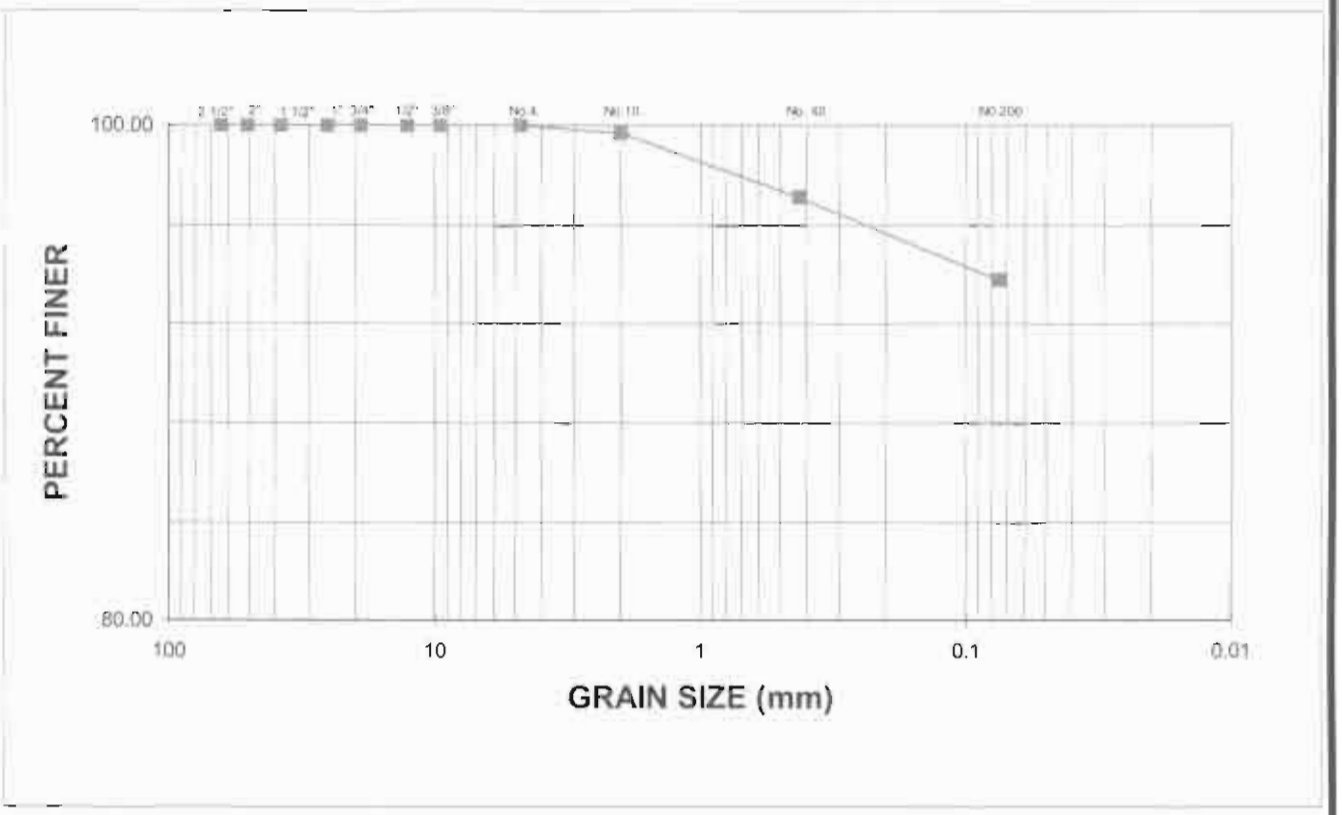
ADVANCED SOIL ENGINEERING
GEOTECHNICAL CONSULTING ENGINEERS
CONCRETE AND MATERIAL TESTING LABORATORIES

P.O. BOX 1286
ISABELA, P.R. 00662

TEL / FAX: (787) 830 - 0366

# GRAIN SIZE DISTRIBUTION TEST REPORT




| % + 75 mm | % GRAVEL | % SAND | % SILT | % CLAY |
|---|---|---|---|---|
| 0.00 | 0.00 | 6.24 | 93.76 | |

| LL | PI | D85 | D60 | D50 | D30 | D15 | D10 | Cc | Cu |
|---|---|---|---|---|---|---|---|---|---|
| 55.3 | 30.5 | | | | | | | | |

| MATERIAL DESCRIPTION | USCS | AASHTO |
|---|---|---|
| Yellowish brown and bluish gray organic clay trace sand | OH | A-7-6 (32) |

Client : Cordeco Northwest, Corp.
Project : Discovery Bay Resort and Marina, Aguada, PR
Location : Boring No.8 (8' - 18')

Remarks :

Tested by : Eduardo Rodriguez
Checked by : Nelson Muñoz, P.E.

Figure No. : 1
Date : July 31, 2007

ASE

# ADVANCED SOIL ENGINEERING

GEOTECHNICAL CONSULTING ENGINEERS
CONCRETE AND MATERIAL TESTING LABORATORIES

P.O. BOX 1286
ISABELA, P.R. 00662

TEL / FAX : (787) 830 - 0366

## GRAIN SIZE DISTRIBUTION TEST DATA

Date : July 31, 2007
Client : Cordeco Northwest, Corp.
Project : Discovery Bay Resort and Marina, Aguada, PR

## SAMPLE DATA

Location of sample : Boring No.9 (48' - 70')
Sample description : Gray and bluish gray organic clay some sand
USCS Class : OL  Liquid Limit : 48.9
AASHTO Class : A-7-6 (22)  Plasticity Index : 23.7

## NOTES

Remaks : Tested by : Eduardo Rodriguez
Checked by : Nelson Muñoz, P.E.
Fig. No. : 1

## MECHANICAL ANALYSIS DATA

| | | Initial | After wash |
|---|---|---|---|
| Dry sample and tare | = | 271.00 | 40.90 |
| Tare | = | 0.00 | 0.00 |
| Dry sample weight | = | 271.00 | 40.90 |
| Minus # 200 from wash | = | 84.91 % | |

Sieve tare method :

| Sieve No. | Weight Soil retained | Percent Retained | Combined % Retained | Percent finer |
|---|---|---|---|---|
| 2 1/2" | 0.00 | 0.00 | 0.00 | 100.00 |
| 2" | 0.00 | 0.00 | 0.00 | 100.00 |
| 1 1/2" | 0.00 | 0.00 | 0.00 | 100.00 |
| 1" | 0.00 | 0.00 | 0.00 | 100.00 |
| 3/4" | 0.00 | 0.00 | 0.00 | 100.00 |
| 1/2" | 0.00 | 0.00 | 0.00 | 100.00 |
| 3/8" | 0.00 | 0.00 | 0.00 | 100.00 |
| No. 4 | 1.30 | 0.48 | 0.48 | 99.52 |
| No. 10 | 4.30 | 1.59 | 2.07 | 97.93 |
| No. 40 | 13.10 | 4.83 | 6.90 | 93.10 |
| No. 200 | 22.20 | 8.19 | 15.09 | 84.91 |

## FRACTIONAL COMPONENTS

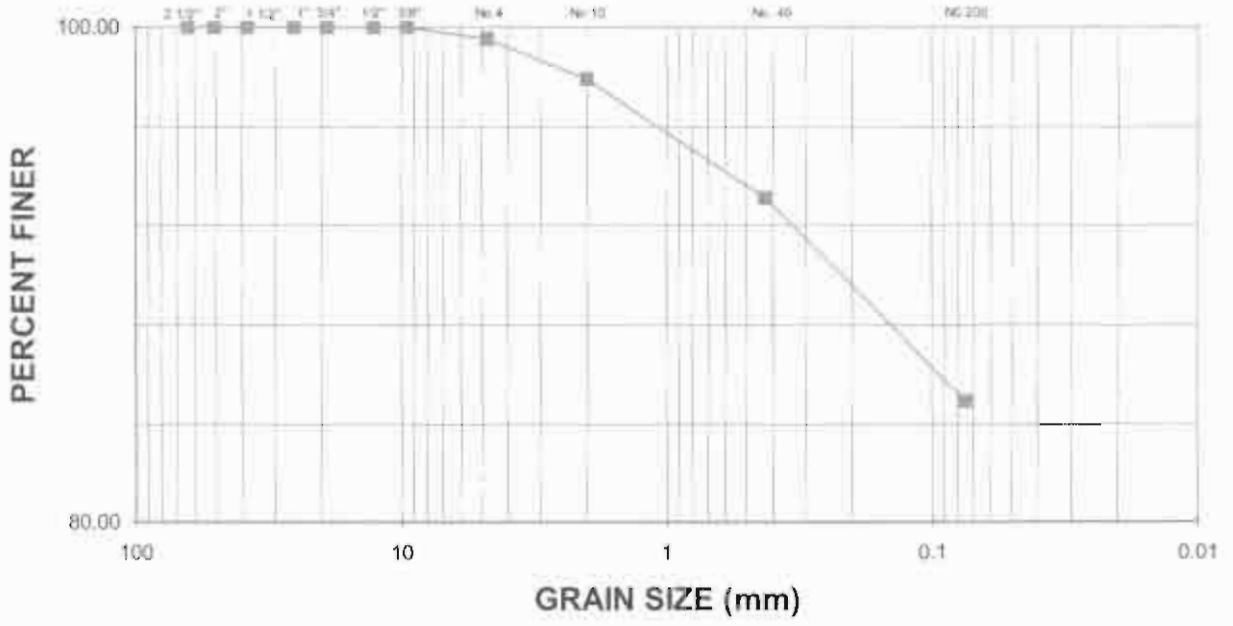
% + 75 mm 0.00  % Gravel = 0.48  % Sand = 14.61  % Finer = 84.91

ADVANCED SOIL ENGINEERING
GEOTECHNICAL CONSULTING ENGINEERS
CONCRETE AND MATERIAL TESTING LABORATORIES

P.O. BOX 1286
ISABELA, P.R. 00662

TEL / FAX: (787) 830 - 0366

# GRAIN SIZE DISTRIBUTION TEST REPORT




| % + 75 mm | % GRAVEL | % SAND | % SILT | % CLAY |
|---|---|---|---|---|
| 0.00 | 0.48 | 14.61 | 84.91 | |

| LL | PI | D85 | D60 | D50 | D30 | D15 | D10 | Cc | Cu |
|---|---|---|---|---|---|---|---|---|---|
| 48.9 | 23.7 | 0.08 | | | | | | | |

| MATERIAL DESCRIPTION | USCS | AASHTO |
|---|---|---|
| Gray and bluish gray organic clay some sand | OL | A-7-6 (22) |

Client : Cordeco Northwest, Corp.
Project : Discovery Bay Resort and Marina, Aguada, PR
Location : Boring No.9 (48' - 70')

Remarks :

Tested by : Eduardo Rodriguez
Checked by : Nelson Muñoz, P.E.

Figure No. : 1
Date : July 31, 2007

ASE

# ADVANCED SOIL ENGINEERING

GEOTECHNICAL CONSULTING ENGINEERS
CONCRETE AND MATERIAL TESTING LABORATORIES

P.O. BOX 1286
ISABELA, P.R. 00662

TEL / FAX : (787) 830 - 0366

## GRAIN SIZE DISTRIBUTION TEST DATA

Date : July 31, 2007
Client : Cordeco Northwest, Corp.
Project : Discovery Bay Resort and Marina, Aguada, PR

## SAMPLE DATA

Location of sample : Boring No.9 (78' - 100')
Sample description : Yellowish brown and light gray sand with silt
USCS Class : SM  Liquid Limit : N.L.
AASHTO Class : A-4  Plasticity Index : N.P.

## NOTES

Remaks : Tested by : Eduardo Rodriguez
Checked by : Nelson Muñoz, P.E.
Fig. No. : 1

## MECHANICAL ANALYSIS DATA

| | | Initial | After wash |
|---|---|---|---|
| Dry sample and tare | = | 341.60 | 199.10 |
| Tare | = | 0.00 | 0.00 |
| Dry sample weight | = | 341.60 | 199.10 |
| Minus # 200 from wash | = | 41.72 % | |

Sieve tare method :

| Sieve No. | Weight Soil retained | Percent Retained | Combined % Retained | Percent finer |
|---|---|---|---|---|
| 2 1/2" | 0.00 | 0.00 | 0.00 | 100.00 |
| 2" | 0.00 | 0.00 | 0.00 | 100.00 |
| 1 1/2" | 0.00 | 0.00 | 0.00 | 100.00 |
| 1" | 0.00 | 0.00 | 0.00 | 100.00 |
| 3/4" | 0.00 | 0.00 | 0.00 | 100.00 |
| 1/2" | 0.00 | 0.00 | 0.00 | 100.00 |
| 3/8" | 0.00 | 0.00 | 0.00 | 100.00 |
| No. 4 | 0.30 | 0.09 | 0.09 | 99.91 |
| No. 10 | 3.30 | 0.97 | 1.05 | 98.95 |
| No. 40 | 33.00 | 9.66 | 10.71 | 89.29 |
| No. 200 | 162.50 | 47.57 | 58.28 | 41.72 |

## FRACTIONAL COMPONENTS

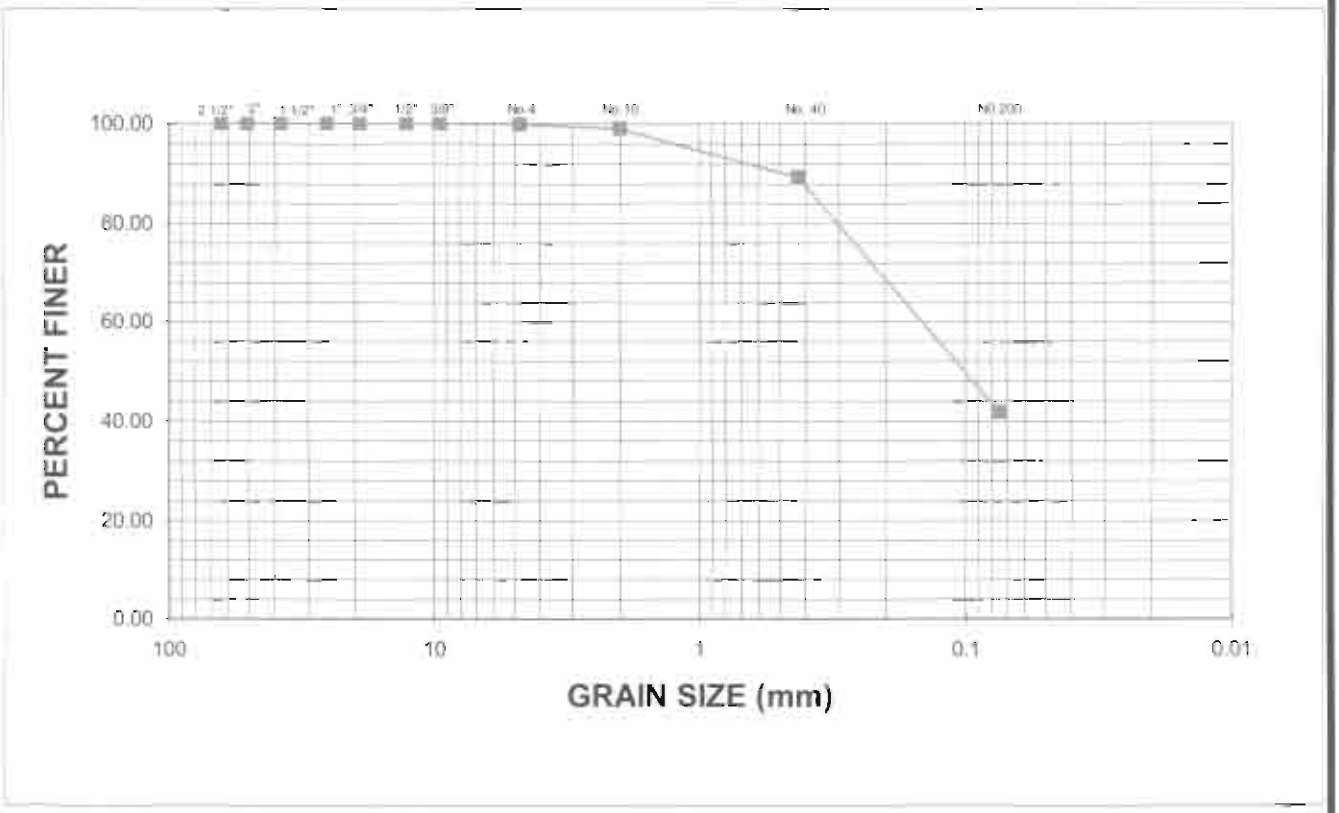
% + 75 mm 0.00  % Gravel = 0.09  % Sand = 58.20  % Finer = 41.72

ADVANCED SOIL ENGINEERING
GEOTECHNICAL CONSULTING ENGINEERS
CONCRETE AND MATERIAL TESTING LABORATORIES

P.O. BOX 1286
ISABELA, P.R. 00662

TEL / FAX: (787) 830 - 0366

# GRAIN SIZE DISTRIBUTION TEST REPORT




| % + 75 mm | % GRAVEL | % SAND | % SILT | % CLAY |
|---|---|---|---|---|
| 0.00 | 0.09 | 58.20 | 41.72 | |

| LL | PI | D85 | D60 | D50 | D30 | D15 | D10 | Cc | Cu |
|---|---|---|---|---|---|---|---|---|---|
| N.L. | N.P. | 0.36 | 0.15 | 0.10 | | | | | |

| MATERIAL DESCRIPTION | USCS | AASHTO |
|---|---|---|
| Yellowish brown and light gray sand with silt | SM | A-4 |

Client : Cordeco Northwest, Corp.
Project : Discovery Bay Resort and Marina, Aguada, PR
Location : Boring No.9 (78' - 100')

Remarks :

Tested by : Eduardo Rodriguez
Checked by : Nelson Muñoz, P.E.

Figure No. : 1
Date : July 31, 2007

ASE

# ADVANCED SOIL ENGINEERING

GEOTECHNICAL CONSULTING ENGINEERS
CONCRETE AND MATERIAL TESTING LABORATORIES

P.O. BOX 1286
ISABELA, P.R. 00662

TEL / FAX : (787) 830 - 0366

## GRAIN SIZE DISTRIBUTION TEST DATA

Date : July 31, 2007
Client : Cordeco Northwest, Corp.
Project : Discovery Bay Resort and Marina, Aguada, PR

## SAMPLE DATA

Location of sample : Boring No.10 (53' - 75')
Sample description : Grayish brown clay some sand
USCS Class : CL Liquid Limit : 47.6
AASHTO Class : A-7-5 (21) Plasticity Index : 23.4

## NOTES

Remaks : Tested by : Eduardo Rodriguez
Checked by : Nelson Muñoz, P.E.
Fig. No. : 1

## MECHANICAL ANALYSIS DATA

| | | Initial | After wash |
|---|---|---|---|
| Dry sample and tare | = | 569.70 | 92.90 |
| Tare | = | 0.00 | 0.00 |
| Dry sample weight | = | 569.70 | 92.90 |
| Minus # 200 from wash | = | 83.69 % | |

Sieve tare method :

| Sieve No. | Weight Soil retained | Percent Retained | Combined % Retained | Percent finer |
|---|---|---|---|---|
| 2 1/2" | 0.00 | 0.00 | 0.00 | 100.00 |
| 2" | 0.00 | 0.00 | 0.00 | 100.00 |
| 1 1/2" | 0.00 | 0.00 | 0.00 | 100.00 |
| 1" | 0.00 | 0.00 | 0.00 | 100.00 |
| 3/4" | 0.00 | 0.00 | 0.00 | 100.00 |
| 1/2" | 0.00 | 0.00 | 0.00 | 100.00 |
| 3/8" | 0.00 | 0.00 | 0.00 | 100.00 |
| No. 4 | 5.30 | 0.93 | 0.93 | 99.07 |
| No. 10 | 8.50 | 1.49 | 2.42 | 97.58 |
| No. 40 | 17.70 | 3.11 | 5.53 | 94.47 |
| No. 200 | 61.40 | 10.78 | 16.31 | 83.69 |

## FRACTIONAL COMPONENTS

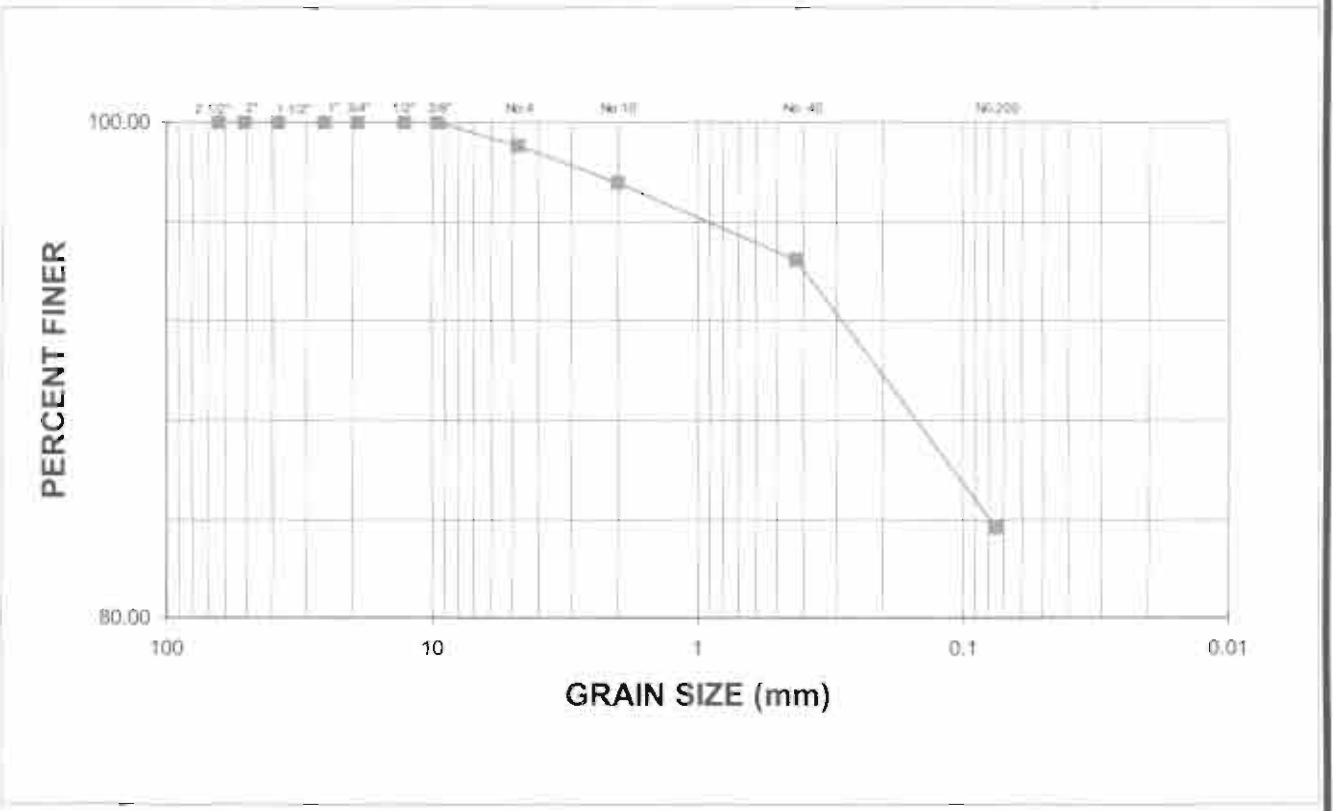
% + 75 mm 0.00 % Gravel = 0.93 % Sand = 15.38 % Finer = 83.69

ADVANCED SOIL ENGINEERING
GEOTECHNICAL CONSULTING ENGINEERS
CONCRETE AND MATERIAL TESTING LABORATORIES

P.O. BOX 1286
ISABELA, P.R. 00662

TEL / FAX: (787) 830 - 0366

# GRAIN SIZE DISTRIBUTION TEST REPORT




| % + 75 mm | % GRAVEL | % SAND | % SILT | % CLAY |
|---|---|---|---|---|
| 0.00 | 0.93 | 15.38 | 83.69 | |

| LL | PI | D85 | D60 | D50 | D30 | D15 | D10 | Cc | Cu |
|---|---|---|---|---|---|---|---|---|---|
| 47.6 | 23.4 | 0.09 | | | | | | | |

| MATERIAL DESCRIPTION | USCS | AASHTO |
|---|---|---|
| Grayish brown clay some sand | CL | A-7-5 (21) |

Client : Cordeco Northwest, Corp.
Project : Discovery Bay Resort and Marina, Aguada, PR
Location : Boring No.10 (53' - 75')

Remarks :

| | | | | | |
|---|---|---|---|---|---|
| Tested by | : | Eduardo Rodriguez | Figure No. | : | 1 |
| Checked by | : | Nelson Muñoz, P.E. | Date | : | July 31, 2007 |

ASE

# ADVANCED SOIL ENGINEERING

GEOTECHNICAL CONSULTING ENGINEERS
CONCRETE AND MATERIAL TESTING LABORATORIES

P.O. BOX 1286
ISABELA, P.R. 00662

TEL / FAX : (787) 830 - 0366

## GRAIN SIZE DISTRIBUTION TEST DATA

Date : July 31, 2007
Client : Cordeco Northwest, Corp.
Project : Discovery Bay Resort and Marina, Aguada, PR

## SAMPLE DATA

Location of sample : Boring No.11 (28' - 40')
Sample description : Light brown and gray silty clay trace sand
USCS Class : CH Liquid Limit : 60.5
AASHTO Class : A-7-5 (37) Plasticity Index : 35.0

## NOTES

Remaks : Tested by : Eduardo Rodriguez
Checked by : Nelson Muñoz, P.E.
Fig. No. : 1

## MECHANICAL ANALYSIS DATA

| | | Initial | After wash |
|---|---|---|---|
| Dry sample and tare | = | 340.20 | 25.10 |
| Tare | = | 0.00 | 0.00 |
| Dry sample weight | = | 340.20 | 25.10 |
| Minus # 200 from wash | = | 92.62 % | |

Sieve tare method :

| Sieve No. | Weight Soil retained | Percent Retained | Combined % Retained | Percent finer |
|---|---|---|---|---|
| 2 1/2" | 0.00 | 0.00 | 0.00 | 100.00 |
| 2" | 0.00 | 0.00 | 0.00 | 100.00 |
| 1 1/2" | 0.00 | 0.00 | 0.00 | 100.00 |
| 1" | 0.00 | 0.00 | 0.00 | 100.00 |
| 3/4" | 0.00 | 0.00 | 0.00 | 100.00 |
| 1/2" | 0.00 | 0.00 | 0.00 | 100.00 |
| 3/8" | 1.80 | 0.53 | 0.53 | 99.47 |
| No. 4 | 0.50 | 0.15 | 0.68 | 99.32 |
| No. 10 | 3.80 | 1.12 | 1.79 | 98.21 |
| No. 40 | 9.90 | 2.91 | 4.70 | 95.30 |
| No. 200 | 9.10 | 2.67 | 7.38 | 92.62 |

## FRACTIONAL COMPONENTS

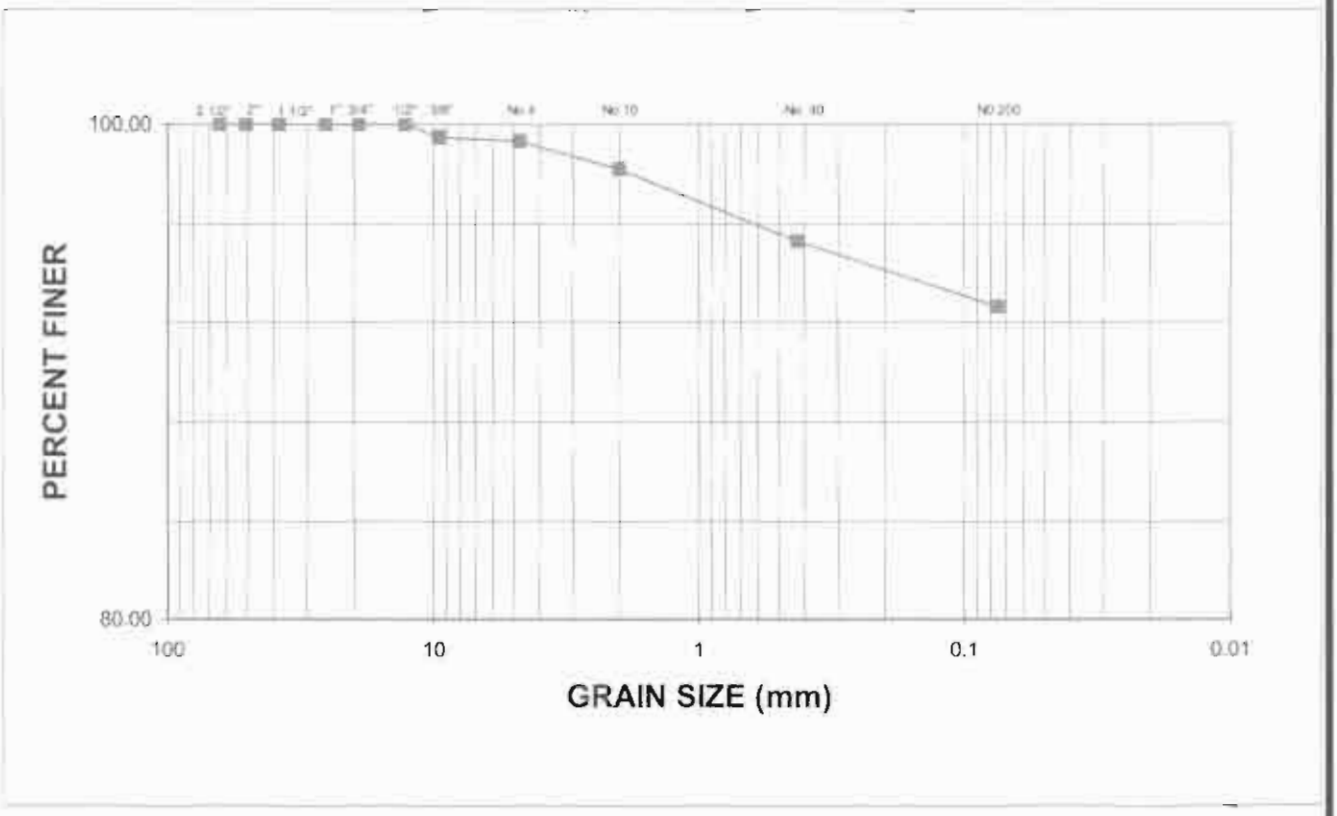
% + 75 mm 0.00 % Gravel = 0.68 % Sand = 6.70 % Finer = 92.62

ADVANCED SOIL ENGINEERING
GEOTECHNICAL CONSULTING ENGINEERS
CONCRETE AND MATERIAL TESTING LABORATORIES

P.O. BOX 1286
ISABELA, P.R. 00662

TEL / FAX: (787) 830 - 0366

# GRAIN SIZE DISTRIBUTION TEST REPORT




| % + 75 mm | % GRAVEL | % SAND | % SILT | % CLAY |
|---|---|---|---|---|
| 0.00 | 0.68 | 6.70 | 92.62 | |

| LL | PI | D85 | D60 | D50 | D30 | D15 | D10 | Cc | Cu |
|---|---|---|---|---|---|---|---|---|---|
| 60.5 | 35.0 | | | | | | | | |

| MATERIAL DESCRIPTION | USCS | AASHTO |
|---|---|---|
| Light brown and gray silty clay trace sand | CH | A-7-5 (37) |

Client : Cordeco Northwest, Corp.
Project : Discovery Bay Resort and Marina, Aguada, PR
Location : Boring No.11 (28' - 40')

Remarks :

| | | | | |
|---|---|---|---|---|
| Tested by : | Eduardo Rodriguez | Figure No. | : | 1 |
| Checked by : | Nelson Muñoz, P.E. | Date | : | July 31, 2007 |

GeoCim LUIS O. GARCIA & ASSOCIATES
GEOTECHNICAL ENGINEERING CONSULTANTS

**Partners**
Luis Oscar García, MSCE, CE, PE
Carlos García Echevarría, MSCE, PE
James A. Baigés, MSCE, PE

**Associate**
Alejandro E. Soto, MS, PG

Discovery Bay Marina Project

Geotechnical/Geological Discussion

Aguadilla, P.R.

The Discovery Bay Marina Project is located within the Espinar Ward of the municipality of Aguadilla, adjacent to the borderline with the Municipality of Aguada. This project is located within the flood plain of the Culebrinas River. The proposed project consist of the construction of an inland marina with approximately 500 slips for different sized boats and various developments providing residential, commercial, and marine facilities. The development of this project will require the construction of flood control structures to prevent the flooding of existing developments in the area; these will include the Aguadilla Levee on the east and the Espinar Levee on the west, allowing the drainage of flood waters through the new marina channel to the ocean.

Figure 1 shows a portion of the Geologic Map of the Aguadilla Quadrangle (Watson H. Monroe, 1969) published for the U.S.Geological Survey (USGS). According to the USGS, the geology of the proposed project area is dominated by Quaternary Alluvium (Qa) with a limited section at the ocean front which is identified as Quaternary Beach Deposits (Qb). The Alluvium consists of sediment deposited by the Culebrinas River and is described as *"clayey sand and sandy clay, containing scattered pebbles and cobbles of volcanic rocks in some areas; gently cross bedded and laminated; 0-10 meters thick"*. The Beach Deposits consist of recent coastal sediment that the USGS describes as *"quartz sand, shell fragments, and scattered grains of other minerals resistant to weathering; cementation to beach rock*

AMELIA DISTRIBUTION CENTER, EMMA STREET NO. 26A, GUAYNABO, PR 00968-8007
TEL. (787) 792-2626 • FAX (787) 782-5990

*common, ....*". The geologic map also shows the existence of Quaternary Swamp Deposits near the mouth of Caño Madre Vieja. These deposits, described as *"sandy organic muck and peat; 0-5 +/- meters thick"*, are slackwater deposits that accumulated between a coastal sand ridge and the alluvial plain deposits.

Results of preliminary geotechnical explorations performed at the project site (ASE, 2002) are in general agreement with the information provided in the geologic map. The results of the borings drilled (within the general area mapped as Alluvium by the USGS) indicate a general subsurface profile that consist of an upper layer of alluvial clay to sandy Clay in a very soft to stiff consistency which extends to depths of approximately 5 to 15 feet from the existing ground surface underlain to the bottom of the borings (mostly to 40 feet depth) by alluvial sand with trace to some silt; the latter generally occurs in a medium dense to dense condition but the borings penetrated a few layers or pockets in a loose to medium dense condition toward the upper portions of this horizon.

Conceptual plans for the project indicate that the flood control structures will consist of the following:

**Aguadilla Levee** – will consist of an earth embankment or dike that will extend from the existing municipal road leading to the Parque Colón in the north end to State Road PR-2 at the south end, just south of the intersection of PR-2 and PR-111. This dike will be approximately 2,000 lineal meters in length and will be wide enough to allow the construction of a two lane roadway along its crest. The approximate location of Aguadilla Levee is shown in Figure 2. This levee will generally be about 2.5 meters in height as required by the Hydrology and Hydraulics study performed by others in order to maintain the design levee crest elevation above the design water

elevation, except at some locations where the height of the levee will be about 3 to 4 meters height such as at the crossings with the Caño Madre Vieja (where the existing ground elevations are lower) and at the south end of the levee where it will raise to the existing PR-2 level.

**Espinar Levee** – the Espinar Levee will extend south and then west along the marina waterfront for approximately 2,100 lineal meters as shown in Figure 2. The levee will consist of a bulkhead rising to an elevation of approximately 8 feet above mean sea level, followed by a level promenade section behind the bulkhead, followed in turn by a further raise in elevation to approximately 15 to 23 feet above sea level using retaining structures or earth embankments; refer to Figures 3, 4, and 5 for conceptual drawings of this levee. The proposed bulkhead will probably consist of a steel sheet pile wall supported at the top with tie rods and "deadman" anchors at some distance behind the wall. The soils in front of the bulkhead will be dredged to approximately 6 to 12 feet below sea level and floating docks will be attached to the bulkhead to provide the marina docking facilities.

The construction procedures for the two types of levee proposed for the project are very different and will have to take into consideration different geological and geotechnical factors. In the case of the Aguadilla Levee, the proposed dike will be constructed by first clearing and grubbing the upper topsoil layer and then placing and compacting earth fill in layers until the earth embankment is completed to the required elevation. The fill materials will be obtained from nearby borrow sources and transported to the site. At present there are several quarries in the limestone hills near the site from which borrow fill materials for roads

and general building development have been and are still being used. This same general type of fill material has been used in other projects for the same purpose such as the flood control dikes in the Barceloneta area. The borrow fill must be fully characterized for the design of the levee, including its compaction, permeability and strength properties. In general, the fill must be placed in 8 to 12 inches thick layers and each layer compacted to 95% of the maximum dry density as obtained in the Modified Proctor test (ASTM D 1557). The typical side slope inclinations for earth embankment to be used for this purpose and constructed as described above may vary from approximately 3(H):1(V) to 2(H):1(V). The levee may require the use of internal or external drainage and permeability reduction mechanisms in order to prevent instability of the structure during or immediately after flooding events when the dike will work as a water retaining structure. Erosion control methods will also be incorporated into the levee design to prevent excessive erosion of the dike surface during flood events.

The design of the proposed levee will also take into consideration the geotechnical characteristics and stability of the underlying soils with a detailed and extensive geotechnical investigation that will establish the consolidation and strength properties of the subsoils. The earth embankment to be constructed will increase the effective stresses in the underlying soils; this may cause consolidation of any underlying weak or soft clayey subsoils with resulting settlement at the ground surface and instability of the subsoils. If the design studies conclude that excessive differential and/or total settlements are likely from the construction of the levee, then different construction alternatives may have to be implemented in order to reduce or eliminate excessive post-construction settlement of the levee. Construction alternatives such as pre-consolidation by surcharging may be implemented at the site; the use

of wick drains to accelerate the consolidation could also be utilized in order to reduce the construction schedule for the surcharge.

Additionally, the liquefaction potential of the underlying sand and sandy soils during a strong motion earthquake will also be investigated. During liquefaction the effective stresses within the sand below the water table are reduced by an increase in pore pressures resulting in a loss of strength of the soil and causing a sudden collapse or settlement of the soils.

In the Espinar Levee, a bulkhead will be constructed by driving a steel sheet pile into the ground and supporting the top of the sheet pile with tie rods attached to a "deadman" anchor a certain distance behind the bulkhead. The depth of the sheetpile will depend on various considerations: the subsoil conditions encountered, the unsupported length of the wall between the upper deadman anchor and the surface of the dredged soils in front of the wall, and the spacing of the deadman anchors. The sheet piles that make up the bulkhead will be driven with impact or vibratory type pile drivers to the required depths. The design of this levee will also require that a detailed geotechnical investigation be performed along the alignment of this levee in order to establish the geotechnical properties of the subsoils and determine the stability and structural requirements of the levee. Grading behind the bulkhead and promenade will require the placement of additional fill to raise grades to elevations of 15 to 23 feet above mean sea level. The design of these facilities will also require the use of engineered fill and the determination of the geotechnical characteristics of the fill and underlying subsoils with the same geotechnical concerns and considerations described for the Aguadilla Levee, including an assessment of liquefaction potential.

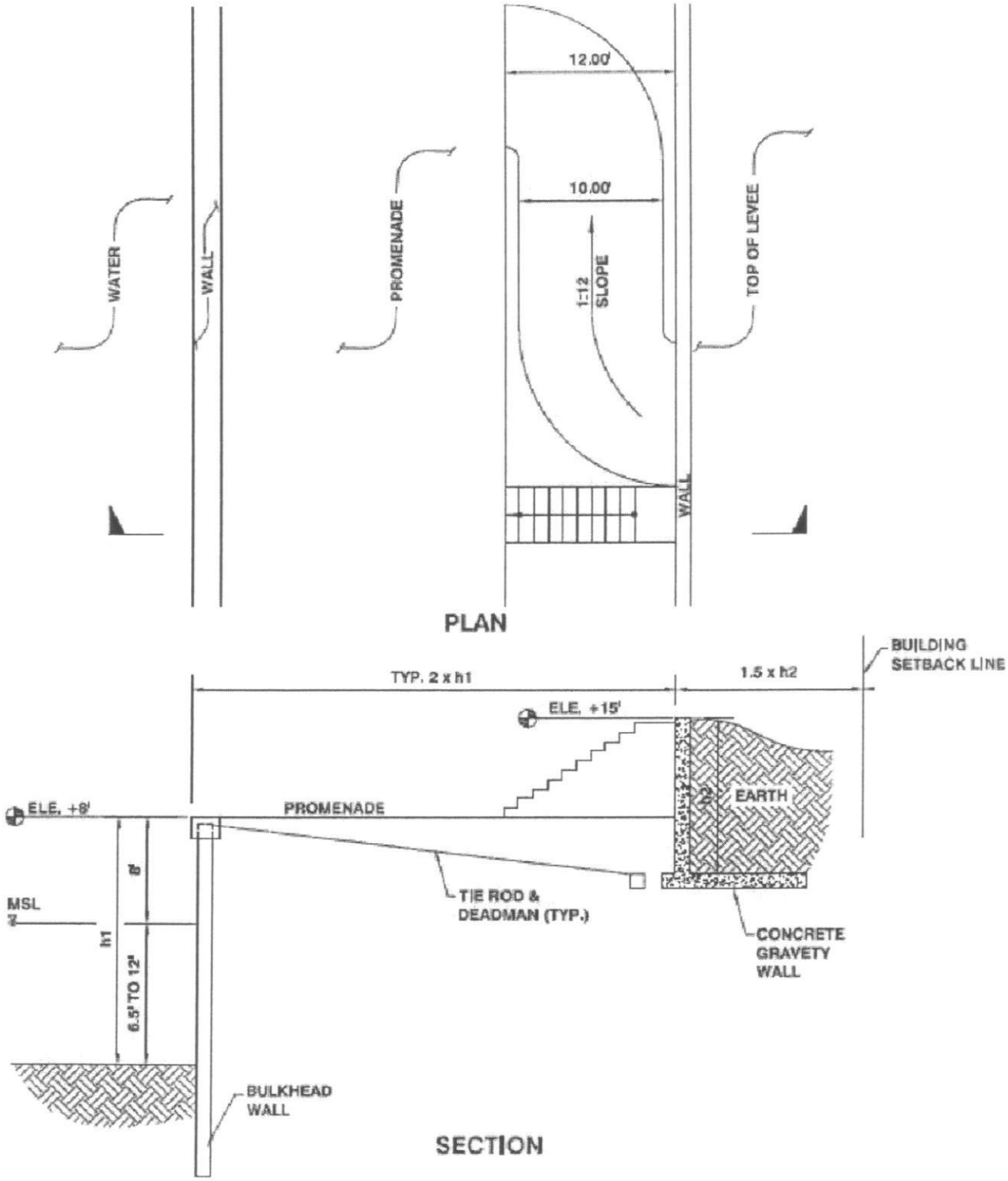
GeoCim
LUIS O. GARCIA & ASSOCIATES

DISCOVERY BAY RESORT & MARINA

AGUADA, P.R.

| DRW. BY: | CKD. BY: | SCALE: | DATE: | JOB. NO: | FIGURE NO: |
|---|---|---|---|---|---|
| G.O.G. | C.G. | N.T.S. | 01/04/05 | 3379-05 | 1 |

Giovanni: f:\Autocad\drawings\Propuestas\Diques\ Site



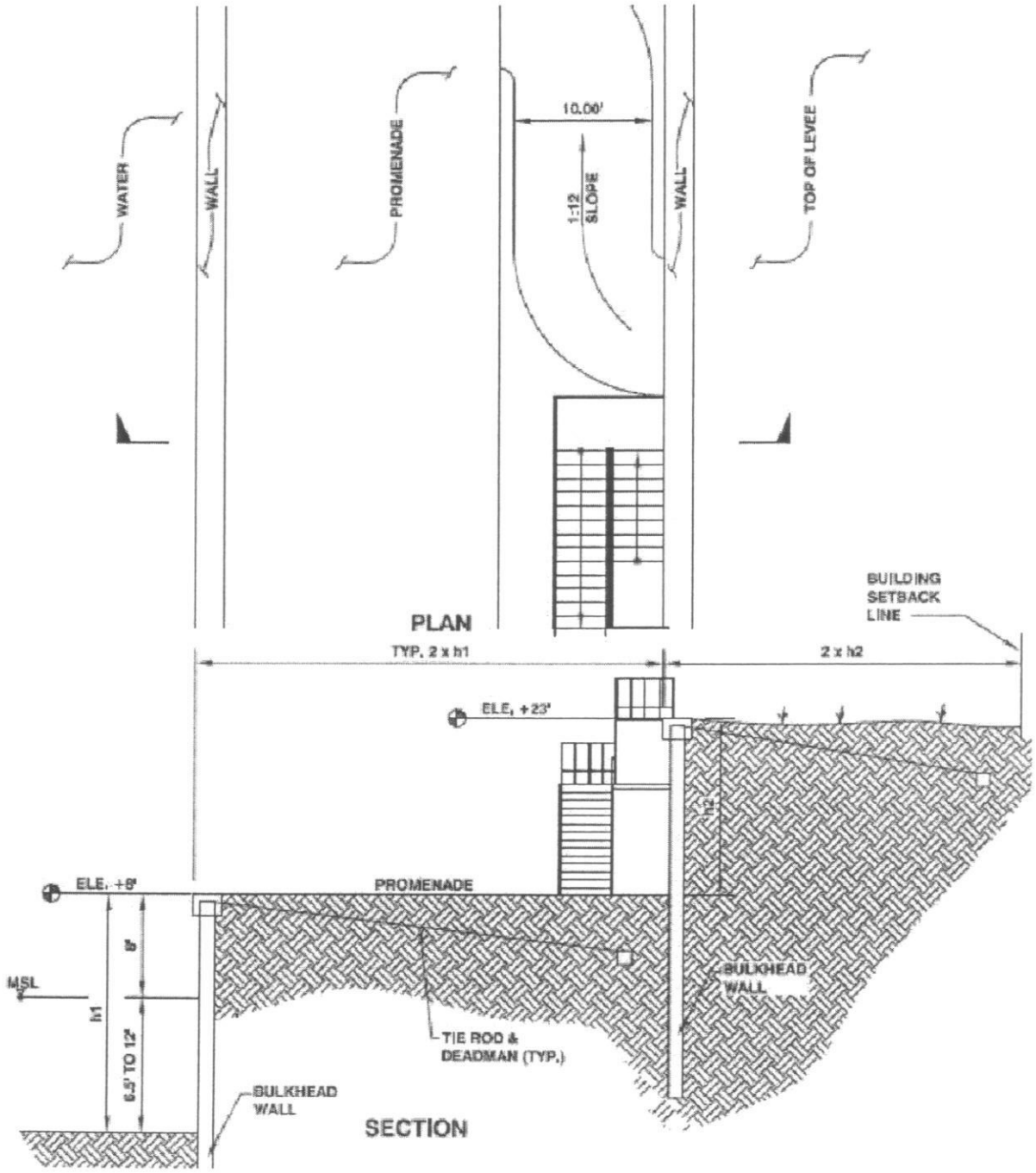

Giovanni: f:\Autocad\drawings\Propuestas\Diques\ FIG 3 4 5

GeoCim
LUIS O. GARCIA & ASSOCIATES

CONCEPTUAL DRAWING - GRAVITY & LOW LEVEL LEVEE

DISCOVERY BAY RESORT & MARINA, AGUADA, P.R.

| DRW. BY: | CKD. BY: | SCALE: | DATE: | JOB. NO: | FIGURE NO: |
|---|---|---|---|---|---|
| G.O.G. | C.G. | N.T.S. | 01/20/06 | 3379-05 | 3 |



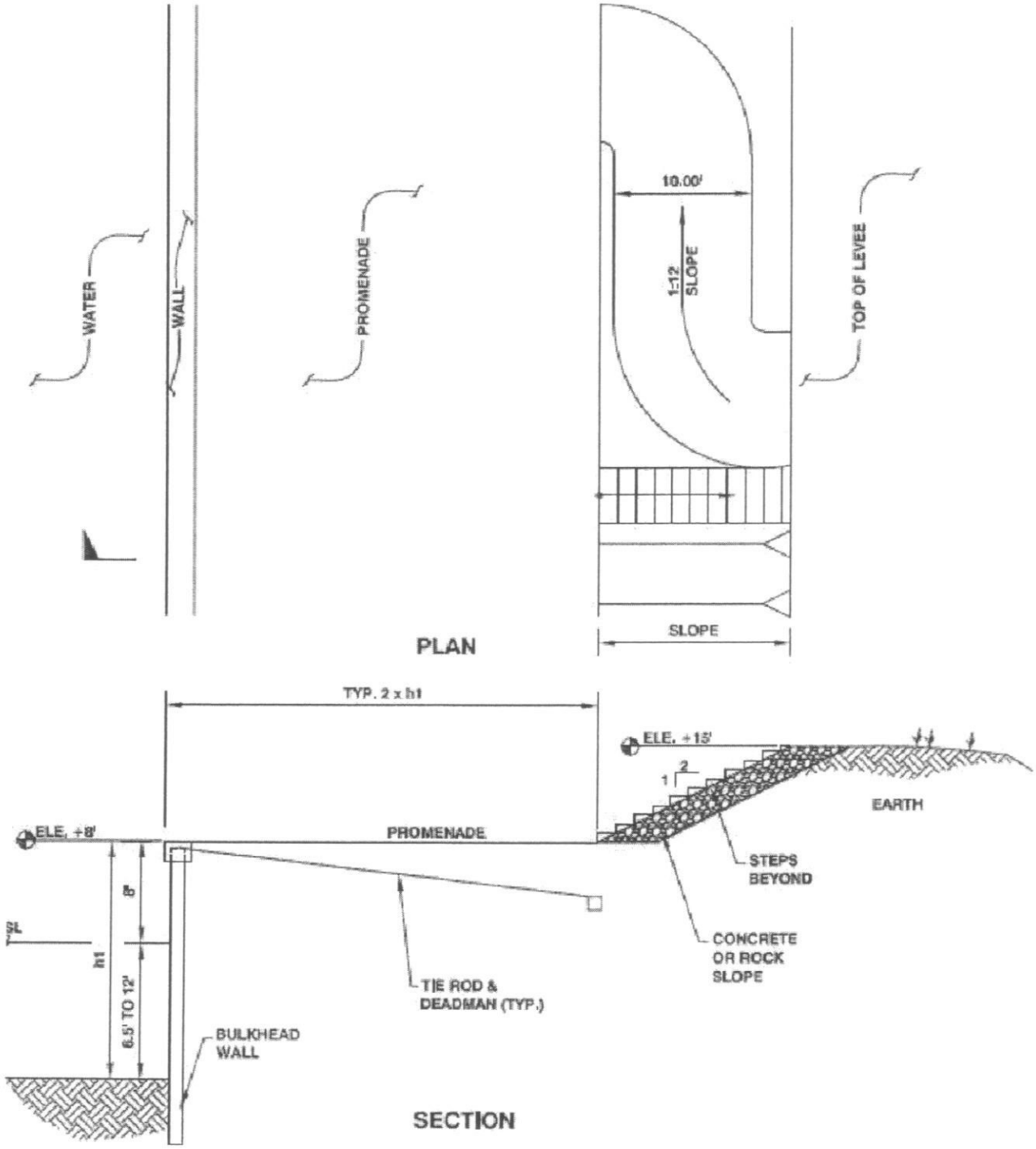

Giovanni: f:\Autocad\drawings\Propuestos\Diques\ FIG 3 4 5

GeoCim
LUIS O. GARCIA & ASSOCIATES

CONCEPTUAL DRAWING - BULKHEAD WALL & HIGH LEVEL LEVEE

DISCOVERY BAY RESORT & MARINA, AGUADA, P.R.

| DRW. BY: | CKD. BY: | SCALE: | DATE: | JOB. NO: | FIGURE NO: |
|---|---|---|---|---|---|
| G.O.G. | C.G. | N.T.S. | 01/20/06 | 3379-05 | 4 |



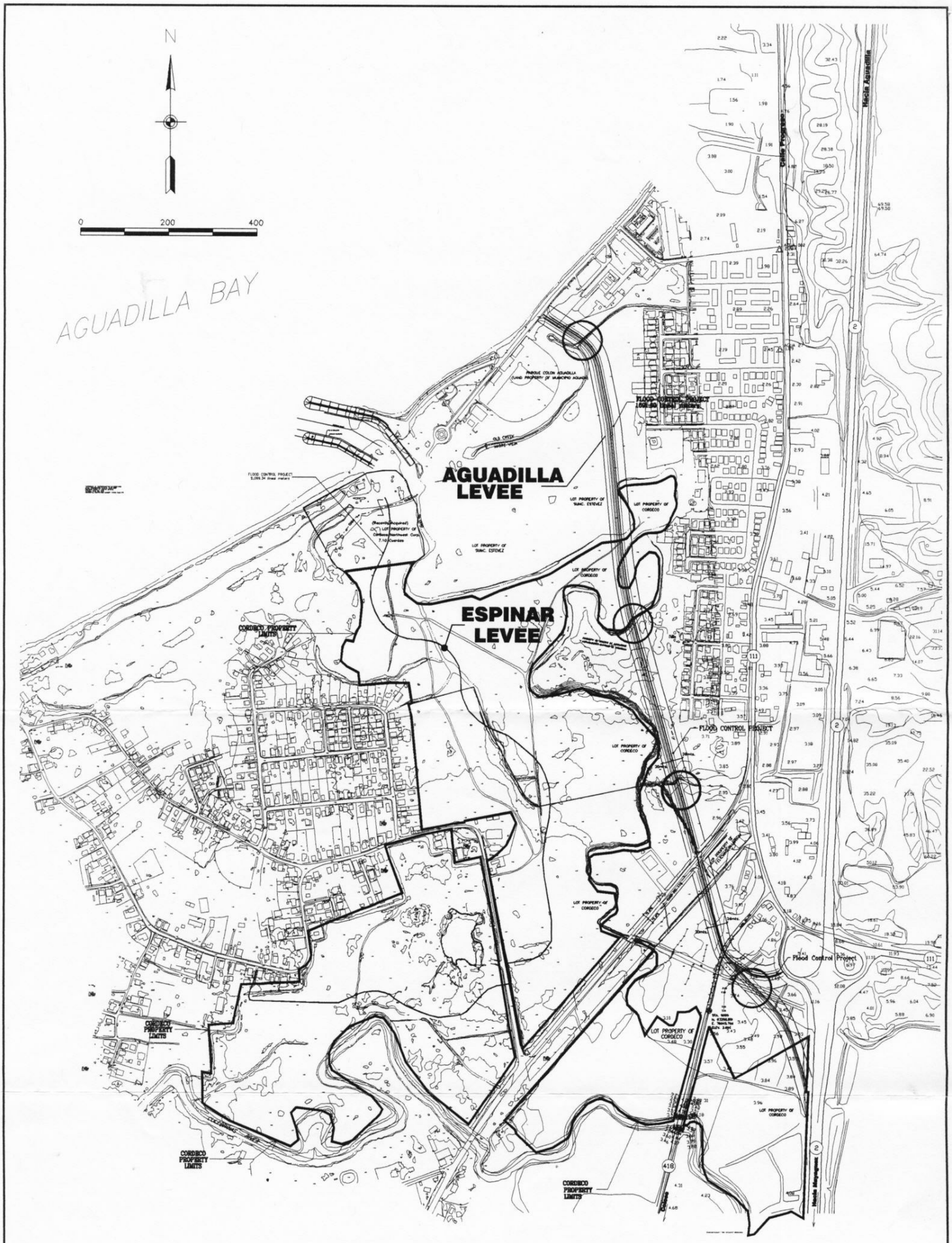

GeoCim
LUIS O. GARCIA & ASSOCIATES

CONCEPTUAL DRAWING - REVETMENT & LOW LEVEL LEVEE

DISCOVERY BAY RESORT & MARINA, AGUADA, P.R.

| DRW. BY: | CKD. BY: | SCALE: | DATE: | JOB. NO: | FIGURE NO: |
|---|---|---|---|---|---|
| G.O.G. | C.G. | N.T.S. | 01/20/06 | 3379-05 | 5 |

Giovanni: f:\Autocad\drawings\Propuestas\Diques\ FIG 3 4 5




GeoCim

LUIS O. GARCIA & ASSOCIATES
GEOTECHNICAL ENGINEERING CONSULTANTS
AMELIA DISTRIBUTION CENTER LOT. 26 A EMMA ST.
GUAYNABO, PUERTO RICO 00968-8007

DISCOVERY BAY RESORT & MARINA
AGUADA, P.R.

| DATE: | JOB NO: | CKD. BY: | SCALE: | DRW. BY: | FIGURE NO: |
|---|---|---|---|---|---|
| 01/03/05 | . | C.G. | N.T.S. | G.O.G. | 2 |

# APENDICE D

ESTADO LIBRE ASOCIADO DE PUERTO RICO
DEPARTAMENTO DE AGRICULTURA
P.O. BOX 10163, SAN JUAN, PR 00908-1163

13 de diciembre de 2001

Hon. Miguel A. Ruíz Hernández
Alcalde
Municipio de Aguada
P. O. Box 517
Aguada, Puerto Rico 00602

**RE: PROYECTO CORDECO DISCOVERY BAY RESORT & MARINA**
**BO. ESPINAL, AGUADA**

Honorable alcalde Ruíz Hernández:

En la consulta de referencia se propone ubicar un proyecto mixto turístico-recreativo y residencial en una finca de 230 cuerdas. La misma está localizada en el barrio Espinal del municipio de Aguada, Carr. 115 y 442.

El suelo de esta finca pertenece a una asociación de seis (6) series de suelo en aproximadamente las siguientes proporciones:

a. 30% Toa Limo arcilloso lómico, con declive de 0-2% y capacidad de uso agrícola I-1.
b. 20%, Coloso limo arcilloso lómico, con declive de 0-2% y capacidad de uso agrícola IIw-6
c. 20%, Bajura arcilloso, con declive de 0-2% y capacidad de uso agrícola IIIw-2.
d. 10%, Cataño arenoso arcilloso lómico, con declive de 2% y capacidad de uso agrícola IVs-18.
e. 10%, Cataño arenoso, con declive de 0-2% y capacidad de uso agrícola VIs-3.
f. 10%, Espinal arenoso, con declive de 0-2% y capacidad de uso agrícola VIs-26

Estos suelos muestran buenas características para el establecimiento de cultivos, donde existen probabilidades de obtener éxito económico. No obstante, el hecho de que discurren dos cuerpos de agua de abundante flujo por los predios objeto de evaluación que nos ocupa, disminuye su uso para la agricultura debido a las inundaciones.

Del estudio de la documentación suministrada por el proponente y de visita al predio objeto de consulta, se ha podido constatar que el mismo está atrapado entre dos grandes comunidades y segregado físicamente tanto por la zona marítimo-terrestre, una carretera estatal y dos zonas densamente pobladas que limitan grandemente su uso para la agricultura.

Sin embargo, es pertinente indicar que las tierras bajo evaluación localizan dentro de los lindes preliminares de la Reserva Agrícola del Valle del Coloso, creada en virtud de la Ley 142 del 4 de agosto de 2000, la cual establece preservar terrenos de alto valor agrícola y establecer un desarrollo integral para la agricultura. No obstante, la Junta de Planificación aún no ha concluído el proceso requerido por ley.

Por consiguiente, estimándose que el proyecto propuesto no afectaría la agricultura de los municipios en la zona, este Departamento desde el punto de vista estrictamente agrícola **no objeta** el mismo.

Cordialmente,

**Agro. Eduardo Siberio Talavera**
**Subsecretario**

**JD/wit**

# APENDICE E

APPPENDIX

HYDROLOGY AND HYDRAULICS

DETAILED PROJECT REPORT
ENVIRONMENTAL IMPACT ASSESSMENT

# LEVEE SYSTEM ALONG THE CAÑO MADRE VIEJA AREA FOR THE DISCOVERY BAY RESORT AND MARINA DEVELOPMENT RIO CULEBRINAS AT AGUADILLA AND AGUADA PUERTO RICO

By

Rafael Segarra-García, Ph.D., P.E.

HC1 Box 11958
Aguadilla, PR 00603-9320

JUNE 2007
REVISED NOVEMBER 2009

## Contents

I. INTRODUCTION ..... 6
II. DESCRIPTION OF STUDY AREA ..... 6
III. FLOODING HISTORY ..... 7
IV. HYDROLOGIC STUDY ..... 7
4.1 Methodology ..... 8
4.2 Watershed Data and Parameters ..... 8
4.3 Hydrologic Modeling Results ..... 10
V. HYDRAULIC STUDY ..... 10
5.1 Methodology ..... 11
5.2 Levee Description ..... 11
5.2.1 Aguadilla Levee ..... 12
5.2.2 Espinar Levee ..... 12
5.3 Simulation Analysis and Results ..... 12
5.3.1 Model Calibration ..... 12
5.3.2 Water Surface Profiles ..... 13
5.3.3 Levee Profiles ..... 13
VI. INTERIOR DRAINAGE ANALYSIS ..... 14
6.1 Methodology ..... 14
6.2 Description of Interior Drainage Areas ..... 14
6.2.1 Aguadilla Interior Area ..... 14
6.2.2 Espinar Interior Area ..... 15
6.3 Data and Results ..... 15
6.3.1 Aguadilla Levee ..... 16
6.3.2 Espinar Levee ..... 17
6.3.3 Flooding at the Tablonal Area ..... 17

VII. EVALUATION OF EXTREME EVENTS ..... 17

REFERENCES ..... 18

TABLES ..... 19

LIST OF TABLES

Table 1. Major Recorded Annual Floods at Río Culebrinas

Table 2. Río Culebrinas' Sub-Basin Areas and Curve Numbers

Table 3. Río Culebrinas Sub-Basin Lag Times

Table 4. 24-hr Rainfall for Río Culebrinas Sub-Basins

Table 5. Comparison of Río Culebrinas' Peak Flows at Highway 2 Bridge

**Table 6. Caño Madre Vieja Resulting Water Surface Elevations for Existing and Project Conditions for 100-Year Flood**

**Table 7. Río Culebrinas Wave Runup and Wind Setup**

Table 8. Río Culebrinas 100-Year Levee Crest Elevations

Table 9. 24-hr Rainfall for Discovery Bay IFH Watershed Study Area

Table 10. Discovery Bay Watershed Hydrologic Model Simulation Parameters for Study Area

Table 11. Estimated Flood Flows for Discovery Bay IFH Watershed Study Area

Table 12. Discovery Bay Interior Drainage Structures Hydraulic Design Data for Aguadilla Levee

Table 13. Aguadilla 10-yr and 100-yr Interior Flood Water Surface Elevations

Table 14. Discovery Bay Interior Drainage Structures Hydraulic Design Data for Espinar Levee

Table 15. Espinar Community 10-yr and 100-yr Interior Flood Water Surface Elevations

Table 16. Tablonal Community 100-year Flood Depths

LIST OF FIGURES AND PLATES

Figure 1. Aerial View of Project Area

Figure 2. Río Culebrinas Caño Madre Vieja Water Surface Profiles for Proposed Discovery Bay Resort and Marina Plan: 100-Year Flood

Figure 3. Río Culebrinas Aguadilla Levee Profiles for Proposed Discovery Bay Resort and Marina Plan: 100-Year Flood

Figure 4. Río Culebrinas Espinar Levee Profiles for Proposed Discovery Bay Resort and Marina Plan: 100-Year Flood

Figure 5. **Comparison of Proposed Levee Profiles with Levees from the Army Corps Study**

Figure 6. Río Culebrinas Aguadilla IFH Water Surface Elevations Profiles for Proposed Discovery Bay Resort and Marina Plan: FEMA, 100 and 10-Year Flood

Figure 7. Río Culebrinas Espinar IFH Water Surface Elevations Profiles for Proposed Discovery Bay Resort and Marina Plan: FEMA, 100 and 10-Year Flood

**Figure 8. Flood Profile Along Levees for Clogged Outlet Scenario**

**Figure 9. Water Surface Profiles within Levees Resulting from a 3.7 meter Coastal Stillwater Elevation**

Plate 1. FEMA Flood Map: Existing Conditions

Plate 2. Río Culebrinas Basins and Sub-Basins Boundaries and River Network

Plate 3. Río Culebrinas Watershed Study Area Soil Associations with Location Map

Plate 4. Río Culebrinas Watershed Study Area Land Use with Location Map

Plate 5. Discovery Bay Resort and Marina, Aguada Puerto Rico Levee Alignment

Plate 6. Aguadilla & Espinar Levee Plan

Plate 7. Aguadilla Levee Cross Section

Plate 8. Espinar Levee Cross Section

Plate 9. Discovery Bay Resort and Marina, Aguada Puerto Rico Interior Flood Hydrology Basins

Plate 10. FEMA Flood Map Revised

Plate 11. Aguadilla Water Surface Elevations and Depths for the Proposed 100-year flood event

Plate 12. Espinar Water Surface Elevations and Depths for the Proposed 100-year flood event

Plate 13. Tablonal Water Surface Elevations and Depths for the Proposed 100-year flood event

# I. INTRODUCTION

Two hydrologic-hydraulic analyses were performed for the marina and resort development project called Discovery Bay Resort & Marina. The first is a comprehensive analysis of the impact of the proposed levee system in the Caño Madre Vieja sector of the Río Culebrinas basin, and the second is the interior drainage analysis related to this same levee system. The study performed for the levee system is the basis of the Flood Insurance Study (FIS) map revision request to be submitted to the Federal Emergency Management Agency (FEMA) via a Conditional Letter of Map Revision (CLOMR) solicitation, and is also the basis of the Environmental Impact Statement (EIS) of which this document is to be a part of.

This appendix includes the results related to the levees and interior drainage studies as well as additional analyses pertaining to EIS related issues. The impact of the residual flooding related to the levee system is also assessed.

## II. DESCRIPTION OF STUDY AREA

Río Culebrinas is located in the Northwestern part of Puerto Rico. It is an intermediate-sized basin coursing along several municipalities. Río Guatemala, Río Caño, and Río Sonador as well as several named and unnamed creeks are all tributaries to Río Culebrinas. Amongst the named creeks are the Grande, Las Marías, Los Morones, Lasalle, Viejo, El Salto, and Salada. The basin is mostly forest and pasture with some urban development related to the towns of San Sebastián, Aguada, and Aguadilla, also including commercial and industrial areas, housing projects, and rural developments. Sugar cane is still grown in the coastal plain but increasing development has encroached into this and other formerly cultivated areas.

The climate of the region is tropical, with a rainy season lasting from June to December, although it is not uncommon to observe significant downpours outside this season. Average annual rainfall in the basin ranges from 70 inches (1,778 mm) along the coast up to 100 inches (2,540 mm) in the mountainous area.

The Río Culebrinas' coastal plain is bounded on the East side by Highway PR-2 (Hwy-2), which connects the hills straddling the flood valley on its North and South sides. Figure 1 shows the photographic image of the project area on which several relevant features are identified. A significant feature of the valley is Caño Madre Vieja, an old outlet of Río Culebrinas which winds its way to the coast Northwest of the Espinar area, in the Parque Colón sector of Aguadilla. Caño Madre Vieja is nearly stagnant as its outlet is frequently blocked by sand dunes. The residential area of Espinar is located near the middle of the coastal valley and, in effect, divides the flood of Río Culebrinas.

The proposed project is to be located in the Caño Madre Vieja sector. It consists of two levees, one labeled the Aguadilla levee and the other the Aguada levee, after the municipalities within which they are located. The Aguadilla levee will run west of this town's built-up area, from Hwy-2 up to an existing coastal road. The Aguada levee will wind along the eastern fringe of the Espinar sector, from a high-ground location near the southeastern tip of the sector up to a

location near the coastline. The study area comprises the floodplain west of Hwy-2. Additionally, the project will include two entrance jetties to protect the North perimeter of the marina basin.

## III. FLOODING HISTORY

A significant number of flooding events have been recorded in Río Culebrinas. The most memorable recorded event, in terms of extent of flooding, is the so-called Eloísa flood of September 16, 1975, resulting from a stationary depression. This was the most severe flooding in the basin since the 1956 flood associated with hurricane Santa Clara, and to date is still the largest on record. The return period of the Eloísa event is hard to ascertain since the systematic period of record is relatively short and discontinuous, and therefore no reliable flood frequency estimates can yet be computed.

Systematic recording of flows by the U.S. Geological Survey (USGS) has been underway since 1968 at three locations within the Culebrinas basin. The gaging station with the best record is USGS 50147800, located at Road PR-404 in the municipality of Moca. A drainage area of 71.2 square miles (184.5 square kilometers) is associated with this station. Table 1 lists the major annual flood events recorded at the Moca gaging station since 1968.

The Federal Emergency Management Agency (FEMA) has performed a Flood Insurance Study (FIS) on Río Culebrinas (Ref. 1) that has served as the basis of the regulatory flood map from the Puerto Rico Planning Board (PRPB). The portion of the regulatory flood map pertaining to the study area is depicted in Plate 1. The current flood map is the baseline condition against which the hydraulic impact of all proposed projects must be assessed.

## IV. HYDROLOGIC STUDY

The hydrologic study was performed for the entire Río Culebrinas' drainage area, and flood hydrographs were computed at selected locations of the river. The study was performed following FEMA guidelines for FIS revisions. In the existing FIS study, a hydrologic analysis was performed as far downstream as Highway 2, at which runoff hydrographs were computed that served as the inflow boundary condition for a two-dimensional hydraulic study of the floodplain. Upstream of Highway 2, a one-dimensional flow analysis was performed to trace the water surface profile. A similar approach has been followed in the present study.

FEMA requirements dictate that a FIS revision request should either duplicate the original study or propose new results based on improved modeling or new field data reflecting different baseline conditions with respect to the original study. Given the size of the drainage area and based on an analysis of the present land use patterns, a revision of the hydrologic results is not warranted. Although in the present study the flow estimates at given locations will exhibit some variation with respect to the FIS flows, these are not deemed significant and are within the expected level of error of such analyses.

The major results of the hydrologic study are the resulting flood hydrographs for various return periods. These hydrographs serve as the inflow boundary conditions of the hydraulic study.

## 4.1 Methodology

The hydrologic study was performed with a rainfall/runoff model. Rainfall depths of various return periods were converted to runoff via the Natural Resource Conservation Service's (NRCS) Curve Number (CN) method, and the standard NRCS unit hydrograph used to generate the resulting flood hydrographs. Hydrographs generated at watershed subdivisions were then routed downstream to the outlet, this being the Highway 2 bridge at the neck of the Río Culebrinas' coastal floodplain.

The hydrologic simulation of the Culebrinas basin required the determination of numerous morphological parameters. These parameters were computed with the Watershed Modeling System, or WMS (Ref. 2). WMS is a comprehensive landform analysis package that can glean morphological attributes from a basin when its attendant topography is in the form of a Digital Elevation Model (DEM). The package includes several hydrology interfaces, one of which is the U.S. Army Corps' Hydrology Modeling System, or HMS (Ref. 3). The NRCS method was applied via the HMS model. DEM coverage for the entire Culebrinas basin was obtained from the U.S. Geological Survey (USGS) and used to trace drainage subdivisions, compute drainage areas, land slope, and other parameters.

Hydrologic parameters, such as the CN, were computed from a digitalized overlay of land use and soil type distribution over the Culebrinas basin. The computations were also performed with the WMS model. Drainage area lag times were computed with WMS as well by selecting an available equation for which the model would, in turn, calculate the required physical parameter.

## 4.2 Watershed Data and Parameters

The Río Culebrinas drainage area was subdivided into 14 sub-basins based on fluvial and morphological characteristics. At each sub-basin the requisite morphological and hydrologic parameters were computed with the WMS model from the available DEM overlay for the Culebrinas area. The DEM coverage of the basin was in turn digitally superposed on the topographic quadrangle to identify land features and fine-tune the drainage divide subdivisions traced by WMS. Drainage subdivisions and other features are identified and labeled in Plate 2.

Land use and soil type data was available in the form of digital map overlays. Each soil type was assigned the appropriate runoff potential index (A, B, C, or D) based on the soil classification listing available in TR-55 (Ref. 4). The distribution of soil types over the drainage area, in terms of the runoff potential index, is presented in Plate 3. It is seen in the plate that soil types B and D predominate. Soil type B is characterized by a relatively good infiltration potential, referring to gravely or sandy soils, while type D have a poor infiltration potential, as would be the case for clayey and loamy soils.

Land use distribution over the drainage area is depicted in Plate 4, using the classification scheme of the NRCS Curve Number tables. The area is mostly grassy or rangy, with woody-type vegetation in the upland areas. The lowland along Río Culebrinas is cultivated with sugarcane, and it has been assumed that this type of crop would be of the grassy type within the peak of the rainy season.

The digital land use/soil type maps were superposed on the drainage subdivisions from the DEM coverage to produce land use/soil type matrixes from which the composite Curve Number (CN) parameter used in the NRCS model was computed by WMS. Table 2 lists the drainage area and computed CN, for both AMC-II and III moisture conditions, for each sub-basin. The total drainage area amounts to 102.6 square miles (266 square kilometers).

Construction of the NRCS unit hydrograph requires the estimation of a watershed's lag-time. The lag-time for each sub-basin was computed with the NRCS equation:

$$t_L = \frac{L^{0.8}(S+1)^{0.7}}{1900\ Y^{0.5}} \qquad (1)$$

where $t_L$ = lag-time (hr); L = hydraulic flow length (ft); S = maximum water retention potential (inches), computed from S = 1000⁄CN − 10; Y = average watershed slope (%).

The computed lag-times for each of the Río Culebrinas sub-basins are listed in Table 3. The lag-times are used in the derivation of the synthetic unit hydrograph for each sub-basin. The unit hydrograph is used to generate the resultant composite hydrograph via the convolution process with the incremental runoff resulting from the rainfall-runoff transformation. The 24-hour precipitation accumulation is distributed according to the standard Type-II rainfall distribution, and the rainfall-runoff transformation computed incrementally.

Precipitation depths over each sub-basin were obtained from the Weather Bureau's Technical Paper No. 42 (Ref. 5), or TP-42. At the time of the performance of the hydrologic analysis, TP-42 was the standard source for rainfall frequency data. An additional justification for using TP-42 was the requirement of relating the present study to the then current FEMA's baseline flood insurance study. **Even for drafting the new Flood Insurance Rate Maps (FIRMs) maps for the island, FEMA did not avail itself of the recently published new rainfall atlas for Puerto Rico (Atlas 14). These maps have been adopted and became effective on November 18, 2009. Concordance with the official FIRM, as pertaining to the CLOMR request, required the consideration of TP-42 rainfalls for the study. However, the future design phase of the levee study will indeed consider Atlas 14 rainfalls.**

The selected precipitation depths for various return periods at each sub-basin are listed in Table 4.

## 4.3 Hydrologic Modeling Results

Prior to modeling the hydrologic response of the drainage area, the assembled precipitation data is converted to runoff depth using the NRCS transformation. This transformation is applied to the standard Type-II, 24-hour cumulative rainfall. The NRCS rainfall-runoff transformation is given as follows:

$$R = \frac{(P - 0.2S)^2}{P + 0.8S} \tag{2}$$

where R = runoff depth (inches); P = cumulative rainfall (inches); S = retention potential described in Equation (1).

The runoff depths are applied to the computed unit hydrograph to perform the requisite convolutions needed to produce the various runoff hydrographs for each sub-basin. This is accomplished with the hydrologic model.

Application of the WMS/HEC-HMS hydrology model to the drainage network of Río Culebrinas yielded runoff hydrographs for various return periods. The hydrographs generated at each subdivision were routed through the channel network down to the selected outlet at the Hwy-2 bridge. Flood hydrographs constitute the flow boundary conditions of the hydraulic model. Hydrographs were generated for various return periods, the most relevant of which were the 100 and 500-year events.

The hydrograph peak flows of the present study are compared to those of from FEMA's FIS study in Table 5. A rather close agreement is observed between the peak flows of the present study and those from the FIS. It is for this reason that the present study has not been presented as a revised hydrologic analysis.

**The hydrologic analysis was performed for the Río Culebrinas' contributing drainage area down to the Highway 2 bridge. Two minor additional contributing areas, on both sides of the river's alluvial fan downstream of Highway 2, were excluded. These areas, comprising the southern sector of the municipality of Aguadilla and the Espinar ward, were accounted for in the interior drainage analysis but presented a negligible contribution to the computed base flood of the entire drainage basin. FEMA's FIS study also excluded them. Runoff flow computations from the interior drainage analysis showed that the fraction of the peak flow contribution for the excluded Aguadilla and Espinar contributing areas with respect to that from the Río Culebrinas' basin amounted to 0.018 and 0.006, respectively – a negligible amount which justified the stated assumption.**

# V. HYDRAULIC STUDY

The hydraulic study was performed with a two-dimensional, unsteady flow model, in conformity with the requirement of using a similar or improved methodology than that used by FEMA for the Río Culebrinas FIS. The overall objective of the hydraulic study is the assessment

of the impact of the proposed levee system on the flooding characteristics of Río Culebrinas. Specifically, the study sought to (a) assess the feasibility of constructing the levee system, (b) amend the regulatory flood map to include the proposed conditions, and (c) analyze the interior drainage system to minimize the impact of residual flooding and provide mitigation against flooding for the interior areas.

## 5.1 Methodology

The hydraulic analysis was conducted with the unsteady, two-dimensional Flo-2D model (Ref. 6), **using the latest version available at the initiation of the study**. Flo-2D utilizes a finite-difference solution of the full dynamic unsteady flow equations. It is capable of simulating a varied range of unsteady flow applications, and is one of the models allowed by FEMA for use in FIS revision studies.

Data for the Flo-2D model was gleaned from a digital aerial survey topographic map supplied by the firm of Hernández Virella & Associates. The model constructed a two-dimensional grid of the Culebrinas flood valley downstream of Hwy-2 down to the coastline. This grid included the Río Culebrinas and Caño Madre Vieja areas. Inflow hydrographs were specified at the boundary nodes of the grid and routed through the network out into Aguadilla Bay.

**Based on modeling criteria provided by the model's user manual, a grid size of 160 meters was selected as a practical conceptualization for the specific purpose of the study. This cell size is within the model's allowable parameters. The user's manual of the Flo-2D model considers cell sizes 30 to 300 meters as appropriate for most applications. The stated grid size used in the model is within the practical range.**

The modeling procedure called for calibrating the model with the current FIS regulatory flood in order to ascertain the hydraulic model parameters, particularly the surface roughness values. After calibration, two sets of simulations were performed, one pertaining to the existing field condition, that is, without the levees, and the other to the proposed condition, with the levees. Existing conditions are those pertaining to the FIS flood, with the updated field data from the aerial survey.

The results of interest in the simulations are the water surface profiles and the flow velocity field within the levees. The water surface profile upstream of the levees should not increase appreciably above that of the FIS profile. Other variables, such as levee height and freeboard are dependent on the water surface profile from the hydraulic simulation.

## 5.2 Levee Description

Two levees are proposed, one labeled the Aguadilla levee to the north, and the other the Espinar levee to the south, straddling the Caño Madre Vieja, with the alignment as depicted in Plate 5. Plate 6 depicts the levee alignment on the topographic map of the plain and includes other related design features. The Aguadilla levee has some similarity to that proposed by the U.S. Army Corps of Engineers (USACOE) in an earlier study (Ref. 7). The Espinar levee is tailored to accommodate the Marina and Tourism oriented activities concept.

Levee heights were determined from the results of the hydraulic simulation with the 100-year flood runoff hydrograph and in compliance with 44 CFR Ch. 1, Section 65.10 of the NFIP regulations. Incremental depths were added to the flood profile to account for freeboard, wave runup, wind setup, wave height, and overtopping considerations.

### 5.2.1 Aguadilla Levee

The Aguadilla levee extends from Hwy-2 to the coastline in the Parque Colón area, running between the San Carlos parochial school and the old municipal baseball park, for a length of about 1.76 kilometers. East of the Aguadilla levee lies the southern part of the municipality of Aguadilla. This area includes the Victoria and García housing projects. The levee will cut across the Caño Madre Vieja stagnant watercourse at several locations. It will also cut across Road PR-115, which will require a ramp and maybe some additional drainage facilities.

The current Aguadilla levee alternative consists of an earthen embankment with 1:2 side slopes and a top width of about 11.5 meters, as depicted in Plate 7, with an average levee height of 3.4 meters. A drainage channel will run along the exterior section which will feed eight flap-gate culvert openings for draining the exterior area of the levee.

### 5.2.2 Espinar Levee

The Espinar levee is more sinuous than the Aguadilla levee. It extends for a distance of about 2.15 kilometers, beginning at a high point south of the Espinar community and ending near the coastline at a point southwest of the present Caño Madre Vieja outlet. The Espinar community is located to the southwest of the levee. A coastal mangrove is located north of the Espinar community, which is drained by a small outlet channel into Caño Madre Vieja between station locations 00+00.00 and 02+00.00, as depicted in Plate 5.

The current Espinar levee alternative consists of a stepped embankment made up of a bulkhead wall and a retaining concrete wall along a promenade area, as depicted in Plate 8. The major opening in the wall is the outlet of the small drainage channel north of the Espinar community. A twin-barreled flap-gated culvert opening is proposed at this location.

## 5.3 Simulation Analysis and Results

The hydraulic analysis of the proposed levee system was performed with the Flo-2D model. It sought to determine the impact of the proposed development on the 100-year water surface profile from the regulatory FIS study for Río Culebrinas. As such, the main objective was to design a system that would not impact the regulatory profile upstream of the encroached segment of the floodplain wherein the levees will be constructed as well as to provide the maximum attainable level of flood mitigation for the interior areas.

### 5.3.1 Model Calibration

FIS flood map amendment procedures require a Duplicate Effective Model of the regulatory profile, against which a map revision request must be evaluated. To this end the

hydraulic model was calibrated to reproduce, as closely as possible, the FIS flood elevations. The end result of the calibration is the matrix of roughness values at each cell of the finite-difference grid of the Culebrinas floodplain.

### 5.3.2 Water Surface Profiles

The regulatory flood profile is only affected by the levee system within the exterior area and does not extend upstream of Hwy-2. Likewise, the flood profile along Río Culebrinas north of Hwy-2 is also unaffected. Figure 2 depicts the comparison between the regulatory flood profile and the proposed profile along the Caño Madre Vieja sector, where it is evident that the relative impact of the levee system largely peters out within 2 kilometers from the outlet.

**The resulting water surface elevations within the levees are listed in Table 6. The major computed difference between the FIS and proposed water surface profiles is in the order of 0.61 meters, at a distance of about 1000 meters upstream from the coast. Just upstream of Hwy-2 the difference in elevations is 0.04 meters, which is considered negligible and well within the expected error limits of the simulation.**

### 5.3.3 Levee Profiles

Levee elevations were ascertained from the computed water surface profiles, wind wave, wave runup, wind setup, and freeboard specifications. Wave runup, wind setup, and wave heights were computed with several procedures available in Sentürk (Ref. 8). The results pertaining to this analysis are presented in Table 7. A wind speed similar to that suggested by the U.S. Army Corps (Ref. 7) was used to compute the wave parameters.

The resulting levee profiles are depicted in Figures 3 and 4, including the regulatory and proposed water surface elevations as well as the location of drainage structures across the levee embankments. Proposed longitudinal levee crest elevations are listed in Table 8. Average levee height for the Aguadilla levee is 3.42 meters while for the Espinar levee it is about 3.46 meters. Figure 5 shows the levee profiles proposed in the study compared to those from the Corps of Engineers (COE) design. **The Army Corps levees are lower than those from the present study, as is evident from an examination of the profiles depicted in Figure 5. This reflects the fact that the Army Corps study was performed with flows which differed from those in the FIS and the present study. Also, the Army Corps performed the hydraulic study with the one-dimensional UNET model, which constitutes a significantly different approach than that of a two-dimensional model.**

**Direct comparison of expected water surface profiles along the levees between the present study and the Army Corps study may not yield significant conclusions due to the fact that the peak flows used in the hydraulic analyses of both projects differed significantly. The 100-year peak flow, at Highway 2, from the present study amounted to 4,062 cubic meters per second, while the Army Corps estimated a peak flow of 1,098 cubic meters per second at the same location. The peak flow from the present study (and FEMA's) exceeded even the SPF estimate from the Army Corps study. The Army Corps**

**project was not concerned with referencing its study to that of FEMA's FIS, and thus was performed under a different set of technical concerns.**

To account for the possibility of levee overtopping, a minimum freeboard was provided at the lower end of the levees, which was then increased upstream in order to constrain this effect to the lower reach of the embankment.

# VI. INTERIOR DRAINAGE ANALYSIS

The interior drainage areas are those lying outside the levee enclosure area, labeled herein as the Espinar and Aguadilla areas. A separate hydrologic study was performed for the interior drainage design while considering several control alternatives. The objective was the determination of the level of residual flooding expected as a result of the construction of the levees. While some level of residual flooding is acceptable, it was desired to mitigate as much as possible the level of flooding so as to provide additional benefits to the neighboring communities.

## 6.1 Methodology

The hydrologic analysis was performed using the same tools as those used for the Río Culebrinas basin study discussed earlier. Runoff hydrographs for the Espinar and Aguadilla areas were computed with the WMS model. In the case of the interior drainage areas, certain simplifying assumptions were required due to the nature of the terrain. Particularly for the Aguadilla sector, the area is heavily urbanized and it was not possible to model accurately the serpentine and complex flow paths existing within the built-up area. The system was simplified for representation in the model.

The hydraulic analyses of the drainage alternatives were performed with the Interconnected Pond Routing (ICPR) package (Ref. 9). An interior flood hydrology analysis requires the dynamic modeling of the system, in which the time-varying stages of the exterior and interior floods are applied concurrently on the interior drainage system in order to trace the extent of the resulting residual flooding. The exterior area was simulated as time-varying stage against which the interior drainage system would operate.

Given the differences in catchment area and wave travel times, it is extremely unlikely that the peak stages from the interior and exterior areas will ever coincide to produce a so-called "worst-case scenario". For example, the peak 100-year floods from both the interior and exterior will have a very small probability of coinciding. It is expected that the interior areas will respond faster than the river basin.

## 6.2 Description of Interior Drainage Areas

### 6.2.1 Aguadilla Interior Area

The Aguadilla interior area comprises the southern sector of the town and a portion of the hilly area east of Hwy-2. These hills, mostly karstic in nature, are characterized by numerous sinkholes and depressions. The drainage divides of the Aguadilla and Espinar interior areas are traced in Plate 9. Tracing drainage areas within a karst topography is highly uncertain due to the nature of this terrain, and thus a given trace is perforce only an estimate.

Runoff draining from the catchment will concentrate along the eastern face of the Aguadilla levee, in the undeveloped patch of land running alongside it. A field survey has identified three significant concentrated runoff avenues into this area. The first is a narrow street running uphill east of Hwy-2 via an underpass in front of the Aponte public housing project. Runoff flowing along this street is intercepted by a cross inlet across from the Aponte housing project and conveyed via a culvert to the undeveloped area west of it, near the northern tip of the Aguadilla levee.

The second is a culvert draining the Monte Brujo sector east of Hwy-2 which drains directly into Caño Madre Vieja along the boundary between the Urbanización Victoria and Urbanización García housing developments. This culvert courses beneath the access road (Juan Santos Street) to Hwy-2 at the Victoria sector, crossing the highway and extending for a short distance to the east of it.

The third is a small gully crossing an undeveloped patch of land in the Victoria sector, west of Hwy-2 and just north of the southern tip of the Aguadilla levee. The gully crosses Road PR-111 near the fork branching off to Road PR-115. It drains part of Hwy-2 and an area to the east of it.

Additional surface runoff from other adjacent area drains directly into the sector east of the Aguadilla levee. The Urbanización García project has no storm sewer facilities beyond street gutters which drain overland into the Caño Madre Vieja sector.

### 6.2.2 Espinar Interior Area

The Espinar interior area is smaller than that of Aguadilla. It comprises part of the Espinar residential community and the area where the marina and resort project is to be located. In this definition the flooded area along the Río Culebrinas' main course is excluded since it is not affected by the proposed project. The Espinar sector has no stormwater sewer facilities. Surface runoff flows overland into the Caño Madre Vieja area.

## 6.3 Data and Results

Because the Aguadilla and Espinar interior areas are so geographically close, the rainfall depths selected for the analysis will be the same. Rainfall depths for the selected return periods are listed in Table 9. The hydrologic parameters of each interior area are presented in Table 10. The CN parameter was computed in a similar fashion as that of the Río Culebrinas' basin. The results of the hydrologic analysis are listed in Table 11 as the peak flow for a given return period. As the results demonstrate, the Aguadilla area is the major runoff contributor to the levee interior flooding.

Determining the extent of residual flooding required choosing a particular combination of return periods for the interior and exterior stages. Usually, a 10 or 25-year return period for interior flooding is considered acceptable. However, in the interest of providing a more extreme scenario for the proposed project, a 100-year interior flood was selected, as well as the required 10-year flood, combined with a 50-year flood stage in the exterior area. The joint occurrence of 100-year stages is considered unlikely.

Several interior flood management alternatives were assessed as part of the hydrologic study. These included such activities as providing drainage outlets to the ocean and pumping stations. Some were technically infeasible, while others were considered too costly and impractical, as was the case with pumping stations. The most practical and cost-efficient alternative is that of providing gravity-outlets in the form of culverts for drainage into the levee exterior zone.

The resulting interior flooded areas area can be compared with the existing regulatory flooding extent in a revised flood map depicted in Plate 10. The levee system entails a significant reduction in the extent of flooding for the regulatory event. The quantitative description of the reduction in expected flood levels is explained below.

### 6.3.1 Aguadilla Levee

A total of eight 60-inch (1,524 mm) pipe culvert outlets are proposed for the Aguadilla levee. The location of these outlets was selected along the points at which runoff from the interior area naturally concentrates. The proposed locations for these outlets have already been indicated in Plate 6, along the Aguadilla levee alignment. Design parameters for each drainage pipe are listed in Table 12.

The residual flooding from the 100-year and 10-year rainfalls at the Aguadilla interior area was determined by simulating of the levee system against the time-varying flood stage of the levee interior area. The extent of the residual flooding along the Aguadilla levee is traced in Plate 11. As simulated in the hydraulic model, interior flooding is mainly the level-pool flooding related to the drainage outlets. The interior area has been treated as basically a storage area for the culverts. The peak stage for the 100-year interior area flooding reached only 2.94 meters, while that of the 10-year flood stood at 2.77 meters.

Numbered locations in Plate 11 refer to water elevation and depth data that are listed in order to provide a quantitative measure of the degree of flood relief resulting from the proposed levee system. Table 13 lists the water surface elevations at the locations indicated in Figure 16, including the difference in elevations resulting from the construction of the levee. A significant reduction in water elevations is obtained at most of the locations, particularly within the residential areas. At a small number of non-residential locations near the coast, a slight increase not exceeding 0.14 meters (5.5 inches) is obtained. These slight differences may well fall within the expected error tolerances of the simulation.

A lateral profile of the interior flood at a location in the Aguadilla levee (see Plate 11 for the location) is presented in Figure 6. The dramatic reduction in the extent and depth of flooding is evident in the profile.

### 6.3.2 Espinar Levee

Two 60-inch culverts are proposed for the Espinar interior drainage area, as located in Plate 6. Design parameters for these culverts are presented in Table 14.

As with the Aguadilla levee, the residual flooding from the 100-year and 10-year rainfalls at the Espinar interior area were determined from the hydraulic simulation of the levee system against the time-varying flood stage of the levee interior area. The extent of the residual flooding along the Espinar levee is traced in Plate 12. The peak stage for the 100-year interior area flooding reached only 2.37 meters, while that of the 10-year flood stood at 2.14 meters.

Numbered locations in Plate 12 refer to the elevations listed in Table 15. Significant beneficiary differences in water surface elevations are achieved in the Espinar area as a result of the construction of the levee. As such, the levee will reduce flood proofing requirements in this sector. A lateral flood profile along the Espinar interior area (located in Plate 12) is depicted in Figure 7, showing the significant reduction in the extent of flooding achieved by the levee system.

### 6.3.3 Flooding at the Tablonal Area

The other significant area flooded by Río Culebrinas is the Tablonal sector, located south of the river and west of Road PR-115. A sizable portion of the community thereon is highly susceptible to frequent flooding due to its proximity to the river. Those homes where built on Río Culbreinas' floodway as indicated on flood map _____. Regulatory Agencies (USACE, DNER) have recommended that these families be relocated due to their risk of flood damage and the fact that building levees on the area are would require relocation of the same families these works would protect.

This area is only slightly affected by the marina project, as evidenced by the comparison between water surface elevations from the FIS and the present study at several locations. Plate 13 identifies the locations where the flood elevations are compared, while Table 16 lists the numerical comparisons. At only one location is a difference observed that would slightly exceed 6 inches, amounting to less than a 13 % change in flood depth. These results are well within tolerances permitted in PR Planning Regulation Number 13.

It is worth noting that the water surface elevations proposed in the U.S. Army Corps levee study (Ref. 7) show an average increase of about 9.8 inches within the Tablonal sector, albeit with a different simulation approach and conceptualization. Also, as stated before, USACE estimated flows were lower than those used on this study and do not meet FEMA requirements. As such, the proposed marina project provides the benefit of a lower impact.

Due to its proximity to the main course of Río Culebrinas, the Tablonal sector would benefit from the implementation of some flood-proofing activity, or non-structural flood measures, for those housing units likely to be affected by flooding.

## VII. EVALUATION OF EXTREME EVENTS

**The hydrologic-hydraulic study discussed in earlier sections is based on an extreme event of a 1% annual excess probability. In the interest of evaluating even more extreme scenarios, two additional levee simulations are discussed in this section considering the most likely catastrophic events that could befall the marina project. These consist of a severe clogging of the marina outlet and an extreme rise in stillwater elevation coincidental with the river base flooding. The latter scenario is extremely unlikely and would represent just about the upper limit of this type of situation.**

**A levee breach scenario will be considered in the design phase of the project, as requested for the LOMR application. The breach analysis must be performed with the final design parameters of the levee system. Likewise, the consideration of global warming effects need not be considered at the present stage. Neither FEMA nor NOAA included global warming effects in their respective studies. The latest FIRM from FEMA did not address global warming concerns. NOAA did not find evidence of global warming effects on the island-wide rainfall data used for developing Atlas 14, and excluded such considerations from their forecasts. At this time there is no reliable prediction of what foreseeable impact global warming will effect on the Aguadilla coastline.**

**The first scenario considered in this section is the clogging of the marina outlet by debris of such density that a nearly complete obstruction of the flow within the levees is obtained. The results of this simulation are presented, in terms of the resulting water surface profile, in Figure 8. In the figure, the resulting flood level is labeled as the 100-year complete obstruction. As expected, the levees will be appreciable overtopped near the coastline, while further inland very little effects are noted up to a distance of about 900 meters, and none beyond that.**

**The second scenario considers the impact of a coastal stillwater elevation of 3.7 meters, which is the suggested elevation in FEMA's revised FIRM for Río Culebrinas. The coincidence of this elevation with the 100-year flood from the river is considered by FEMA as an extremely unlikely event and was not modeled in their FIS. Nevertheless, the simulation has been performed for this study and the results are presented in Figure 9. The levees would be overtopped very near the coastline, but only slightly so, and not beyond an upstream distance of about 400 meters.**

**Interpretation of the results of the catastrophic events must accommodate the low probability of the extreme scenarios considered in the simulation. Designing a levee system to withstand such events may not be a practical alternative since the attendant return period would probably exceed even that of the probable maximum flood.**

# REFERENCES


1. Federal Emergency Management Agency (1999). *Flood Insurance Study: Commonwealth of Puerto Rico*, Washington, DC.

2. Scientific Software Group (2003). *Watershed Modeling System: User's Manual*, Washington, DC.

3. U.S. Army Corps of Engineers (2003). *Hydrology Modeling System: HEC-HMS*, Hydrologic Engineering Center, Davis, CA.

4. Soil Conservation Service (1986). *Urban Hydrology for Small Catchments*, Technical Release No. 55, Water Resources Publications, Littleton, Co.

5. U.S. Weather Bureau (1961). *Generalized Estimates of Probable Maximum Precipitation and Rainfall Frequency Data for Puerto Rico and the Virgin Islands*, Washington, D.C.

6. O'Brien, J.S. (2003). *Flo-2D User's Manual*, Nutrioso, AZ

7. U.S. Army Corps of Engineers (undated). *Draft Detailed Project Report and Environmental Assessment: Appendix A. Hydrology and Hydraulics*, Jacksonville District, Florida.

8. Sentürk, F. (1994). **Hydraulics of Dams and Reservoirs**, Water Resources Publications, Highlands Ranch, Co.

9. Streamline Technologies, Inc. (2002). *Interconnected Pond Routing: User's Manual*, Florida

TABLES

**Table 1. Major Recorded Annual Floods at Río Culebrinas**

| Date | Flow ($ft^3/s$) |
|---|---|
| September 16, 1975 | 41,200 |
| September 22, 1998 | 36,900 |
| May 17, 2003 | 31,800 |
| September 26, 2004 | 33,100 |
| November 17, 1968 | 30,00 |
| October 4, 1993 | 28,400 |

**Table 2. Río Culebrinas' Sub-Basin Areas and Curve Numbers**

| Sub-Basin | Drainage Area, $mi^2$ | Curve Number AMC-II | Curve Number AMC-III |
|---|---|---|---|
| A | 12.63 | 79.3 | 93.6 |
| B | 19.39 | 75.3 | 91.2 |
| C | 4.75 | 72.6 | 89.1 |
| D | 11.83 | 72.6 | 89.1 |
| E | 2.56 | 74.3 | 90.4 |
| F | 5.45 | 72.7 | 89.2 |
| G | 4.48 | 73.5 | 89.8 |
| H | 1.21 | 73.9 | 90.1 |
| I | 6.58 | 72.1 | 88.7 |
| J | 12.44 | 71.4 | 88.1 |
| K | 2.62 | 78.4 | 93.0 |
| L | 6.85 | 75.0 | 91.0 |
| M | 3.51 | 79.7 | 93.8 |
| N | 8.34 | 80.2 | 94.1 |

**Table 3. Río Culebrinas' Sub-Basin Lag Times**

| Sub-Basin | Lag Times, hrs AMC-II | AMC-III |
|---|---|---|
| A | 1.61 | 0.95 |
| B | 2.19 | 1.27 |
| C | 1.34 | 0.79 |
| D | 2.18 | 1.28 |
| E | 1.05 | 0.61 |
| F | 1.18 | 0.69 |
| G | 1.22 | 0.71 |
| H | 0.77 | 0.45 |
| I | 1.36 | 0.80 |
| J | 1.47 | 0.86 |
| K | 1.06 | 0.62 |
| L | 1.34 | 0.78 |
| M | 1.18 | 0.69 |
| N | 1.22 | 0.72 |

**Table 4. 24-hr Rainfall (inches) for Río Culebrinas Sub-Basins**

| | Percent Chance Storm | | | | | | |
|---|---|---|---|---|---|---|---|
| Sub-Basin | .02 | 1 | 2 | 4 | 10 | 20 | 50 |
| A | 12.5 | 9.00 | 8.00 | 7.50 | 7.00 | 6.00 | 4.50 |
| B | 12.5 | 9.50 | 9.00 | 8.10 | 7.25 | 6.20 | 4.63 |
| C | 12.5 | 9.00 | 8.00 | 7.50 | 7.00 | 6.00 | 4.50 |
| D | 12.5 | 9.00 | 8.25 | 7.75 | 7.00 | 6.00 | 4.50 |
| E | 12.5 | 9.00 | 8.00 | 7.50 | 7.00 | 6.00 | 4.50 |
| F | 12.5 | 9.00 | 8.10 | 7.50 | 7.00 | 6.00 | 4.50 |
| G | 12.5 | 9.00 | 8.00 | 7.50 | 7.00 | 6.00 | 4.50 |
| H | 12.5 | 9.00 | 8.00 | 7.50 | 7.00 | 6.00 | 4.50 |
| I | 12.5 | 9.00 | 8.10 | 7.50 | 7.00 | 6.00 | 4.50 |
| J | 12.5 | 9.00 | 8.00 | 7.50 | 7.00 | 6.00 | 4.50 |
| K | 12.5 | 9.00 | 8.10 | 7.50 | 7.00 | 6.00 | 4.50 |
| L | 12.5 | 9.00 | 8.00 | 7.50 | 7.00 | 6.00 | 4.50 |
| M | 12.5 | 9.25 | 8.25 | 7.50 | 7.00 | 6.00 | 4.50 |
| N | 12.5 | 9.00 | 8.00 | 7.50 | 7.00 | 6.00 | 4.50 |

**Table 5. Comparison of Río Culebrinas' Peak Flows at Highway-2 Bridge**

| Return Period (years) | Peak Flows ($m^3/s$) | |
|---|---|---|
| | Present Study* | FEMA FIS |
| 500 | 5743 | 5759 |
| 100 | 4062 | 4063 |
| 50 | 3198 | 3200 |
| 25 | 1757 | Not computed |
| 10 | 1639 | 1642 |
| 5 | 1286 | Not computed |
| 2 | 784 | Not computed |

* - The 500, 100, and 50-year floods are for AMC-III conditions. The others are for AMC-II conditions.

**Table 6. Caño Madre Vieja Resulting Water Surface Elevations for Existing and Project Conditions for 100-year Flood**

| | BRIDGE | PARTIAL DISTANCE, METERS | STATION, METERS | PRE-PROJECT WATER SURFACE ELEVATION | POST-PROJECT WATER SURFACE ELEVATION | DIFFERENCE IN WATER SURFACE ELEVATION, METERS |
|---|---|---|---|---|---|---|
| Reach : Caño Madre Vieja | | | | | | |
| | | 63.65 | 26+63.65 | 8.78 | 8.80 | 0.02 |
| | | 100.00 | 26+00.00 | 8.74 | 8.78 | 0.04 |
| | | 100.00 | 25+00.00 | 8.58 | 8.62 | 0.04 |
| | PR-2 | 100.00 | 24+00.00 | 8.25 | 8.29 | 0.04 |
| | | 100.00 | 23+00.00 | 7.73 | 7.90 | 0.17 |
| | | 100.00 | 22+00.00 | 7.40 | 7.73 | 0.33 |
| | | 100.00 | 21+00.00 | 7.07 | 7.42 | 0.35 |
| | | 100.00 | 20+00.00 | 6.95 | 7.23 | 0.28 |
| | | 100.00 | 19+00.00 | 6.84 | 7.12 | 0.28 |
| | PR-418 | 100.00 | 18+00.00 | 6.73 | 7.05 | 0.32 |
| | | 100.00 | 17+00.00 | 6.62 | 6.98 | 0.36 |
| | | 100.00 | 16+00.00 | 6.52 | 6.90 | 0.38 |
| | | 100.00 | 15+00.00 | 6.43 | 6.83 | 0.40 |
| | | 100.00 | 14+00.00 | 6.32 | 6.77 | 0.45 |
| | PR-115 | 100.00 | 13+00.00 | 6.19 | 6.70 | 0.51 |
| | | 100.00 | 12+00.00 | 5.92 | 6.52 | 0.60 |
| | | 100.00 | 11+00.00 | 5.66 | 6.27 | 0.61 |
| | | 100.00 | 10+00.00 | 5.32 | 5.93 | 0.61 |
| | | 100.00 | 09+00.00 | 5.04 | 5.61 | 0.57 |
| | | 100.00 | 08+00.00 | 4.79 | 5.27 | 0.48 |
| | | 100.00 | 07+00.00 | 4.55 | 5.01 | 0.46 |
| | | 100.00 | 06+00.00 | 4.32 | 4.78 | 0.46 |
| | | 100.00 | 05+00.00 | 4.01 | 4.50 | 0.49 |
| | | 100.00 | 04+00.00 | 3.64 | 4.21 | 0.57 |
| | | 100.00 | 03+00.00 | 3.23 | 3.78 | 0.55 |
| | | 100.00 | 02+00.00 | 2.80 | 3.30 | 0.50 |
| | | 100.00 | 01+00.00 | 2.80 | 3.00 | 0.20 |
| | | 0.00 | 00+00.00 | 2.80 | 3.00 | 0.20 |

Table 7. Rio Culebrinas Wave Runup and Wind Setup

| LEVEE SEGMENT | LEVEE STATION | FETCH LENGTH (M) | WIND SPEED KM/HR | WAVE PERIOD (SEC) | WAVE HEIGHT (M) | WAVE RUNUP (M) | WIND SETUP (M) | TOTAL (M) |
|---|---|---|---|---|---|---|---|---|
| AGUADILLA | 6+67 | 502 | 48 | 1.58 | 0.57 | 0.30 | 0.01 | 0.88 |
| ESPINAR | 4+09 | 645 | 48 | 1.58 | 0.57 | 0.30 | 0.01 | 0.88 |

Table 8. Rio Culebrinas 100-year Levee Crest Elevations

| LEVEE SEGMENT | ROAD RAMP | PARTIAL DISTANCE (M) | DISTANCE | LEVEE STATION (M) | WAVE RUNUP AND WIND SETUP FOR 48 KM/HOUR WIND (M) | TOTAL MINIMUM FREEBOARD (M) | LEVEE CREST ELEVATION (M) | AVERAGE GROUND ELEVATION (M) | LEVEE HEIGHT (M) | POST-PROJECT WATER SURFACE ELEVATION (M) | PRE-PROJECT WATER SURFACE ELEVATION (M) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AGUADILLA | | | | | | | | | | | |
| | | 19.59 | 1762.88 | 17+62.88 | 0.88 | 1.07 | 8.07 | 6.91 | 1.16 | 7.00 | 6.32 |
| | | 80.41 | 1743.29 | 17+43.29 | 0.88 | 1.07 | 8.05 | 3.66 | 4.39 | 6.98 | 6.30 |
| | | 100.00 | 1662.88 | 16+62.88 | 0.88 | 1.06 | 7.95 | 3.49 | 4.46 | 6.89 | 6.27 |
| | PR-418 | 100.00 | 1562.88 | 15+62.88 | 0.88 | 1.22 | 7.92 | 2.79 | 5.13 | 6.70 | 6.19 |
| | | 100.00 | 1462.88 | 14+62.88 | 0.88 | 1.22 | 7.74 | 3.00 | 4.74 | 6.52 | 6.07 |
| | PR-115 | 100.00 | 1362.88 | 13+62.88 | 0.88 | 1.03 | 7.40 | 3.80 | 3.60 | 6.37 | 5.88 |
| | | 100.00 | 1262.88 | 12+62.88 | 0.88 | 1.02 | 7.22 | 2.50 | 4.72 | 6.20 | 5.63 |
| | | 100.00 | 1162.88 | 11+62.88 | 0.88 | 1.01 | 7.05 | 2.80 | 4.25 | 6.04 | 5.37 |
| | | 100.00 | 1062.88 | 10+62.88 | 0.88 | 1.01 | 6.75 | 2.50 | 4.25 | 5.74 | 5.12 |
| | | 100.00 | 962.88 | 09+62.88 | 0.88 | 1.00 | 6.40 | 2.50 | 3.90 | 5.40 | 4.86 |
| | | 100.00 | 862.88 | 08+62.88 | 0.88 | 0.99 | 6.08 | 2.50 | 3.58 | 5.09 | 4.61 |
| | | 100.00 | 762.88 | 07+62.88 | 0.88 | 0.98 | 5.77 | 0.50 | 5.27 | 4.79 | 4.37 |
| | | 100.00 | 662.88 | 06+62.88 | 0.88 | 0.97 | 5.47 | 2.20 | 3.27 | 4.50 | 4.15 |
| | | 100.00 | 562.88 | 05+62.88 | 0.88 | 0.96 | 5.16 | 0.50 | 4.66 | 4.20 | 3.91 |
| | | 100.00 | 462.88 | 04+62.88 | 0.88 | 0.95 | 4.85 | 2.00 | 2.85 | 3.90 | 3.66 |
| | | 100.00 | 362.88 | 03+62.88 | 0.88 | 0.95 | 4.56 | 2.00 | 2.56 | 3.61 | 3.41 |
| | | 100.00 | 262.88 | 02+62.88 | 0.88 | 0.94 | 4.27 | 1.60 | 2.67 | 3.33 | 3.17 |
| | | 100.00 | 162.88 | 01+62.88 | 0.88 | 0.93 | 4.06 | 1.70 | 2.36 | 3.13 | 2.91 |
| | | 53.22 | 62.88 | 00+62.88 | 0.88 | 0.92 | 3.92 | 1.40 | 2.52 | 3.00 | 2.80 |
| | | 9.66 | 9.66 | 00+09.66 | 0.88 | 0.92 | 3.92 | 2.50 | 1.42 | 3.00 | 2.80 |
| | | 0.00 | 0.00 | 00+00.00 | 0.88 | 0.91 | 3.30 | 3.30 | 0.00 | 3.00 | 2.80 |
| | | | | | | | | Avg. Height = | 3.42 | | |
| ESPINAR | | | | | | | | | | | |
| | | 94.0 | 2194.0 | 21+93.99 | 0.88 | 1.07 | 5.47 | 4.50 | 0.97 | 4.40 | 4.44 |
| | | 100.0 | 2100.0 | 21+00.00 | 0.88 | 1.06 | 5.50 | 3.00 | 2.50 | 4.44 | 4.46 |
| | | 100.0 | 2000.0 | 20+00.00 | 0.88 | 1.05 | 5.70 | 3.00 | 2.70 | 4.65 | 4.65 |
| | | 100.0 | 1900.0 | 19+00.00 | 0.88 | 1.05 | 6.18 | 3.00 | 3.18 | 5.13 | 5.09 |
| | | 100.0 | 1800.0 | 18+00.00 | 0.88 | 1.04 | 6.54 | 3.00 | 3.54 | 5.50 | 5.46 |
| | | 100.0 | 1700.0 | 17+00.00 | 0.88 | 1.03 | 7.03 | 3.50 | 3.53 | 6.00 | 5.88 |
| | | 100.0 | 1600.0 | 16+00.00 | 0.88 | 1.22 | 7.62 | 2.90 | 4.72 | 6.40 | 6.10 |
| | PR-442 | 100.0 | 1500.0 | 15+00.00 | 0.88 | 1.22 | 7.59 | 4.50 | 3.09 | 6.37 | 6.12 |
| | | 100.0 | 1400.0 | 14+00.00 | 0.88 | 1.22 | 7.54 | 3.50 | 4.04 | 6.32 | 6.11 |
| | | 100.0 | 1300.0 | 13+00.00 | 0.88 | 1.22 | 7.49 | 3.90 | 3.59 | 6.27 | 6.03 |
| | | 100.0 | 1200.0 | 12+00.00 | 0.88 | 1.00 | 7.11 | 4.00 | 3.11 | 6.11 | 5.77 |
| | | 100.0 | 1100.0 | 11+00.00 | 0.88 | 0.99 | 6.92 | 2.50 | 4.42 | 5.93 | 5.44 |
| | | 100.0 | 1000.0 | 10+00.00 | 0.88 | 0.98 | 6.67 | 2.30 | 4.37 | 5.69 | 5.19 |
| | | 100.0 | 900.0 | 09+00.00 | 0.88 | 0.98 | 6.36 | 1.50 | 4.86 | 5.38 | 4.92 |
| | | 100.0 | 800.0 | 08+00.00 | 0.88 | 0.97 | 6.07 | 1.50 | 4.57 | 5.1 | 4.69 |
| | | 100.0 | 700.0 | 07+00.00 | 0.88 | 0.96 | 5.83 | 1.50 | 4.33 | 4.87 | 4.42 |
| | | 100.0 | 600.0 | 06+00.00 | 0.88 | 0.96 | 5.56 | 1.00 | 4.56 | 4.6 | 4.08 |
| | | 100.0 | 500.0 | 05+00.00 | 0.88 | 0.95 | 5.26 | 1.30 | 3.96 | 4.31 | 3.78 |
| | | 100.0 | 400.0 | 04+00.00 | 0.88 | 0.94 | 5.00 | 1.50 | 3.50 | 4.06 | 3.53 |
| | | 100.0 | 300.0 | 03+00.00 | 0.88 | 0.94 | 4.71 | 1.50 | 3.21 | 3.77 | 3.23 |
| | | 100.0 | 200.0 | 02+00.00 | 0.88 | 0.93 | 4.46 | 1.50 | 2.96 | 3.53 | 2.96 |
| | | 50.0 | 100.0 | 01+00.00 | 0.88 | 0.92 | 4.04 | 2.00 | 2.04 | 3.12 | 2.80 |
| | | 50.0 | 50.0 | 00+50.00 | 0.88 | 0.92 | 3.92 | 1.50 | 2.42 | 3.00 | 2.80 |
| | | 0.0 | 0.0 | 00+00.00 | 0.88 | 0.91 | 3.91 | 1.00 | 2.91 | 3.00 | 2.80 |
| | | | | | | | | Avg. Height = | 3.46 | | |

**Table 9. 24-hr Rainfall (in.) for Discovery Bay IFH Watershed Study Area**

| Return Periods | Precipitation, in. |
|---|---|
| 100-year | 9.5 |
| 50-year | 8.5 |
| 25-year | 7.5 |
| 10-year | 7.0 |
| 5-year | 6.0 |
| 2-year | 4.5 |
| 1-year | 3.5 |

**Table 10. Discovery Bay Watershed Hydrologic Model Simulation Parameters for Study Area**

| Sub-Basin | Area, $mi^2$ | Lag times, hrs | CN |
|---|---|---|---|
| Aguadilla Levee | 1.14 | 0.60 | 79.5 |
| Espinar Levee | 0.38 | 0.65 | 83.6 |

**Table 11. Estimated Flood Flows for Discovery Bay IFH Watershed Study Area**

| Return Period, years | Peak Flows, $m^3/s$ | |
|---|---|---|
| | Aguadilla | Espinar |
| 100 | 74.9 | 25.1 |
| 50 | 65.0 | 22.0 |
| 25 | 55.1 | 18.8 |
| 10 | 50.2 | 17.3 |
| 5 | 40.4 | 14.1 |
| 2 | 26.0 | 9.5 |
| 1 | 17.0 | 6.4 |

**Table 12. Discovery Bay Interior Drainage Structures Hydraulic Design Data Aguadilla Levee**

| ID | Station | Diameter (in.) | Length (m) | Slope | Upstream Invert Elevation (m) | Downstream Invert Elevation (m) | Type of Control |
|---|---|---|---|---|---|---|---|
| A1 | 1+06.39 | 60 | 21.330 | 0.02344 | 0.500 | 0.000 | FLAPGATE |
| A2 | 4+42.74 | 60 | 21.330 | 0.02344 | 0.500 | 0.000 | FLAPGATE |
| A3 | 5+58.53 | 60 | 21.330 | 0.02344 | 0.500 | 0.000 | FLAPGATE |
| A4 | 8+82.81 | 60 | 21.330 | 0.02344 | 2.500 | 2.000 | FLAPGATE |
| A5 | 11+33.01 | 60 | 21.330 | 0.02344 | 2.000 | 1.500 | FLAPGATE |
| A6 | 12+90.61 | 60 | 21.330 | 0.02344 | 2.000 | 1.500 | FLAPGATE |
| A7 | 15+94.27 | 60 | 21.330 | 0.01360 | 2.790 | 2.500 | FLAPGATE |
| A8 | 17+00.13 | 60 | 21.330 | 0.04219 | 3.500 | 2.600 | FLAPGATE |

Table 13. Aguadilla 10-yr and 100-yr Interior Flood Water Surface Elevations

| ID | GROUND ELEVATION (M) | FEMA EFFECTIVE BFE (M) | PROPOSED WSE 100YR (M) | PROPOSED WSE 10YR (M) | 100-YEAR DIFFERENCE (M) |
|---|---|---|---|---|---|
| 1 | 2.64 | | | | |
| 2 | 2.24 | 2.80 | 2.94 | 2.77 | 0.14 |
| 3 | 1.98 | 2.80 | 2.94 | 2.77 | 0.14 |
| 4 | 1.54 | 2.97 | 2.94 | 2.77 | -0.03 |
| 5 | 2.19 | 3.10 | 2.94 | 2.77 | -0.16 |
| 6 | 2.22 | 3.26 | 2.94 | 2.77 | -0.32 |
| 7 | 2.70 | 2.80 | 2.94 | 2.77 | 0.14 |
| 8 | 2.00 | 2.89 | 2.94 | 2.77 | 0.05 |
| 9 | 2.30 | 2.80 | 2.94 | 2.77 | 0.14 |
| 10 | 1.50 | 2.80 | 2.94 | 2.77 | 0.14 |
| 11 | 1.40 | 3.03 | 2.94 | 2.77 | -0.09 |
| 12 | 2.30 | 3.02 | 2.94 | 2.77 | -0.08 |
| 13 | 2.10 | 3.06 | 2.94 | 2.77 | -0.12 |
| 14 | 2.89 | 3.30 | 2.94 | 2.77 | -0.36 |
| 15 | 2.64 | 3.41 | 2.94 | 2.77 | -0.47 |
| 16 | 2.60 | 3.12 | 2.94 | 2.77 | -0.18 |
| 17 | 1.80 | 3.34 | 2.94 | 2.77 | -0.40 |
| 18 | 2.20 | 3.77 | 2.94 | 2.77 | -0.83 |
| 19 | 2.30 | 4.01 | 2.94 | 2.77 | -1.07 |
| 20 | 2.10 | 3.68 | 2.94 | 2.77 | -0.74 |
| 21 | 2.10 | 4.01 | 2.94 | 2.77 | -1.07 |
| 22 | 2.70 | 4.03 | 2.94 | 2.77 | -1.09 |
| 23 | 2.80 | 4.25 | 2.94 | 2.77 | -1.31 |
| 24 | 1.70 | 4.24 | 2.94 | 2.77 | -1.30 |
| 25 | 2.60 | 4.49 | 2.94 | 2.77 | -1.55 |
| 26 | 2.40 | 4.54 | 2.94 | 2.77 | -1.60 |
| 27 | 2.10 | 4.63 | 2.94 | 2.77 | -1.69 |
| 28 | 2.70 | 4.84 | 2.94 | 2.77 | -1.90 |
| 29 | 2.30 | 4.98 | 2.94 | 2.77 | -2.04 |
| 30 | 2.40 | 5.18 | 2.94 | 2.77 | -2.24 |

**Table 14. Discovery Bay Interior Drainage Structures Hydraulic Design Data Espinar Levee**

| ID | Station | Diameter (in.) | Length (m) | Slope (m/m) | Upstream Invert Elevation (m) | Downstream Invert Elevation (m) | Type of Control |
|---|---|---|---|---|---|---|---|
| E1 | 1+14.09 | 60 | 15.240 | 0.09843 | 1.500 | 0.000 | FLAPGATE |
| E2 | 1+14.09 | 60 | 15.240 | 0.09843 | 1.500 | 0.000 | FLAPGATE |

Table 15. Espinar Community 10-yr and 100-yr Interior Flood Water Surface Elevations

| ID | GROUND ELEVATION (M) | FEMA EFFECTIVE BFE (M) | PROPOSED WSE 100YR (M) | PROPOSED WSE 10YR (M) | DIFFERENCE (M) |
|---|---|---|---|---|---|
| 1 | 2.60 | 3.20 | 2.37 | 2.14 | -0.83 |
| 2 | 1.60 | 3.24 | 2.37 | 2.14 | -0.87 |
| 3 | 1.30 | 2.97 | 2.37 | 2.14 | -0.60 |
| 4 | 1.70 | 3.20 | 2.37 | 2.14 | -0.83 |
| 5 | 1.10 | 2.97 | 2.37 | 2.14 | -0.60 |
| 6 | 1.30 | 3.28 | 2.37 | 2.14 | -0.91 |
| 7 | 2.70 | 3.36 | 2.37 | 2.14 | -0.99 |
| 8 | 2.20 | 3.80 | 2.37 | 2.14 | -1.43 |
| 9 | 2.30 | 3.93 | 2.37 | 2.14 | -1.56 |
| 10 | 2.10 | 4.15 | 2.37 | 2.14 | -1.78 |
| 11 | 2.50 | 4.15 | 2.37 | 2.14 | -1.78 |
| 12 | 1.60 | 2.54 | 2.37 | 2.14 | -0.17 |
| 13 | 1.00 | 2.95 | 2.37 | 2.14 | -0.58 |
| 14 | 1.90 | 3.20 | 2.37 | 2.14 | -0.83 |
| 15 | 2.30 | 3.60 | 2.37 | 2.14 | -1.23 |
| 16 | 2.60 | 3.73 | 2.37 | 2.14 | -1.36 |
| 17 | 2.20 | 4.06 | 2.37 | 2.14 | -1.69 |
| 18 | 2.30 | 4.19 | 2.37 | 2.14 | -1.82 |
| 19 | 1.70 | 4.24 | 2.37 | 2.14 | -1.87 |
| 20 | 1.50 | 4.41 | 2.37 | 2.14 | -2.04 |
| 21 | 2.50 | 4.58 | 2.37 | 2.14 | -2.21 |
| 22 | 2.60 | 4.60 | 2.37 | 2.14 | -2.23 |

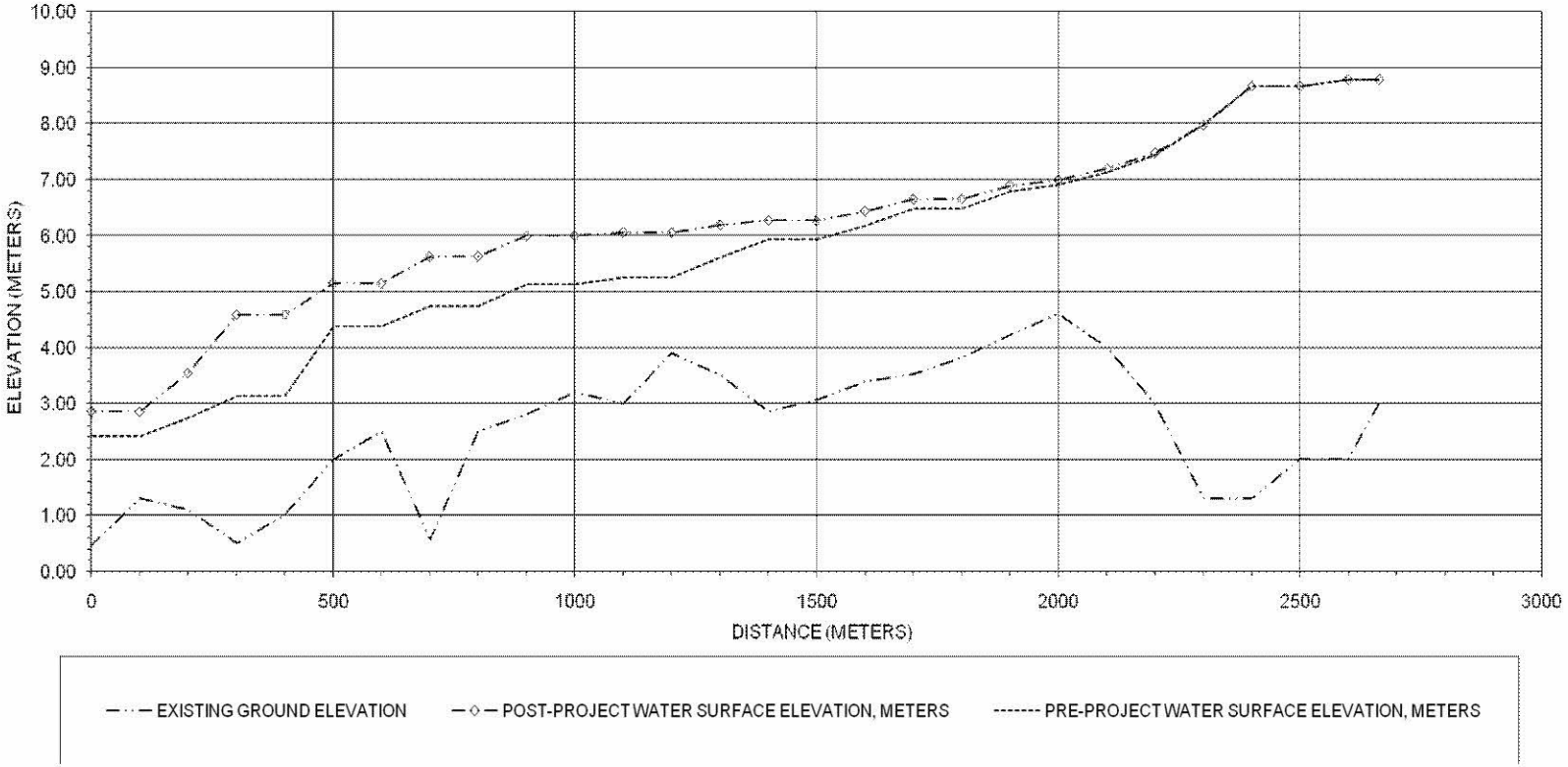
Table 16. Tablonal Community 100-year Flood Depths

| ID | GROUND ELEVATION (M) | EXISTING BFE (M) | PROPOSED WSE 100YR (M) | DIFFERENCE (M) | DIFFERENCE (INCHES) | WATER DEPTH (M) |
|---|---|---|---|---|---|---|
| 1 | 2.51 | 3.56 | 3.65 | 0.09 | 3.5 | 1.14 |
| 2 | 2.05 | 3.65 | 3.76 | 0.11 | 4.3 | 1.71 |
| 3 | 2.75 | 3.84 | 3.94 | 0.10 | 3.9 | 1.19 |
| 4 | 2.44 | 3.90 | 4.05 | 0.15 | 5.9 | 1.61 |
| 5 | 2.93 | 4.07 | 4.16 | 0.09 | 3.5 | 1.23 |
| 6 | 2.42 | 4.11 | 4.23 | 0.12 | 4.7 | 1.81 |
| 7 | 2.62 | 4.17 | 4.28 | 0.11 | 4.3 | 1.66 |
| 8 | 2.71 | 4.26 | 4.36 | 0.10 | 3.9 | 1.65 |
| 9 | 3.02 | 4.30 | 4.39 | 0.09 | 3.5 | 1.37 |
| 10 | 3.29 | 4.63 | 4.80 | 0.17 | 6.7 | 1.51 |
| 11 | 4.27 | 5.67 | 5.81 | 0.14 | 5.5 | 1.54 |
| 12 | 5.60 | 6.11 | 6.22 | 0.11 | 4.3 | 0.62 |

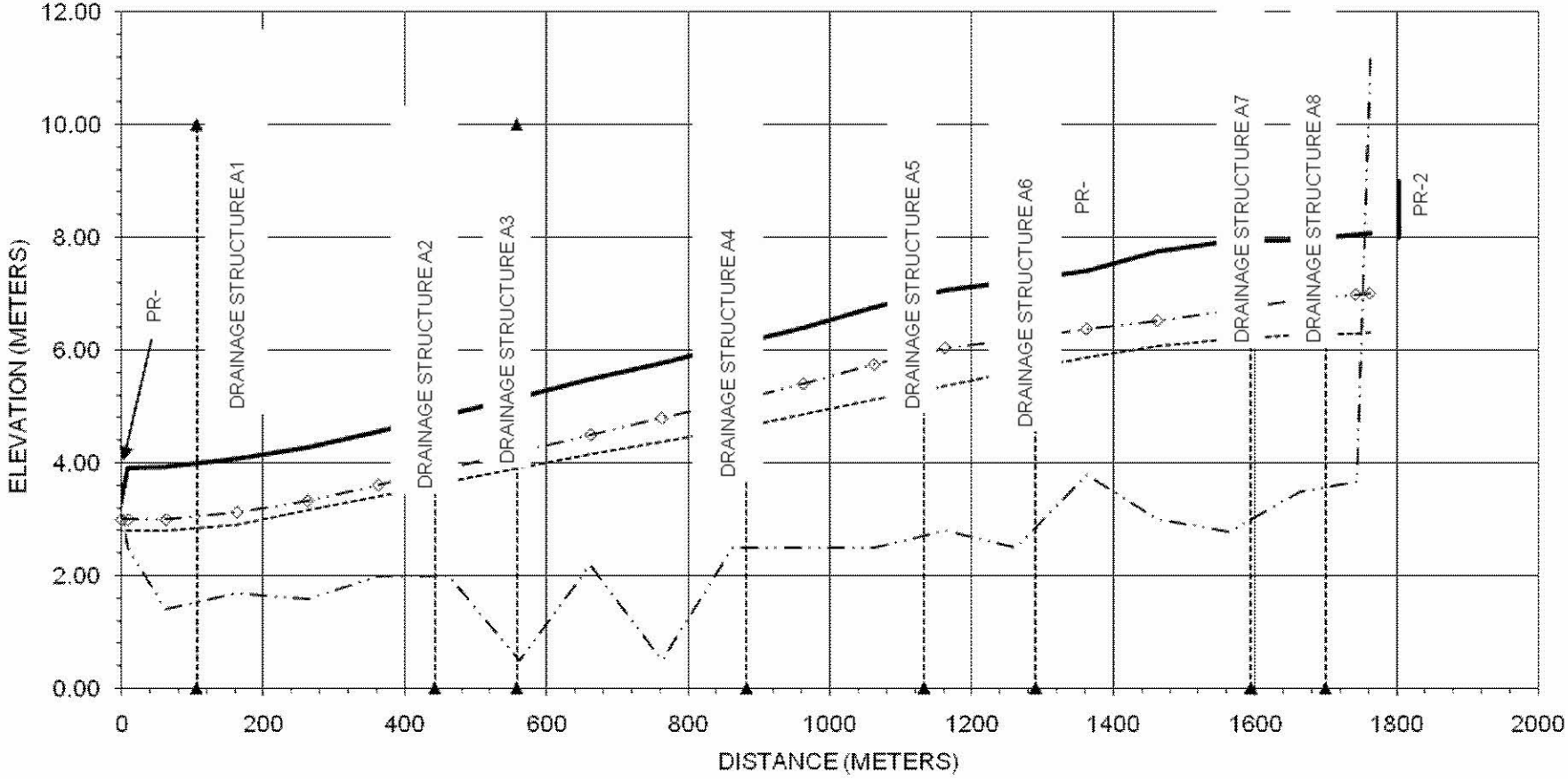
# IX. FIGURES

Figure 1. Aerial View of Project Area

FIGURE 2. RIO CULEBRINAS
CAÑO MADRE VIEJA WATER SURFACE PROFILES
FOR PROPOSED DISCOVERY BAY RESORT AND MARINA PLAN
100-YEAR FLOOD



# FIGURE 3. RIO CULEBRINAS
# AGUADILLA LEVEE PROFILES
# FOR PROPOSED DISCOVERY BAY RESORT AND MARINA PLAN
# 100-YEAR FLOOD




EXISTING GROUND ELEVATION
LEVEE CREST ELEVATION
POST-PROJECT WATER SURFACE ELEVATION (M)
PRE-PROJECT WATER SURFACE ELEVATION (M)

FIGURE 4. RIO CULEBRINAS
ESPINAR LEVEE PROFILES
FOR PROPOSED DISCOVERY BAY RESORT AND MARINA PLAN
100-YEAR FLOOD

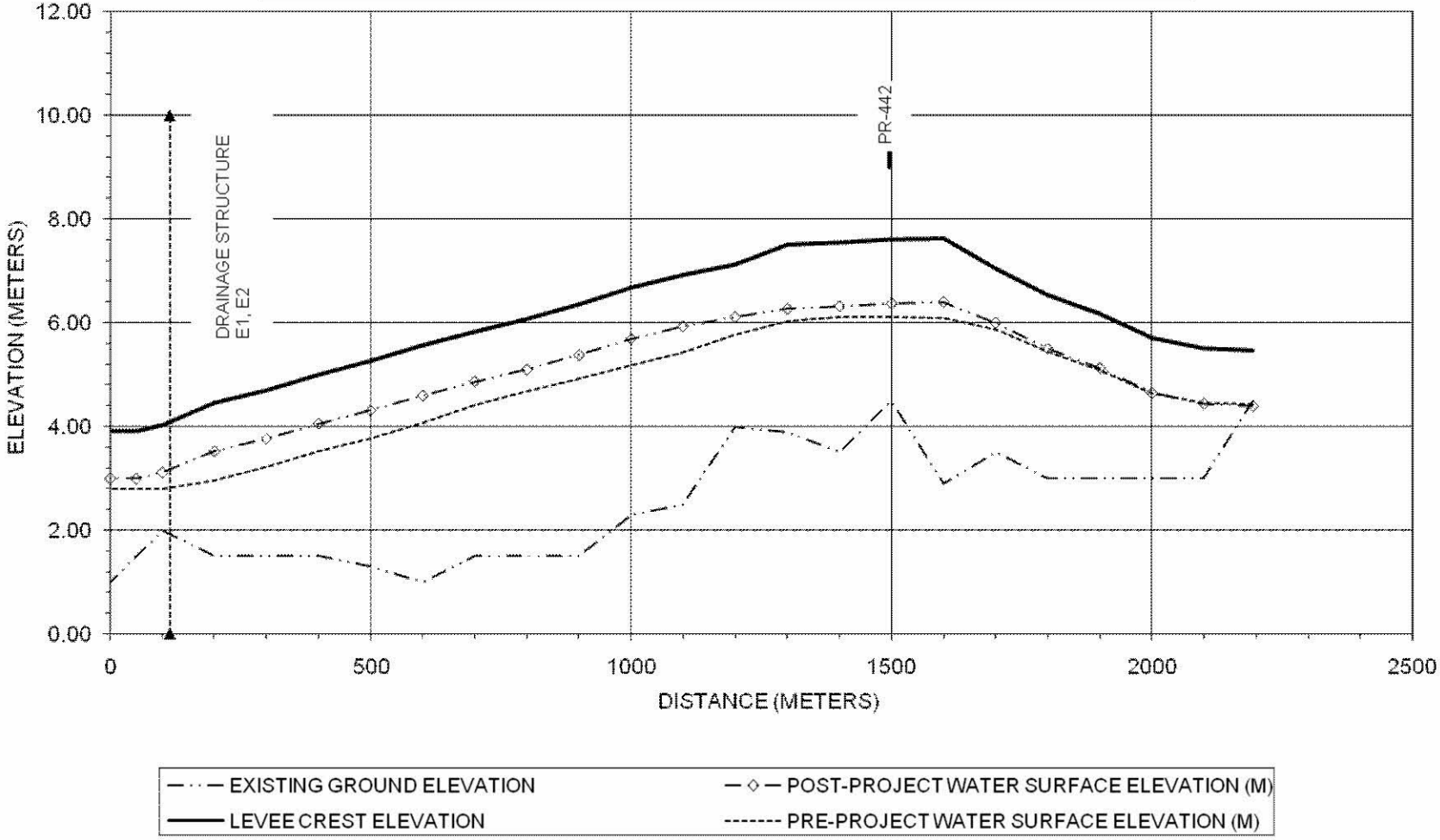


**FIGURE 5**
**COMPARISON OF PROPOSED LEVEE PROFILES WITH LEVEES FROM THE ARMY CORPS STUDY**

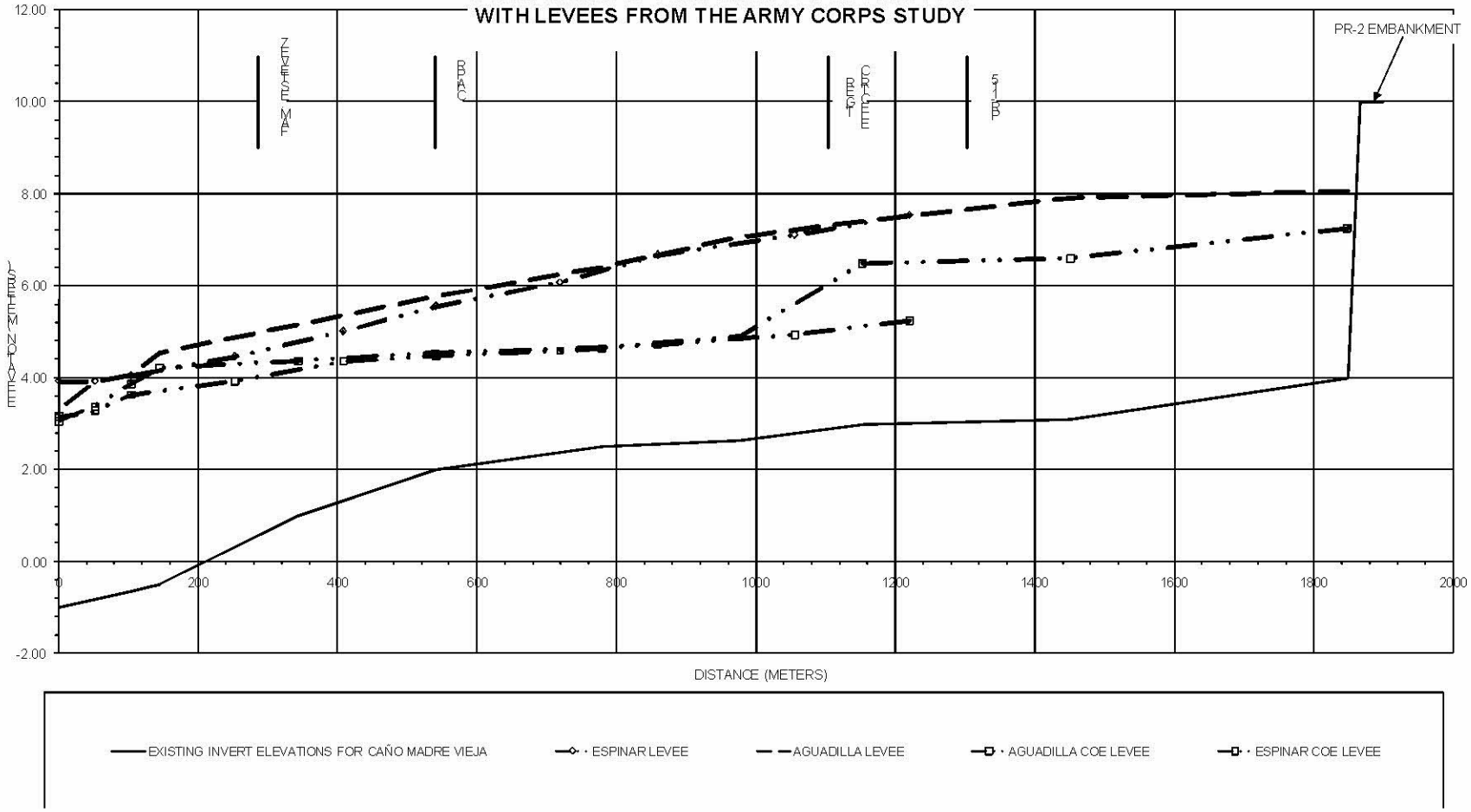


FIGURE 6. RIO CULEBRINAS
AGUADILLA IFH WATER SURFACE ELEVATIONS PROFILES
FOR PROPOSED DISCOVERY BAY RESORT AND MARINA PLAN
FEMA, 100 and 10 YEAR FLOOD

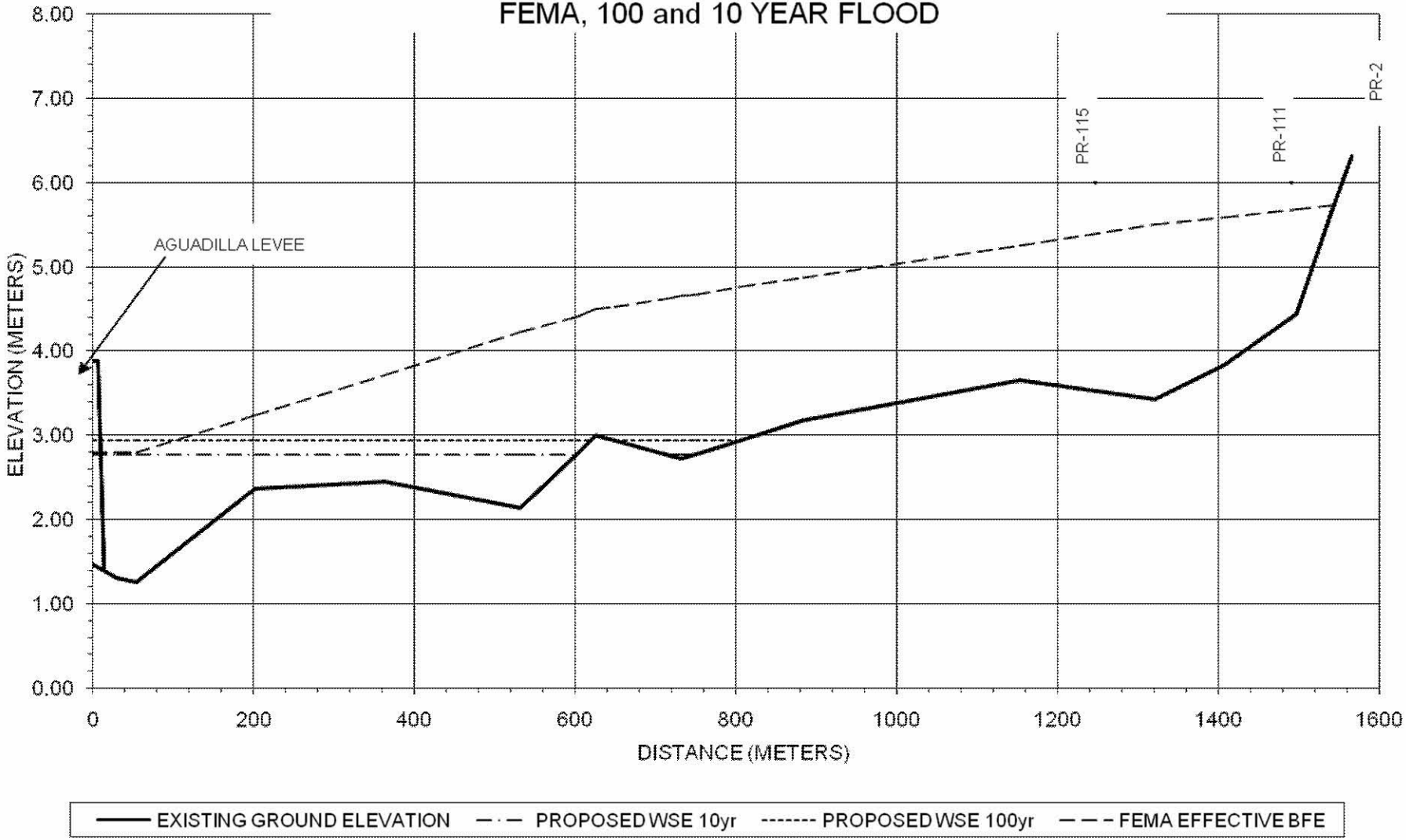


FIGURE7. RIO CULEBRINAS
ESPINAR IFH WATER SURFACE ELEVATIONS PROFILES
FOR PROPOSED DISCOVERY BAY RESORT AND MARINA PLAN
FEMA, 100 and 10 YEAR FLOOD

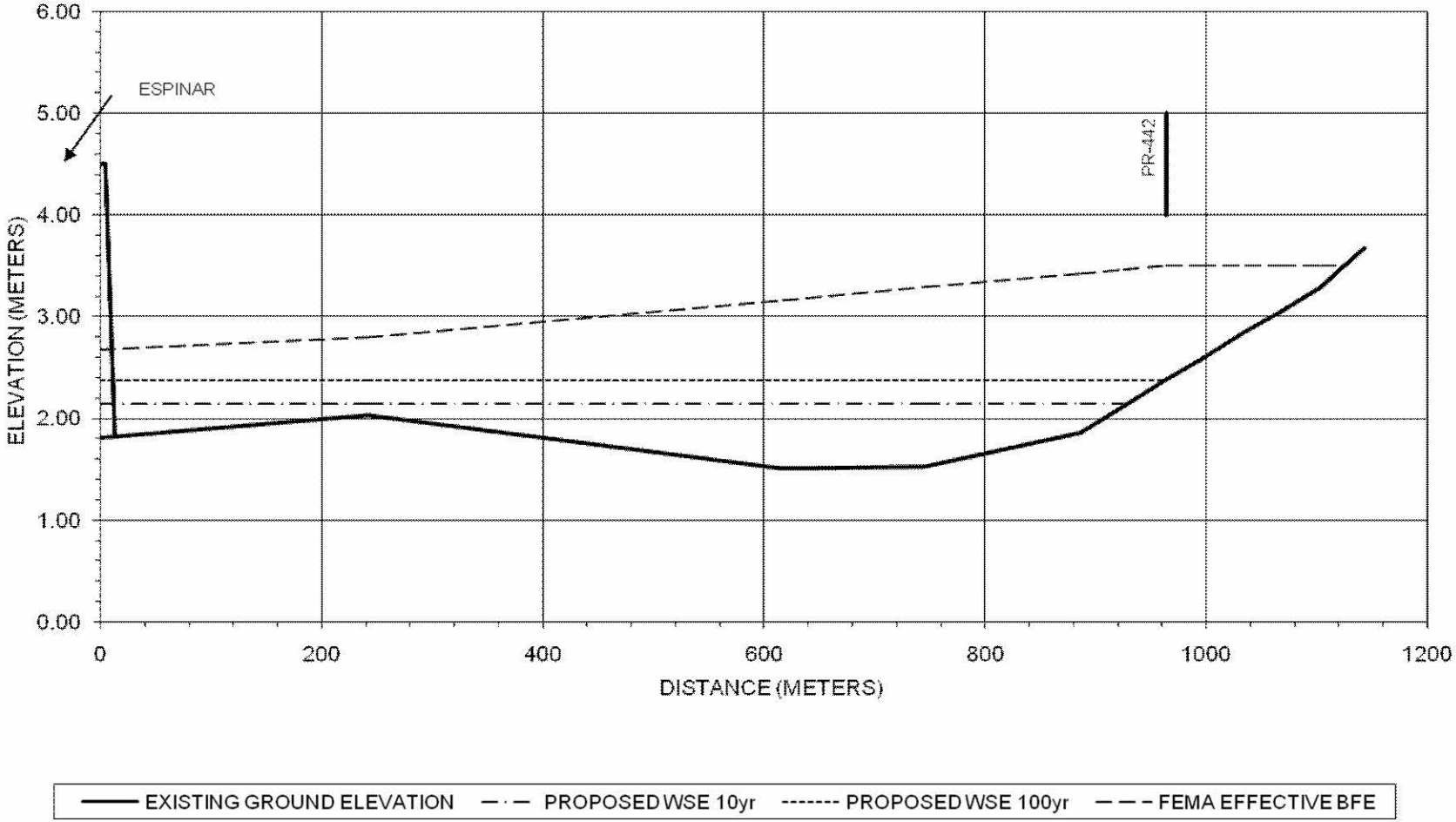
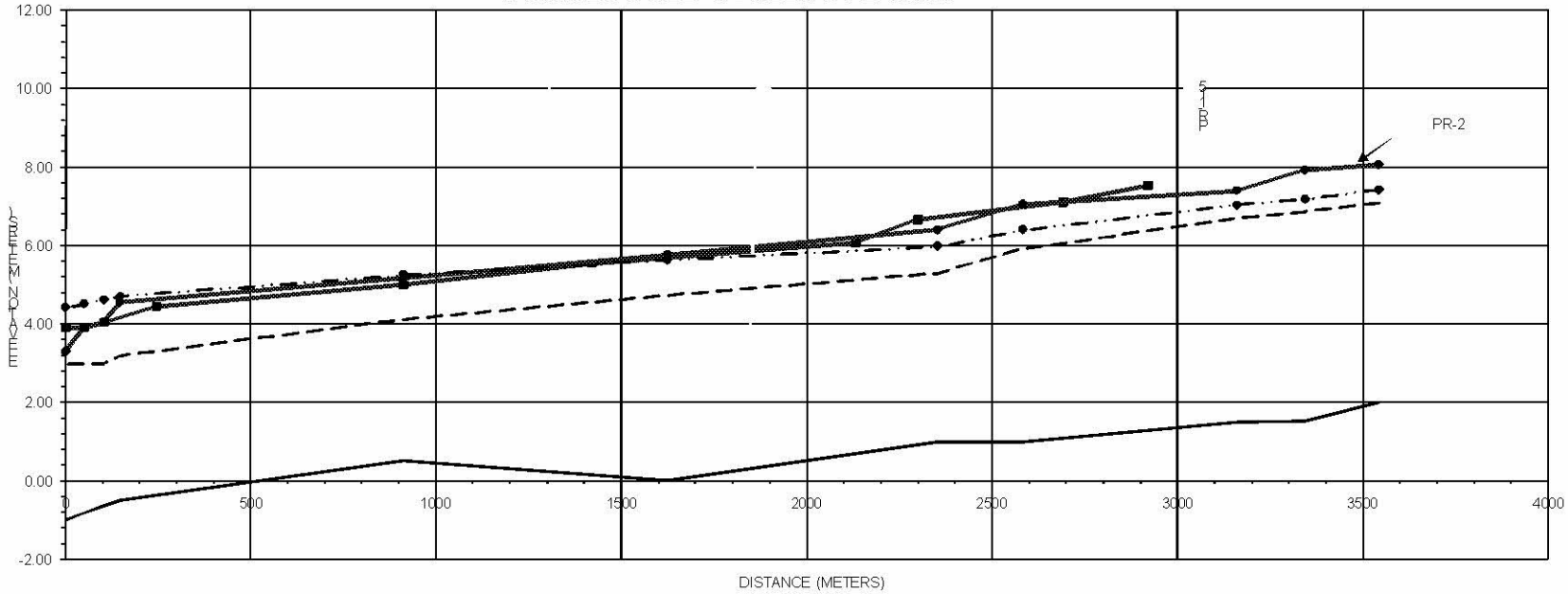


**FIGURE 8**
**FLOOD PROFILE ALONG LEVEES**
**FOR CLOGGED OUTLET SCENARIO**




EXISTING INVERT ELEVATIONS FOR CAÑO MADRE VIEJA — ESPINAR LEVEE — AGUADILLA LEVEE — 100-YR PROPOSED WATER SURFACE ELEVATION — 100-YR COMPLETE OBSTRUCTION BETWEEN LEVEES

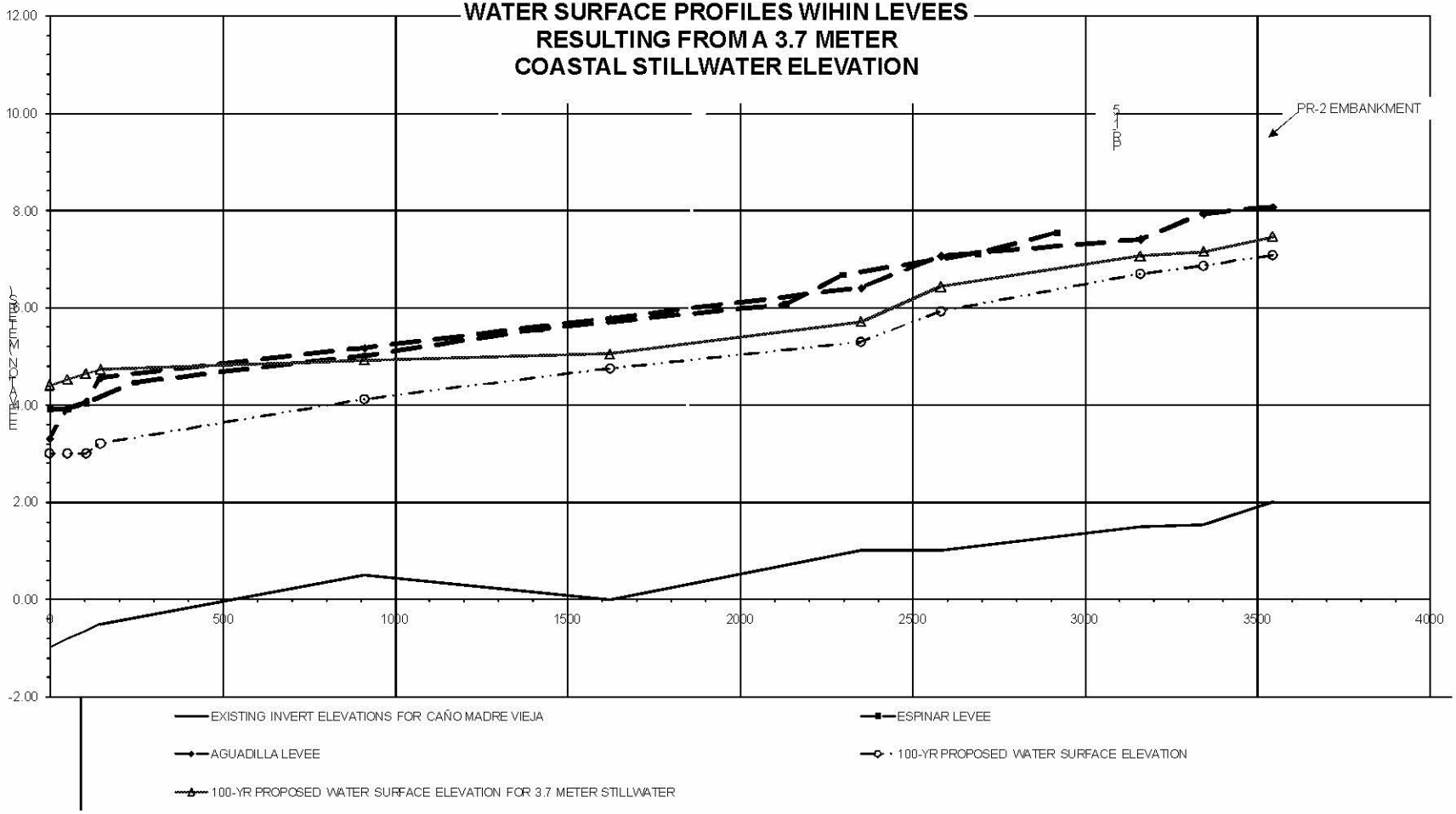



**FIGURE 9.**
**WATER SURFACE PROFILES WIHIN LEVEES RESULTING FROM A 3.7 METER COASTAL STILLWATER ELEVATION**