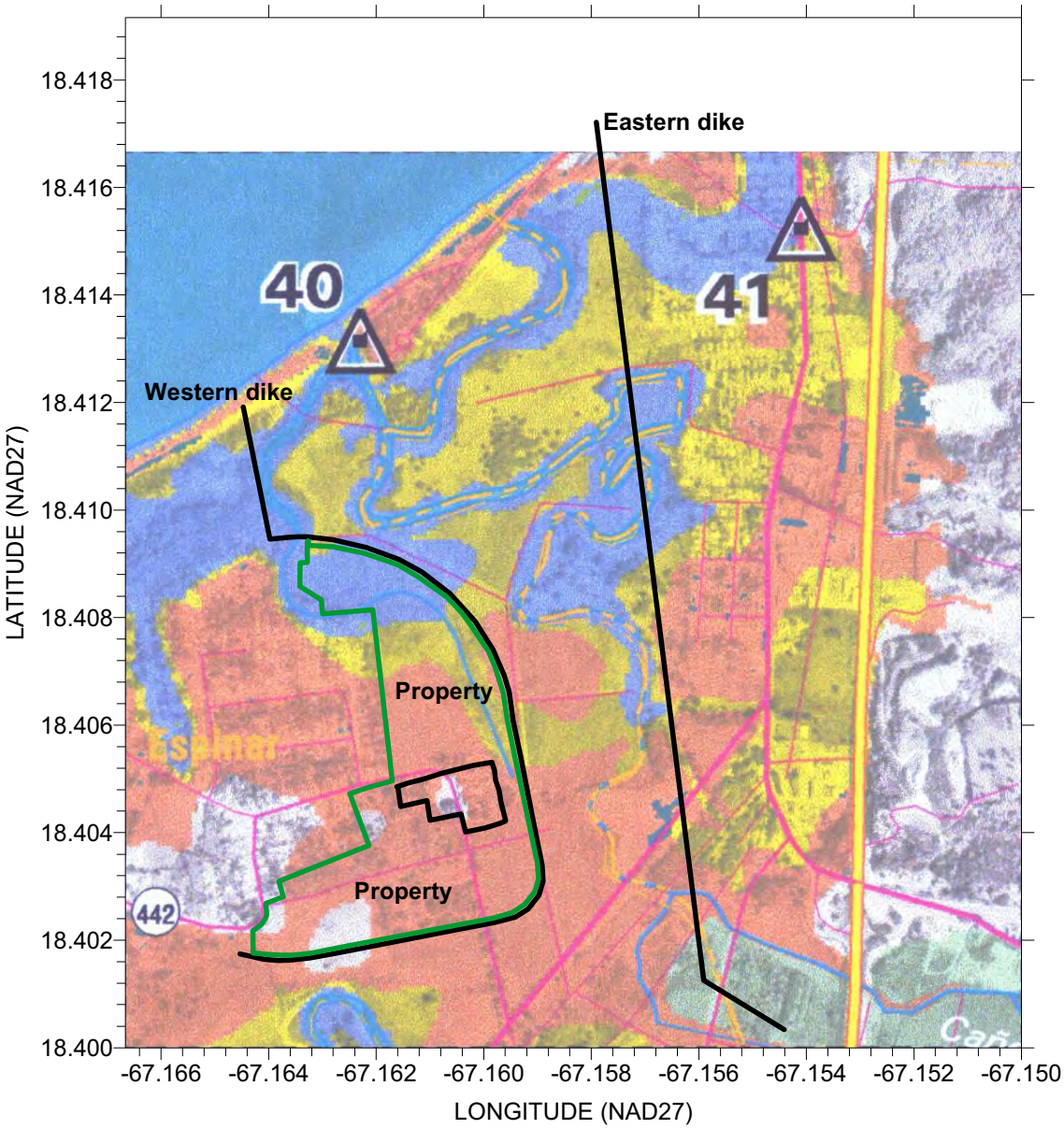


Figure 5 - Scanned image of the storm surge atlas map covering the area of the study. This shows the areas floodable by the storm surge due to Category 1, 3, and 5 hurricanes. See Figure 6 for the elevation color bar scale.

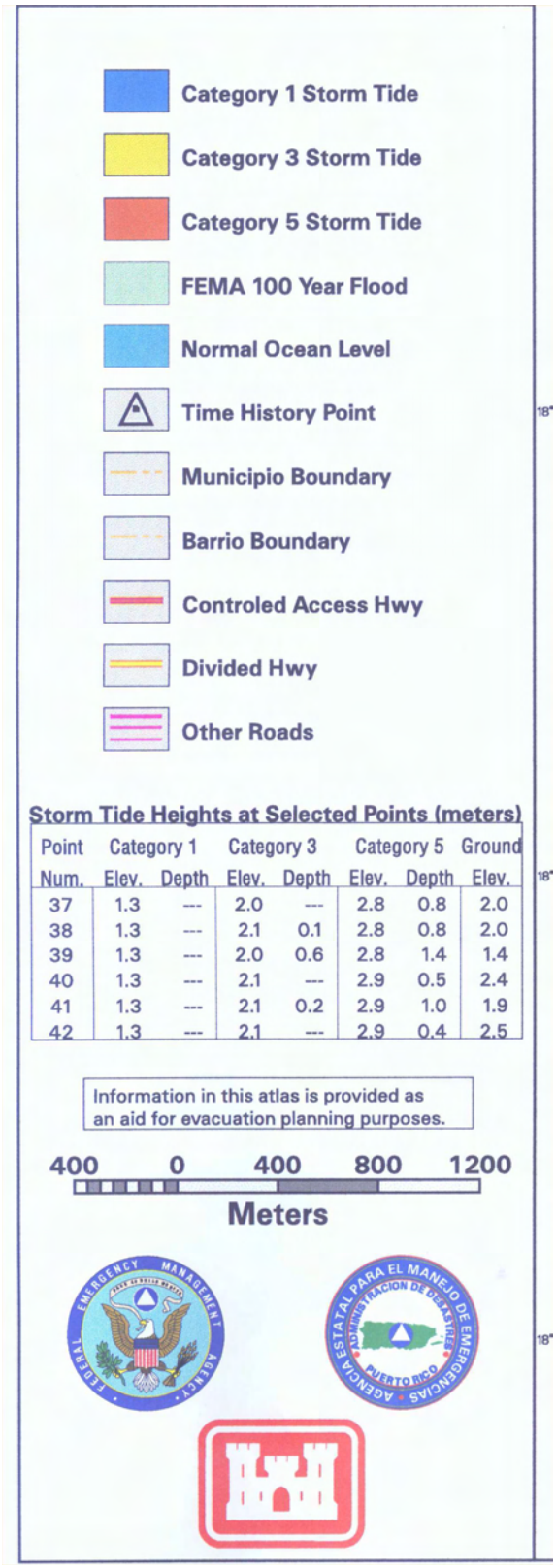


Figure 6 - Color bar code assigned to elevations shown in Figure 5. Also shown is a table indicating expected SWL due to category 1, 3, and 5 hurricanes.

Conclusion

This study shows that the proposed complex is potentially floodable by the 100-year storm surge SWL, but only a small fraction along its northern end. But this conclusion is based on the assumption that the present topography is the same as the one measured back in 1922 and 1937. This flooding can still occur even if the USACoE dikes are constructed since the ocean water can move inland just south of the western dike. Again, assuming that the topography along that pathway has not varied since the Aguadilla USGS quadrangle was made. One way to obviate this potential problem is by raising the property's topographical elevation above 1.43 m relative to MSL. We also proved that ocean wave action should be of no concern to the property developers and owners since the VE zone stays seaward of the part of the property closest to the shoreline.

We have also seen that the 100-year river discharge completely dominates over the 100-year storm surge flood, and that this scenario should be the big concern. On the other hand, although hurricane evacuation coastal flood maps are not regulatory, we have also seen that part of the property is floodable by the expected storm surge from a Category 3 hurricane. We also concluded that all of the property is floodable by the expected storm surge from a Category 5 hurricane, and that this flooding can occur even if the dikes are constructed. Again, this conclusion is valid if the present topography is the same as the one shown in the USGS Aguadilla quadrangle map because the Hurricane Storm Tide Atlas map is also based on the same topographic information. This concern can also be taken care off by raising the property topographical elevation above the expected storm surge elevation from these hurricanes (2.1 and 2.9 m for Category 3 and 5, respectively).

Construction of the dikes, if constructed to a sufficient height, should take the property out of the riverine flooding. Raising the topographical elevation of the property by the stipulated elevations should take the property out of the coastal flooding concern.

References

FEMA, 2000. Coastal Construction Manual. 3rd Edition, Chapter 11, page 11.7.

Mercado, A., 1990. Flood Insurance Study for the Commonwealth of Puerto Rico and the U.S. Virgin Islands. Vols. 1 to 5. Submitted to the Federal Emergency Management Agency, Washington, D.C.

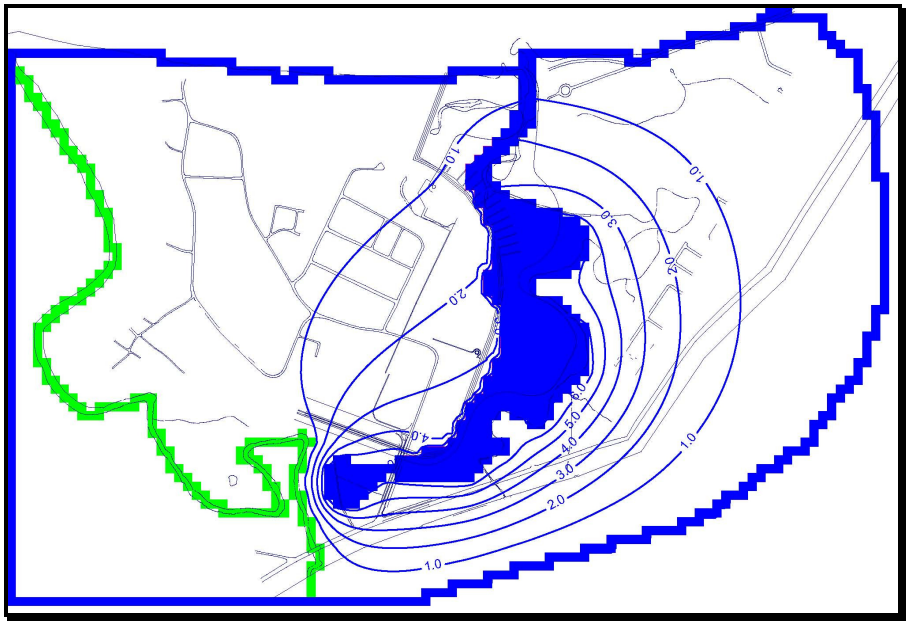
Mercado, A., 1994. On the use of NOOA's storm surge model, SLOSH, in managing coastal hazards - the experience in Puerto Rico. ***Journal of Natural Hazards***, Vol. 10:235-246.

APENDICE F

RESULTS OF GROUNDWATER FLOW MODELING

PROPOSED DISCOVERY BAY RESORT AND MARINA
Espinar Ward, Aguada, Puerto Rico

PROJECT NO. 09-4131B



Prepared for:

Mr. Thomas C. Cordero, President
Cordeco Land Services Corp.
P.O. Box 610
Aguada, Puerto Rico 00602

December 1, 2009

HYDRO-ENVIRONMENTAL ASSOCIATES, INC.
HYDROGEOLOGIC & ENVIRONMENTAL CONSULTING

• 10014 North Dale Mabry Highway, Suite 205, Tampa, Florida 33618 • (813) 969-6995 •

TABLE OF CONTENTS

INTRODUCTION **1**

SITE HYDROGEOLOGY **3**

REVISED MODEL SETUP **5**

AQUIFER PARAMETERS **7**

RESULTS **8**

REFERENCES **9**

FIGURES **10**

Figure 1 – Model Grid 11

Figure 2 – Simulated Water Level Elevations in Surficial Aquifer Without Marina 12

Figure 3 – Simulated Water Level Elevations in Surficial Aquifer With Marina 13

Figure 4 – Simulated Drawdown in Surficial Aquifer 14

APPENDIX A **15**

Technical Memorandum: Summary of Discovery Bay Marina Groundwater Flow Analysis June 1, 2005

INTRODUCTION

Hydro-Environmental Associates, Inc. (HEA) was retained by Cordeco Land Services Corp. (Cordeco) to conduct a Hydrologic Assessment of the proposed Discovery Bay Marina Development, located in Aguadilla, Puerto Rico. The goal of the assessment is to address potential impacts to the groundwater quality resulting from the construction of a proposed 500-slip inland marina basin, which is to extend approximately 4,000 feet inland from the existing Mean Sea Level (MSL) line of the Atlantic Ocean. The excavated basin elevation is proposed to be 15.0 feet below MSL, and the existing land surface within the proposed inner harbor area ranges from zero to approximately ten (10) feet above MSL. Portions of the subject site are used as an active sand mine.

One of the initial tasks of the Hydrologic Assessment was to create a groundwater flow model to determine the rate and volume of groundwater flow contribution from the surficial aquifer to the proposed marina basin. The initial groundwater flow model was created in 2005, based on limited hydrogeologic information and a preliminary conceptual design. The purpose of this report is to describe the modifications to the groundwater flow model based on updated technical information and site drawings. Based on comments from the Puerto Rico Department of Environmental and the United States Department of the Interior Fish and Wildlife Service (FWS) regarding the Preliminary Environmental Impact Statement (P-EIS) and Joint Permit Application, the groundwater flow model was also modified to predict the environmental impacts of the marina basin on the surrounding surficial aquifer and the flow of the Rio Culebrinas.

Moffatt & Nichol Engineers, Inc. is conducting a study to evaluate the circulation of water within the proposed marina basin. In order for the marina to sustain a healthy aquatic environment, proper water circulation and tidal flushing is required. Due to limitations in the shape of the property, the proposed marina configuration may possibly limit the natural circulation and flushing of seawater. Based upon site observations during dewatering of the sand mine, it is apparent that a significant component of marina circulation may be obtained by groundwater flow from the shallow aquifer within the proposed marina basin.

The results of the initial groundwater flow modeling indicated that the average rate of total groundwater inflow into the proposed marina basin would be approximately 2.44 million gallons per day (MGD), while maintaining the water level in the marina basin at mean sea level. Approximately 33 percent of this total flow would be generated from the base of the surficial aquifer. The report indicated that the freshwater flow into the marina basin would offset any significant salt water intrusion from the excavation. However, since the initial groundwater flow model was developed in 2005, the marina layout has been significantly modified through 2007, including the addition of a sea wall along the west side of the basin, and an overall reduction in size. Also, since the time of the initial groundwater modeling, ten (10) monitoring wells have been installed and accurate water level elevations have been obtained throughout the site. The addition of the sea wall would greatly reduce the volume of groundwater flow into the marina basin from the surficial aquifer.

The groundwater flow model has been updated to include the current basin layout, and the addition of the sea wall along the west side of the basin. In addition, the water level elevations along the

model boundaries have been updated to more accurately reflect field conditions, the base flow elevations of the Rio Culebrinas have been modified to coincide with the water level elevations, and the aquifer parameters have been modified to better reflect local hydrogeology. The following sections of this memorandum describe the modifications to the groundwater flow. A complete copy of the Technical Memorandum that discusses the results of the initial groundwater flow modeling is included as Appendix A. The Technical Memorandum was dated June 1, 2005.

SITE HYDROGEOLOGY

Based upon the previous Hydrogeologic Assessment, three principal geologic units are identified within the subject site. These hydrogeologic units consist of 1) the unconsolidated deposits of Quaternary age lying within the Rio Culebrinas and Madre Vieja Creek valleys, 2) deposits of the basal San Sebastian Formation, and 3) the carbonate platform strata of the Cibao Formation.

The study area is typically underlain by Recent (Quaternary) age unconsolidated alluvial sediments generally consisting of an upper clayey sand and sandy clay. Swamp deposits consisting of sandy organic muck and peat have also been mapped on the northernmost area of the site. Underneath the upper sandy clay layer is a layer of cross bedded quartz sand and shell, with minor amounts of pebbles and cobble of volcanic rock. A consistent stiff gray alluvial silty clay layer has been identified underlying the surficial sands. The gray silty clay was identified at depths ranging from about 50 to 70 feet.

Underlying the Quaternary alluvial deposits is the San Sebastian Formation of Tertiary age. Within the subject site, the San Sebastian Formation consists of alternated clay, sandy clay, very fine sand, and soft clay lenses. Due to the depth, the San Sebastian Formation was only identified at the location of monitoring well WB-9. It should be noted that the original groundwater model assumed that the Aymamon Limestone was overlain by the surficial sands. However, drilling conducted after the initial groundwater flow model was created, did not identify the Aymamon Limestone.

Near the eastern limit of the subject site, at the location of monitoring well WB-10, the Cibao Formation of Tertiary (Miocene) age was identified. The Cibao Formation is composed of a calcareous clay and clayey sand with occasional clay lenses. It is thought that the Cibao Formation pinches out along the eastern extent of the subject site, near the location Route PR-115. It is thought that volcanic basement rocks underlie the San Sebastian Formation and Cibao Formation, however, direct drilling has not been conducted to confirm this assumption.

The only potable aquifer within the subject site and vicinity is a limited surficial aquifer. Based on our review of on-site lithologic data, the surficial aquifer is estimated to be approximately 50 - 60 feet in thickness across the subject site and consists of quartz sand, shell fragments, and pebbles and cobble of volcanic rock.

Below a depth of 60 feet, a stiff to very stiff gray clay was encountered at the deep soil boring locations. These clays probably form the base of the Quaternary alluvial sediments. This clay would represent a confining layer, preventing the upward or downward movement of water from the surficial aquifer.

Underlying the Quaternary alluvial deposits is the San Sebastian Formation. The San Sebastian Formation, due to the lithology, is also a confining layer, preventing the upward or downward movement of water from the surficial aquifer. As discussed above, it is expected that volcanic basement rock underlies the San Sebastian Formation. It is suspected that the Cibao Formation, which was identified at the location of upgradient monitoring well WB-10, pinches out near the eastern portion of the subject site. The Cibao Formation, which is mainly composed of a calcareous

clay, is also a confining layer, preventing upward, downward or lateral groundwater flow. The revised groundwater flow model substituted the aquifer parameters of the Aymamon Limestone with the San Sebastian Formation.

The recharge to the surficial aquifer is from predominately precipitation and infiltration from the Rio Culebrinas basin. Average precipitation in the area ranges from 60 to 70 inches per year (USGS, 1984). The persistent easterly and southeasterly tradewinds contribute to produce precipitation throughout the year, although seasonal variations occur. Due to the excessively high rates of evaporation, evapotranspiration, and runoff, only a relatively small amount of the precipitation is available for recharge to the aquifer.

REVISED MODEL SETUP

The site, as modeled, consists of the proposed marina basin configuration as presented on the Road Plan, dated February 16, 2009, prepared by EDSA, Inc., Ft. Lauderdale Fla. Figure 1 presents the modeled area. The areas shaded in blue represent the effective surface area of the proposed marina basin as simulated. The model was set up as a three layer hydrogeologic system, with the first upper two layers representing the surficial aquifer, and the third layer representing the underlying San Sebastian Formation. The surficial aquifer was divided into two layers to simulate the effects of the proposed marina basin. The bottom elevation of layer one was set to an elevation of -15 feet below mean sea level (MSL), which is the proposed bottom elevation of the marina basin.

Each model layer was discretized into 10,000 100-foot by 100-foot cells (100 rows by 100 columns). Constant head boundaries were used to define the Atlantic Ocean and the Cordillera Jaicoa outcroppings. The model elevation of the constant head boundary representing the Atlantic Ocean was assumed to be zero feet. The constant head boundary cells representing the face of the Cordillera Jaicoa to the north of the Rio Culinebras was estimated to at an elevation of 10 feet NGVD, based upon a review of the Aquadilla USGS 7.5 minute quadrange map, as well as review of site water level elevations. The original model assumed the constant head elevations along the face of the Cordiller Jaicoa to at the elevation of 15 feel NGVD. The constant head boundaries representing the face of Cordillera Jaicoa south of the Rio Culinebras was varied linearly from a maximum of 10 feet to zero feet NGVD, based upon the general topography of the area. The original groundwater flow model assumed a constant head range of 15 feet to zero feet south of the Cordillera Jaicoa.

The river package was used to simulate the Rio Culinebras. The upstream elevation of the Rio Culinebras was estimated to be 6.0 feet NGVD, based on review of the Aquadilla USGS 7.5 minute quadrangle map, and site water level information. The upstream extent of the river was located at the intersection of State Road 115. The downstream river elevation was assumed to be at zero feet NGVD. Figure 1 shows the model grid and boundaries. The areas shaded in blue represent the constant head boundaries, and the areas shaded in green represent the river cell boundaries. The original groundwater flow model assumed that the upstream elevation of the Rio Culebrinas was 9.0 feet.

The top of the surficial aquifer for the purposes of this model simulation was conservatively assumed to be flat at an assumed model elevation of 4 feet NGVD. The base of the surficial aquifer was assumed to be at -60.0 feet NGVD, based upon site stratigraphic data. The base of the marina basin was assumed to be at an elevation of -15 feet below NGVD. The original groundwater flow model assumed that the base of the surficial aquifer was at an elevation of -100 feet below NGVD, and the base of the marina basin at -12 feet NGVD.

The marina basin was simulated using the Modular Three-Dimensional Finite Difference Groundwater Flow Model (MODFLOW TM) code, developed by McDonald and Harbaugh of the U.S. Geological Survey. The finite-difference approach is block-centered, which means that all data for a particular cell is located within the center of the cell. Layers may be simulated as confined, unconfined, or convertible. Flow associated with external influences such as wells, areal recharge,

evapotranspiration (ET), springs, drains, and streams can also be simulated. The solution technique is by the Conjugate Gradient Procedure. Version 4.0 of Groundwater Vistas was used as a preprocessor to set up to the model and postprocessor to review and map the results. The original model used Version 2.0 of Groundwater Vistas as a preprocessor.

A series of constant head cells were used to simulate the groundwater contribution into the proposed marina basin. The locations of the constant head cells correlate with the footprint as identified from the Road Plan, dated February 16, 2009, prepared by EDSA, Inc., Ft. Lauderdale, Fla. The constant head cells in the proposed marina basin were modeled at an assumed elevation of mean sea level, which should represent average tidal conditions. To provide a conservative estimate of the groundwater influence into the proposed marina basin, the model was conducted using steady-state conditions, without the influence of precipitation or evapotranspiration. The original groundwater flow model used the marina basin footprint as identified from the Conceptual Master Plan, dated March 28, 2005, also prepared by EDSA, Inc. The marina footprint was significantly larger in the 2005 Conceptual Plan.

The barrier wall package of MODFLOW was used to simulate the sea wall. The sea wall is proposed to extend along most of the west side of the proposed marina basin. The sea wall will greatly limit groundwater discharge into the proposed marina basin from the surficial aquifer. The original groundwater flow model did not include the sea wall.

AQUIFER PARAMETERS

Hydraulic conductivity values for the surficial aquifer were based field data collected at the site by HEA representatives. In-situ hydraulic conductivity (permeability) values were obtained for the site by conducting single well aquifer recovery tests (slug tests) at six (6) existing monitoring wells located at the subject site. The monitoring wells were spatially located within the actual area of the proposed marina. The monitoring wells were installed by Advanced Soil Engineering, Inc. of Isabella, P.R. These in-situ hydraulic conductivity values were required to estimate groundwater flow volumes anticipated to discharge into the marina area.

The hydraulic conductivity values derived from the on the in-situ slug tests conducted on the six monitoring wells ranged from approximately 26 to 62 feet per day (ft/d) and averaged approximately 44.5 ft/d. It appears that this average hydraulic conductivity value appears to be representative for the soils comprising the surficial aquifer at the site and was used in the groundwater flow model of the site to estimate groundwater discharge into the marina basin. The average hydraulic conductivity values for both the drawdown and recovery tests were essentially the same and therefore, the average value of 45 ft/d within the surficial aquifer appears reasonable. Some variability of hydraulic conductivity values between the monitoring well locations suggests some heterogeneity within the surficial aquifer at the site. The heterogeneity would be expected in the alluvial deposits comprising the surficial aquifer. The hydraulic conductivity of the surficial aquifer was not modified in the revised model.

The hydraulic conductivity of the San Sebastion Formation (Layer 3) used in the model was also 45 ft/d, which is the same as for the overlying alluvial deposits. The original groundwater flow model assumed a hydraulic conductivity of 100 ft/d for the Aymamon Limestone, which is based on a typical limestone aquifer. However, as discussed previously, the Aymamon Limestone was not encountered in any of the soil borings throughout the site, therefore, the Aymamon Limestone was substituted for the San Sebastion Formation in the groundwater flow model.

RESULTS

The results of the revised groundwater flow modeling indicate that, based on the current configuration, groundwater discharge into the marina basin should be in the range of approximately 0.5 mgd. By reducing the size of the marina basin, adding the sea wall along the west side of the basin, modifying the aquifer parameters, and reducing the initial water level elevations along the model boundaries, the resultant groundwater discharge into the marina basin is substantially less than initially predicted. These revisions contributed to an 80 percent reduction in discharge from the surficial aquifer into the marina basin from the initial groundwater flow modeling. The areas shaded in blue are the locations of the constant head cells which were set to represent the proposed marina basin. Of this 0.5 mgd, approximately 20 percent, or only 97,300 gallons per day, would be in a lateral direction from the vicinity of the Rio Culebrinas. Most of this diversion would occur near the inland extent of the marina basin, where the marina basin is only within 300 feet of the Rio Culebrinas. The addition of approximately 0.5 mgd of freshwater into the marina basin would have no significant impact on the salinity of the estuary.

The U.S Geological Survey maintains a gaging station on the Rio Culebrinas at HWY 404 near Moca, which is several miles upstream of the project area. During the most recent 40 years of record, the mean discharge of the Rio Culebrinas at that location was 486 mgd and the minimum discharge during the same 40 year time period was 93 mgd. Therefore, under the worst case scenario, only 0.001 percent of the total flow of the Rio Culebrinas (0.1 mgd) would be diverted into the marina basin. This diversion would have no significant impact on the salt water wedge associated with the river, or on the migration of native river fauna.

In order to estimate the overall drawdown in the surficial aquifer due to the construction of the marina basin, the pre-development water level elevations were subtracted from the post-development water level elevations. The simulated pre-development water level elevations are presented in Figure 2. Simulated pre-development water level elevations were determined by running the groundwater flow model to steady state without the influence of the proposed marina basin. The simulated pre-development water level elevations compare favorably to the actual water level elevations calculated on May 9, 2007 outside of the area of influence of the sand mine. Figure 1 of the Hydrogeologic Assessment shows the water actual water level elevations for comparison.

Figure 3 shows the simulated post-development water level elevations. Simulated post-development water level elevations were generated by the groundwater model at the end of the steady state simulation with the influence of the proposed marina basin.

Figure 4 shows the drawdown in the surficial aquifer from the proposed marina basin. Figure 4 was calculated as the difference between Figure 2 (pre-development) and Figure 3 (post-development). The one foot drawdown contour within the surficial aquifer, as shown in Figure 4, extends around the perimeter of the marina within 1,500 to 2,000 feet from the edge of the basin. There is no significant drawdown in the lower aquifers due to the thickness of the clay confining layers. Drawdown in the wetlands would be offset by the constant flow of fresh water from the Cano Madre Vieja.

REFERENCES

Advanced Soil Engineering, Inc., 2005. Cordeco Discovery Bay & Marina Soil Boring Logs.

Environmental Simulations, Inc., 1998. Guide to Using Groundwater Vistas.

ESDA, Inc., March 28, 2005. Discovery Bay Resort and Marina, Puerto Rico, Conceptual Master Plan.

ESDA, Inc., February 16, 2009. Road Plan, Discovery Bay Resort and Marina, Puerto Rico.

Hernandez-Virella, A., January 12, 2007. Discovery Bay Conceptual Master Plan.

Hydro-Environmental Associates, Inc., June 20, 2007. Hydrogeologic Assessment of the Proposed Discovery Bay Resort and Marina, Espinar Ward, Aguada, Puerto Rico. Prepared for Mr. Thomas C. Cordero, President, Cordeco Land Services Corp

McDonald, M.G. and A. W. Harbaugh, 1988. A Modular Three-Dimensional Finite Difference Ground-Water Flow Model. Techniques of the United States Geological Survey, Open File Report 83-875.

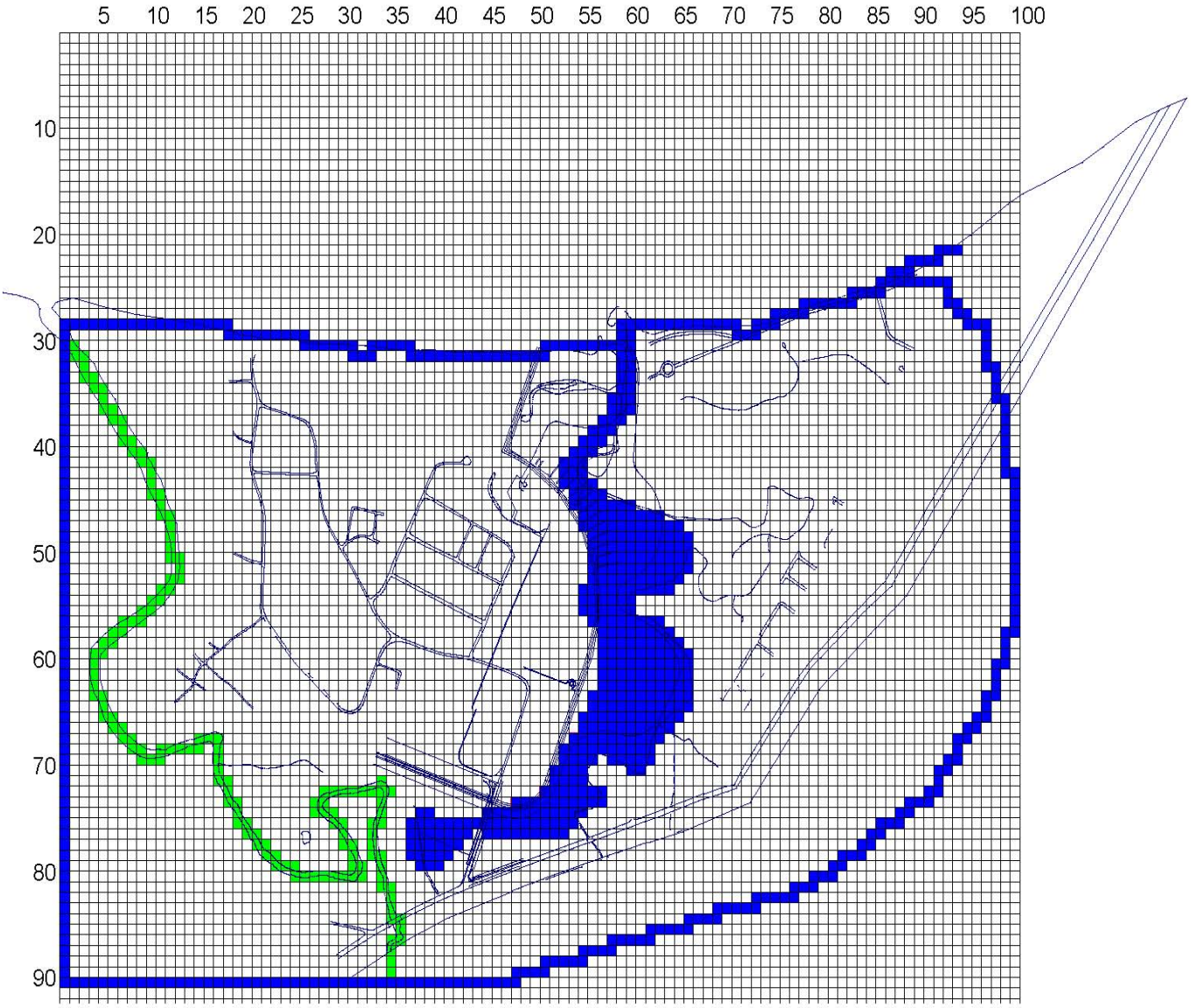
Mitchell, R.C., 1954. A Survey of the Geology of Puerto Rico. University of Puerto Rico. Agricultural Experimental Experiment Station.

Monroe, W. H., 1969. Geologic Quadrangle Maps of the United States, Geology of the Aguadilla Quadrangle, Puerto Rico: U.S. Geological Survey Map Series GQ-191, prepared in cooperation with the Commonwealth of Puerto Rico Economic Development Administration Industrial Research Department.

Torrez-Gonzalez, Arturo and Jose R. Diaz, 1984. Water Resources of the Sabana Seca to Vega Baja Area, Puerto Rico: U.S. Geological Survey Water Resources Investigations Report 82-4115, prepared in cooperation with the Puerto Rico Department of Agriculture.

FIGURES

FIGURE 1



N

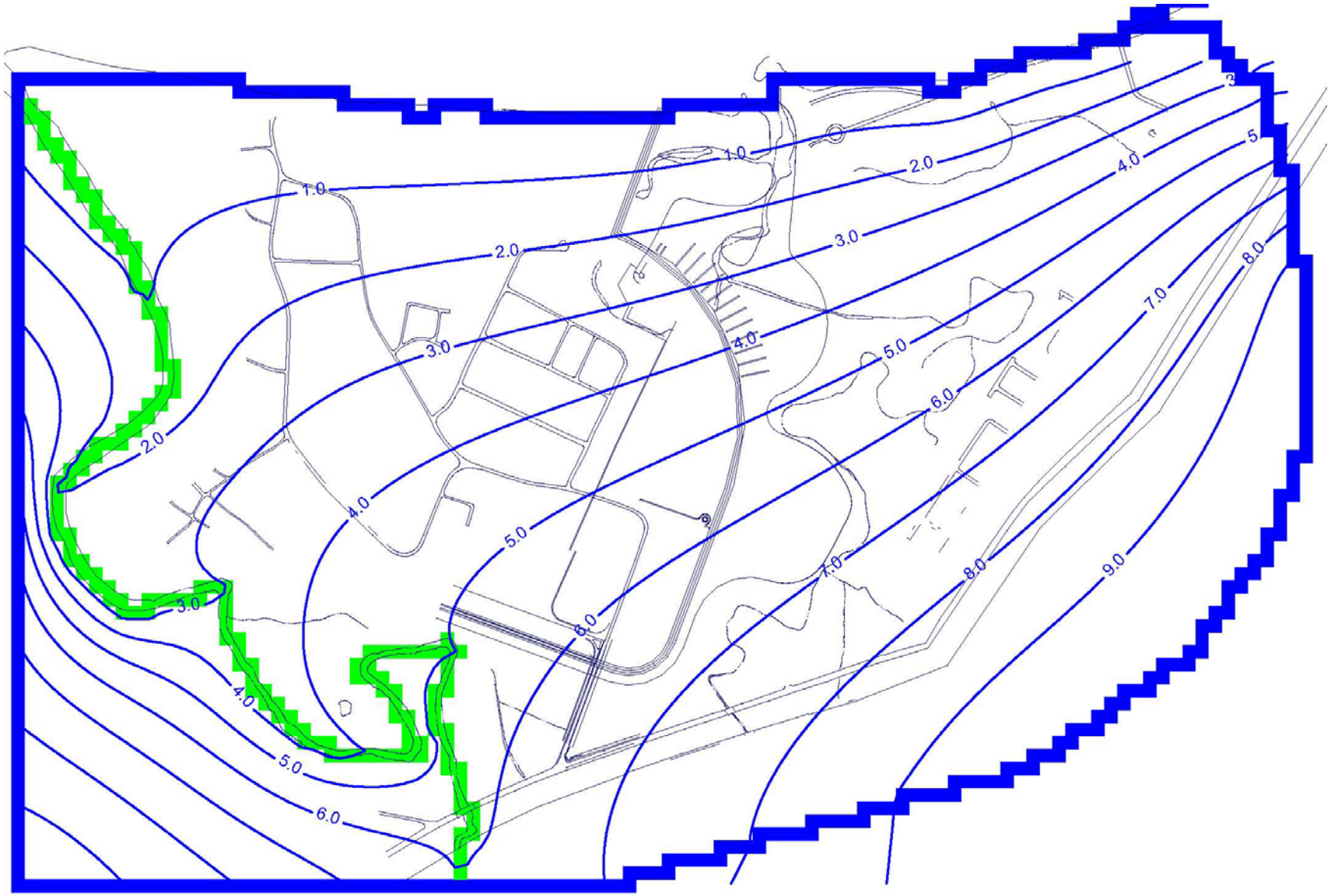
Scale: 1 grid cell = 100 feet

MODEL GRID
DISCOVERY BAY MARINA, AQUADILLA PR

PREPARED FOR:
Cordeco Land Services Corp.

HYDRO-ENVIRONMENTAL ASSOCIATES, INC.
10014 N. Dale Mabry Hwy., #205
Tampa, Florida 33618
(813) 969-6995

FIGURE 2

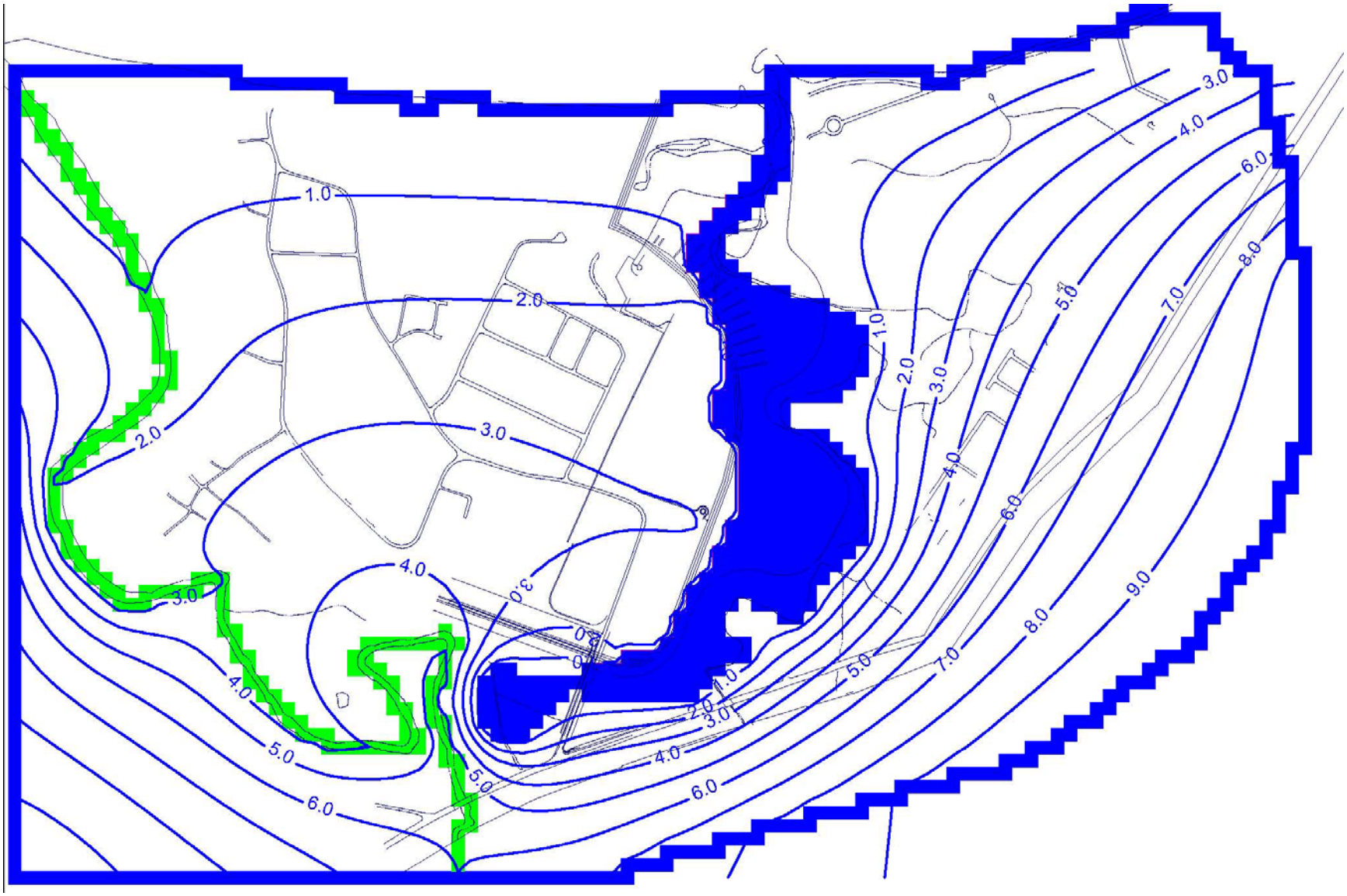


SIMULATED WATER LEVEL ELEVATIONS IN SURFICIAL AQUIFER WITHOUT MARINA
DISCOVERY BAY MARINA, AQUADILLA, P.R.
Scale: 1 inch = 1,000 feet

PREPARED FOR: Cordeco Land Services Corp.

HYDRO-ENVIRONMENTAL ASSOCIATES, INC.
10014 N. Dale Mabry Hwy.
Suite #205
Tampa, Florida 33618
(813) 969-6995

FIGURE 3

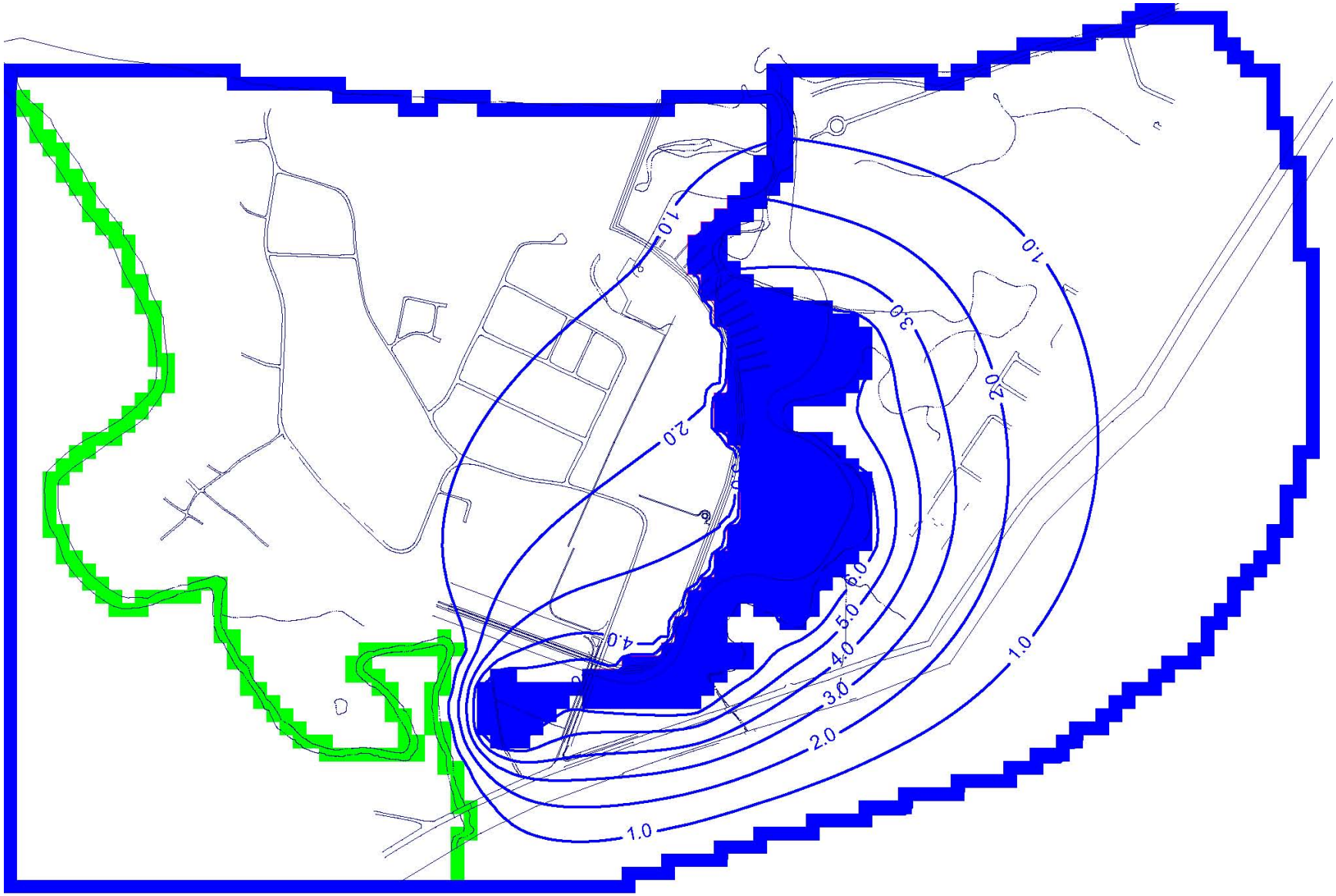


SIMULATED WATER LEVEL ELEVATIONS IN SURFICIAL AQUIFER WITH MARINA
DISCOVERY BAY MARINA, AQUADILLA, P.R.
Scale: 1 inch = 1,000 feet

PREPARED FOR: Cordeco Land Services Corp.

HYDRO-ENVIRONMENTAL ASSOCIATES, INC.
10014 N. Dale Mabry Hwy
Suite 205
Tampa, Florida 33618
(813) 969-6995

FIGURE 4



SIMULATED DRAWDOWN IN SURFICIAL AQUIFER
DISCOVERY BAY MARINA, AQUADILLA, P.R.
Scale: 1 inch = 1,000 feet

PREPARED FOR: Cordeco Land Services Corp.

HYDRO-ENVIRONMENTAL ASSOCIATES, INC.
10014 N. Dale Mabry Hwy.
Suite #205
Tampa, Florida 33618
(813) 969-6995

APPENDIX A

Technical Memorandum

Summary of Discovery Bay Marina Groundwater Flow Analysis

June 1, 2005

HYDRO-ENVIRONMENTAL ASSOCIATES, INC.

Hydrogeologic & Environmental Consulting

TECHNICAL MEMORANDUM

Date: June 1, 2005

To: Mr. Mark Pirrello, P.E.,
Moffatt & Nichol Engineers, Inc.

From: Kenneth C. Jones, P.G. KCJ
(813) 969-6995, Fax: (813) 969-6988

Re: **Summary of Discovery Bay Marina Groundwater Flow Analysis**
Bahia de Aguadilla, Puerto Rico

INTRODUCTION

Hydro-Environmental Associates, Inc. (HEA) was retained by Cordeco Northwest Corporation (Cordeco) to conduct a groundwater flow analysis of a proposed inland marina at the above-referenced site. This Technical Memorandum and accompanying attachments complete the requirements of the Scope of Services for the project.

Moffatt & Nichol Engineers, Inc. is currently implementing a study to evaluate the potential development of the subject site as a residential complex that includes a 500-slip inland marina. The proposed marina will require the excavation of surface soils to an estimated depth of approximately 15-feet below existing ground surface. The surface soils excavated are anticipated to be used as fill material for the residential development and proposed levees. Portions of the subject site and proposed basin area are currently being used as an active sand mine. The subject site is located on the northwest coast of the island of Puerto Rico.

In order for the marina to sustain a healthy aquatic environment, proper water circulation and tidal flushing is required. Due to limitations in the shape of the property, the proposed marina configuration may possibly limit the natural circulation and flushing of seawater. Based upon site observations made during dewatering of the sand mine, it is apparent that a significant component of marina water circulation may be obtained from groundwater flow discharging from the shallow aquifer within the groundwater basin of the proposed marina. The Scope of Service for this project included a preliminary evaluation of the possible ranges of flow within the surficial aquifer based upon regional soil characteristics, followed by a field investigation to determine the hydraulic conductivity of the surficial aquifer within the basin area, and groundwater flow modeling to more accurately evaluate the rate and volume of groundwater flow contribution to the proposed marina basin. The preliminary evaluation was previously

• 10014 N. Dale Mabry Highway, Suite 205, Tampa, Florida 33618 •
• (813) 969-6995 • FAX (813) 969-6988 •

addressed.

SITE GEOLOGY AND HYDROGEOLOGY

The subject site lies within the alluvial deposits immediately north of the Rio Culebrinas, west of the Cordillera Jaicoa, and east of the Atlantic Ocean. The Rio Culebrinas flows in a general westerly direction, bisecting the Cordillera Jaicoa, and discharging into the Atlantic Ocean. The subject site is within the flood plain of the Rio Culebrinas. The Cordillera Jaicoa is incised by the Rio Culebrinas, and becomes highly eroded along the south side of the incision. Geographic features in the vicinity of the subject site consist of coastal beach deposits, alluvial sediment, and karst uplands. This area is specifically detailed on the Geologic Map of the Aguadilla Quadrangle.

The coastal beach deposits form an almost continuous north-south trending ridge between Tamarindo on the north to Rincon on the south. This ridge is roughly sub-parallel to the coastal shoreline and terminates approximately 400 feet inland from the coast. The subject site is relatively flat at an average elevation of approximately 10 feet above mean sea level (MSL).

The surficial aquifer in the area of the site is typically composed of stratified layers of alluvial quartz sand and shell of quaternary age, with minor amounts of silt and clay. Based on our review of on-site lithologic data, the surficial aquifer is estimated to be approximately 120 feet in thickness.

Underlying the surficial aquifer is the Aymamon Limestone. Based upon our review of available geologic information in the area of the site, the Aymamon Limestone is typically composed of a pale orange to white fossiliferous, permeable limestone. The Aymamon Limestone is of Miocene age and directly underlies the alluvial sands. The Aymamon Limestone is approximately 600 feet in thickness in the vicinity of the subject site. The Aymamon Limestone is underlain by the Aguada Limestone, also of Miocene age. The Aguada Limestone consists of a hard calcarenite alternating with chalky and rubbly limestone.

MODEL CONFIGURATION AND SETUP

The marina basin was simulated using the Modular Three-Dimensional Finite Difference Groundwater Flow Model (MODFLOW ™) code, developed by McDonald and Harbaugh of the U.S. Geological Survey. The finite-difference approach is block-centered, which means that all data for a particular cell is located within the center of the cell. Layers may be simulated as confined, unconfined, or convertible. Flow associated with external influences such as wells, aerial recharge, evapotranspiration (ET), springs, drains, and rivers can also be simulated. The solution technique is by the Conjugate Gradient Procedure. Version 2.0 of Groundwater Vistas was used as a preprocessor to set up to the model and postprocessor to review and map the

results.

A series of constant head cells were used to simulate the proposed marina basin. The constant head cells in the proposed marina basin were modeled at an assumed elevation of mean sea level, which should represent average tidal conditions. To provide a conservative estimate of the groundwater influence into the proposed marina basin, the model was conducted using steady-state conditions, without the influence of precipitation or evapotranspiration.

The site, as modeled, consists of the proposed marina basin configuration as presented on the Conceptual Master Plan, dated March 28, 2005, as prepared by EDSA, Inc., Ft. Lauderdale Fla. Figure 1 presents the extent of the modeled area. The areas shaded in blue, shown on Figure 1, represent the constant head cell simulating the area of the proposed marina basin. The model was set up as a three layer hydrogeologic system, with the upper two layers representing the surficial aquifer, and the third layer representing the underlying Aymamon Limestone Aquifer. The surficial aquifer was divided into two layers to simulate the effects of the proposed marina basin. The bottom elevation of layer one was set to an elevation of -12 feet below MSL, which is the proposed bottom elevation of the marina basin.

Each model layer was discretized into 10,000 cells, 100-foot by 100-foot in size (100 rows by 100 columns). Constant head boundaries were used to define the Atlantic Ocean and the Cordillera Jaicoa outcroppings. The model elevation of the constant head boundary representing the Atlantic Ocean was assumed to be at MSL. The constant head boundary cells representing the face of the Cordillera Jaicoa to the north of the Rio Culebrinas was estimated to at an elevation of 15 feet above MSL, based upon a review of the Aguadilla USGS 7.5- minute quadrangle map. For modeling purposes, the constant head boundaries representing the face of Cordillera Jaicoa south of the Rio Culebrinas was varied linearly from a maximum of 15 feet to zero feet NGVD, based upon the general topography of the area.

The MODFLOW river package was used to simulate the Rio Culebrinas. The upstream elevation of the Rio Culebrinas was estimated to be 9.0 feet above MSL, based on review of the Aguadilla USGS 7.5-minute quadrangle map. The upstream extent of the river was located at the intersection of State Road 115. The downstream river elevation was assumed to be at MSL. Figure 1 also shows the model grid and boundaries. The areas shaded in blue represent the constant head boundaries, and the areas shaded in green represent the river cell boundaries.

The top of the surficial aquifer for the purposes of this model simulation was conservatively assumed to be flat at an assumed model elevation of 4 feet above MSL. The base of the surficial aquifer was assumed to be at -100.0 feet MSL. The base of the marina basin, as discussed above, was assumed to be at an elevation of -12 feet MSL.

AQUIFER PARAMETERS

Hydraulic conductivity (permeability) values for the surficial aquifer were based field data collected at the site by HEA representatives. In-situ hydraulic conductivity values were obtained for the site by conducting single well aquifer recovery tests (slug tests) at six (6) existing monitoring wells located at the subject site. The monitoring wells were spatially located within the actual area of the proposed marina. The monitoring wells were installed by Advanced Soil Engineering, Inc. of Isabella, P.R. These in-situ hydraulic conductivity values were required to estimate groundwater flow volumes anticipated to discharge into the marina area.

Based upon information provided by the client, as well as measurements obtained in the field, the monitoring wells were constructed using ten feet of two-inch diameter, schedule 40 PVC machine slotted wellscreen (0.010-inch slot size), and solid two-inch diameter PVC riser pipe. The monitoring wells were installed to depths ranging from 18.7 to 19.5 feet, below ground surface using the hollow-stem auger method conducted in general accordance with ASTM D1452-80 procedures.

The shallow monitoring wells were installed through the center of the hollow-stem augers and positioned at the appropriate depths. The annular space outside the well screen was filled with a natural formation sand to act as a filter pack around the slotted wellscreen portions of the well. A bentonite seal was placed above the filter pack. The remaining annular space was grouted with a cement slurry to the approximate ground surface.

Static water level depths ranged from approximately 1.89 feet, bgs in monitoring well P-1 to as much as 7.10 feet, bgs in monitoring well P-5. Monitoring well P-1 was located in the northern portion of the site near the coast, and monitoring well P-5 was located in the higher elevations of the southern portion of the site. As shown on Table 1, the saturated lengths of the wells ranged from 11.1 to 16.8 feet.

The hydraulic conductivity values were calculated from the slug tests based on the assumptions and well geometry presented by Bouwer and Rice (1976). The slug tests were performed by inserting a solid PVC and cement filled cylinder with a volume equivalent to an approximate 4.5-foot change in water level in a two-inch diameter monitoring well (1.92-inches in diameter by 4.84 feet in length). When the water level had returned to equilibrium, the cylinder was quickly removed and the water levels were allowed to return to equilibrium.

Both recovery and drawdown data were obtained using an electronic water level datalogger, manufactured by Solinst Canada Ltd, Georgetown, Ontario, Canada. The datalogger used for the slug test was the Model 3001 Levelogger®. The Model 3001 Levelogger® is approximately 7/8-inches in diameter and 4.9 inches in length with an accuracy of 0.1%. Prior to conducting the slug test, the Levelogger® was lowered to the bottom of the well and measurements were

made to ensure that the depth to groundwater had stabilized and reached equilibrium before conducting the slug test. During each of the tests, the water level datalogger recorded the depth to water to the nearest 0.01 foot at a linear measurement frequency of one reading per second. This method of collecting both drawdown and recovery data was performed since it typically provides a more accurate and reliable value of in-situ permeability.

The single well aquifer slug tests were performed on April 21, 2005 by Mr. Kenneth C. Jones, P.G., of HEA. The data collected from the slug tests were used to calculate horizontal hydraulic conductivity values in the surficial aquifer at the site. The results of these slug tests are included in Appendix A and are summarized on the enclosed Table 1. A total of 12 in-situ hydraulic conductivity tests were performed at the site, including six slug-in tests and six slug-out tests. However, two of the recovery tests for monitoring wells P-5 and P-6 were not analyzed due to disturbance of the Levelogger® during the removal of the slug from the well.

The hydraulic conductivity values derived from the on the in-situ slug tests conducted on the six monitoring wells ranged from approximately 26 to 62 feet per day (ft/d) and averaged approximately 45 ft/d. This average hydraulic conductivity value appears to be representative for the soils comprising the surficial aquifer at the site and was used in the groundwater flow model of the site to estimate groundwater discharge into the marina basin. The average hydraulic conductivity values for both the drawdown and recovery tests were essentially the same and therefore, the average value of 45 ft/d within the surficial aquifer appears reasonable. Some variability of hydraulic conductivity values between the monitoring well locations suggests some heterogeneity within the surficial aquifer at the site. The heterogeneity would be expected in the alluvial deposits comprising the surficial aquifer.

It should be noted that due to the remote nature of the site, the monitoring wells could not be developed prior to conducting the hydraulic conductivity tests and some fine sediment was noted at the bottom of the wells. It is felt that the fine sediment may have biased the test results somewhat, and that the actual value of hydraulic conductivity may be slightly higher than the values reported. Therefore, the average hydraulic conductivity value of 45 ft/d used in the groundwater flow model is likely conservative. However, the values for hydraulic conductivity should be viewed as an approximation since the slug tests provide hydraulic conductivity values for the materials immediately adjacent to the tested well screen.

The hydraulic conductivity of the Aymamon Limestone used in the model was 100 ft/d, which is typical for a limestone aquifer.

RESULTS

The results of this simulation indicate that the average rate of total groundwater inflow into the proposed marina basin is approximately 2.44 million gallons per day (MGD), while maintaining the water level in the marina basin at mean sea level. Based upon a meeting with representatives

of Moffatt & Nichol Engineers, Inc. on May 12, 2005, the marina basin was divided into 20 separate zones. The groundwater flow contribution into the marina basin was calculated from each of the cells from within these 20 zones. The groundwater flow contribution from the 20 zones were to be used as input into the overall circulation analysis of the marina basin. Based upon review of the data, approximately 22 percent of the groundwater flow is in a lateral direction from the vicinity of the Rio Culebrinas, approximately 36 percent of the flow is in a lateral direction from the north originating from the Cordillera Jaicoa, approximately 9 percent of the flow is lateral from the south, and approximately 33 percent represents upward groundwater flow from the base of the surficial aquifer. Figure 2 shows the water level contours generated at the end of the simulation.

REFERENCES

Environmental Simulations, Inc., 1998. Guide to Using Groundwater Vistas.

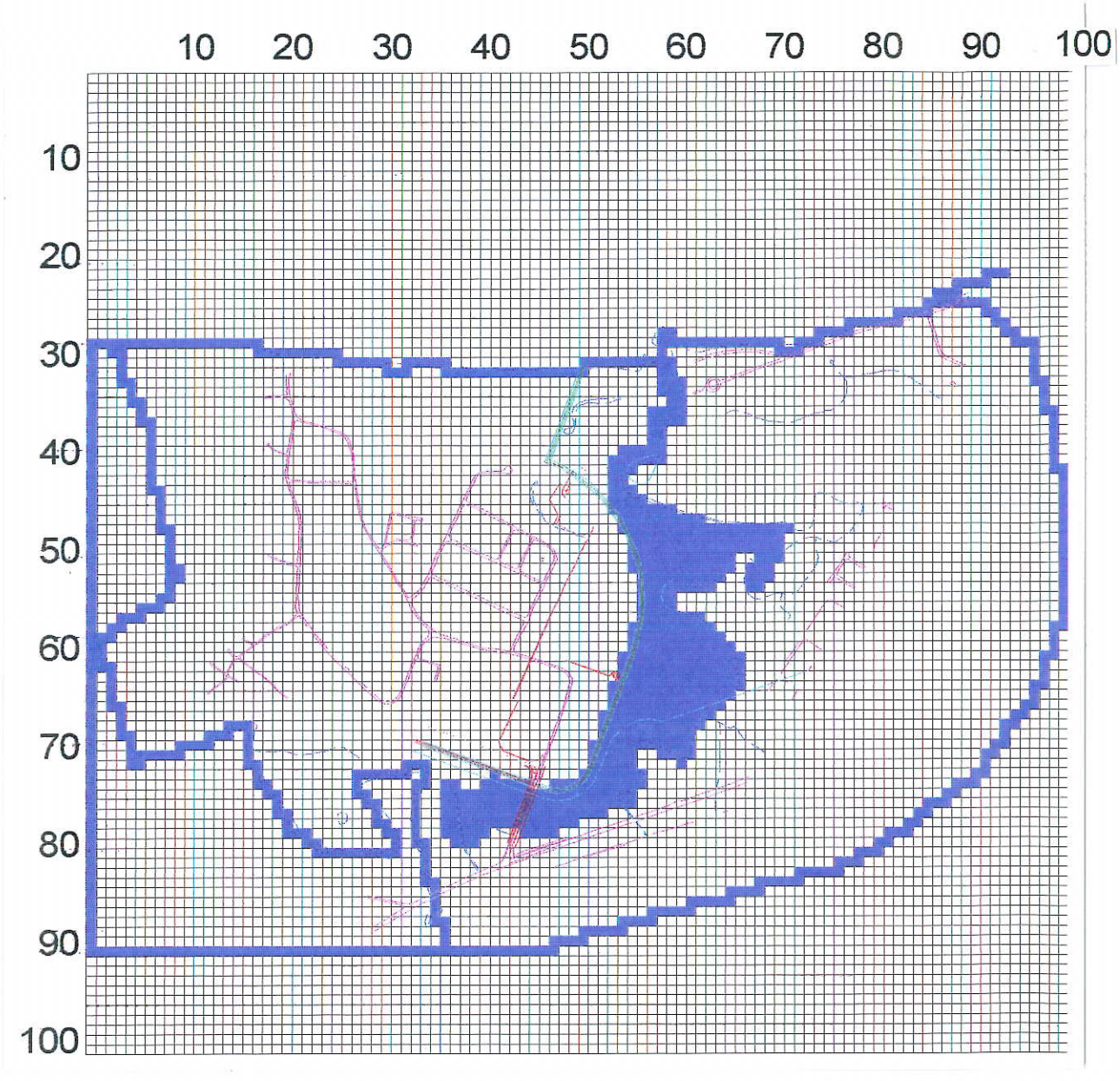
McDonald, M.G. and A. W. Harbaugh, 1988. A Modular Three-Dimensional Finite Difference Ground-Water Flow Model. Techniques of the United States Geological Survey, Open File Report 83-875.

Monroe, W. H., 1969. Geologic Map of the Aguadilla Quadrangle, Puerto Rico. Unites States Geological Survey, Miscellaneous Geologic Investigations MAP I-569.

ESDA, 2005. Discovery Bay Resort and Marina, Puerto Rico, Conceptual Master Plan.

Mitchell, R.C., 1954. A Survey of the Geology of Puerto Rico. University of Puerto Rico Agricultural Experimental Experiment Station.

Advanced Soil Engineering, Inc., 2005. Cordeco Discovery Bay & Marina Soil Boring Logs.



Base Map: As provided by AHV Asociados, Aguada, Puerto Rico **Scale: N.T.S.**

FIGURE 1

MODEL AREA AND FINITE DIFFERENCE GRID
DISCOVERY BAY RESORT AND MARINA
AGUADILLA, PUERTO RICO

HYDRO-ENVIRONMENTAL ASSOCIATES, INC.
10014 N. Dale Mabry Hwy., #205
Tampa, Florida 33618
(813) 969-6995

Base Map: As provided by AHV Asociados, Aguada, Puerto Rico

Scale: N.T.S.

FIGURE 2

RESULTS OF GROUNDWATER FLOW MODEL
DISCOVERY BAY RESORT AND MARINA
AGUADILLA, PUERTO RICO

HYDRO-ENVIRONMENTAL ASSOCIATES, INC.
10014 N. Dale Mabry Hwy., #205
Tampa, Florida 33618
(813) 969-6995