TECHNICAL MEMORANDUM

Date: June 1, 2005

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

From: Kenneth C. Jones, P.G.
(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

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.

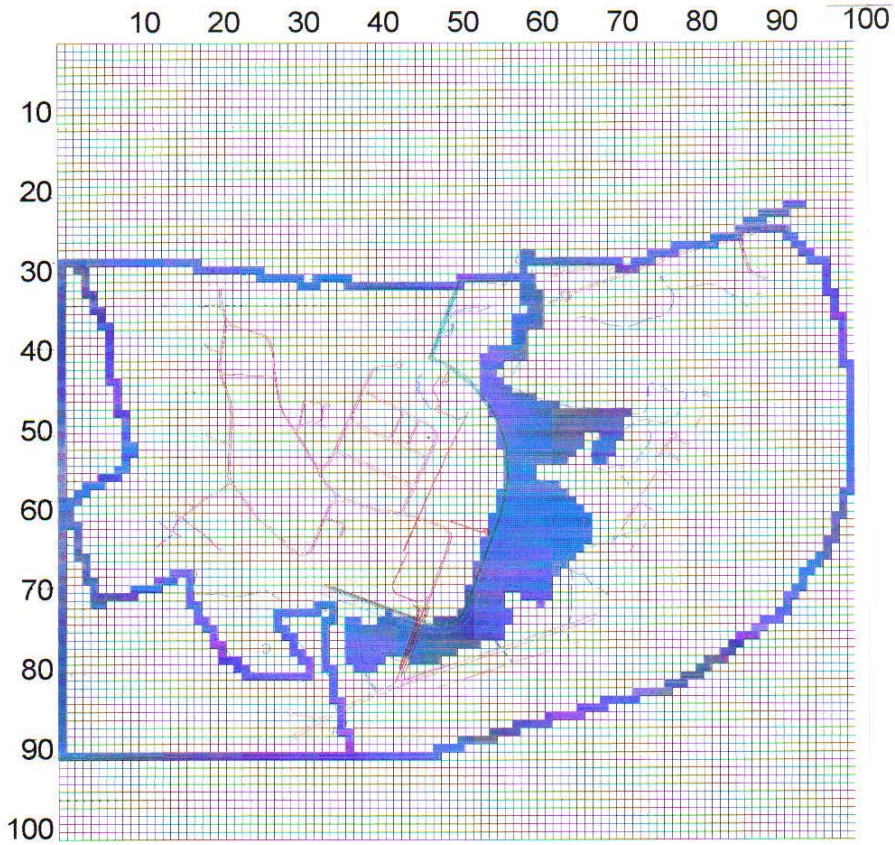
McDonald, M.G. and A. W. Harbaugh, 1988. A Modular Three-Dimensional Finite Difference Ground-Water Flow Model. Techniques of the United States Geological Survey, Open File Report 83-875.

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.

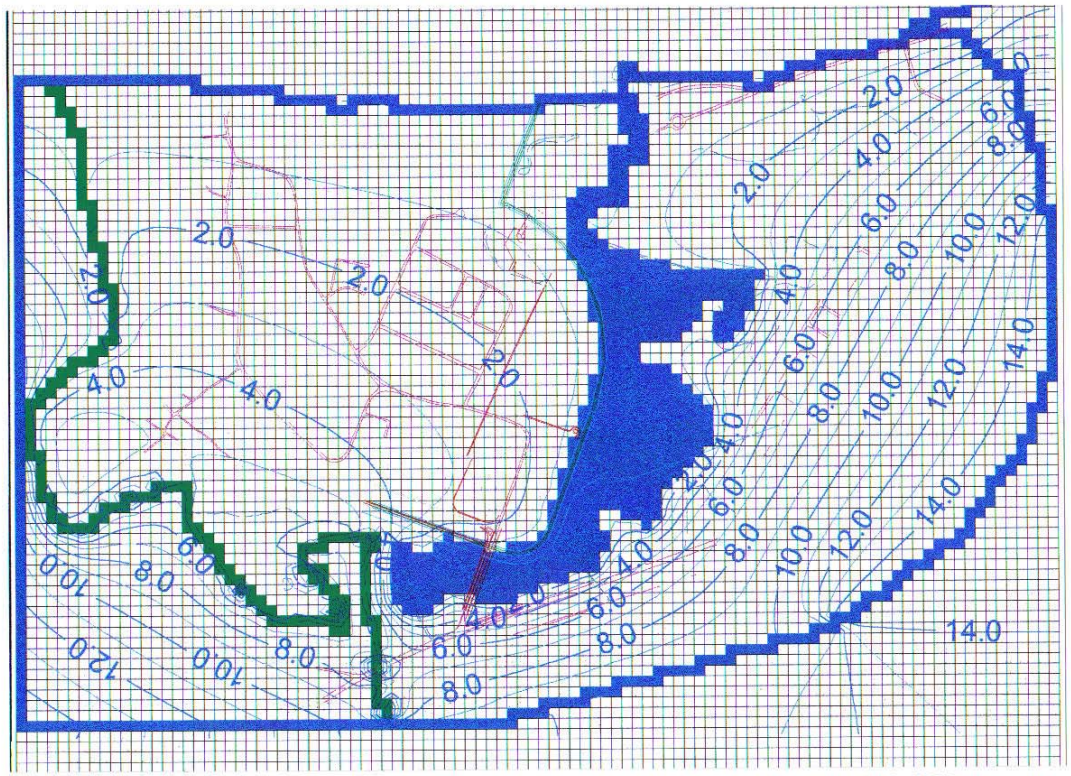


Base Map: As provided by AHV Asociados, Aguada, Puerto Rico **Scale: N.T.S.**

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

TABLE 1

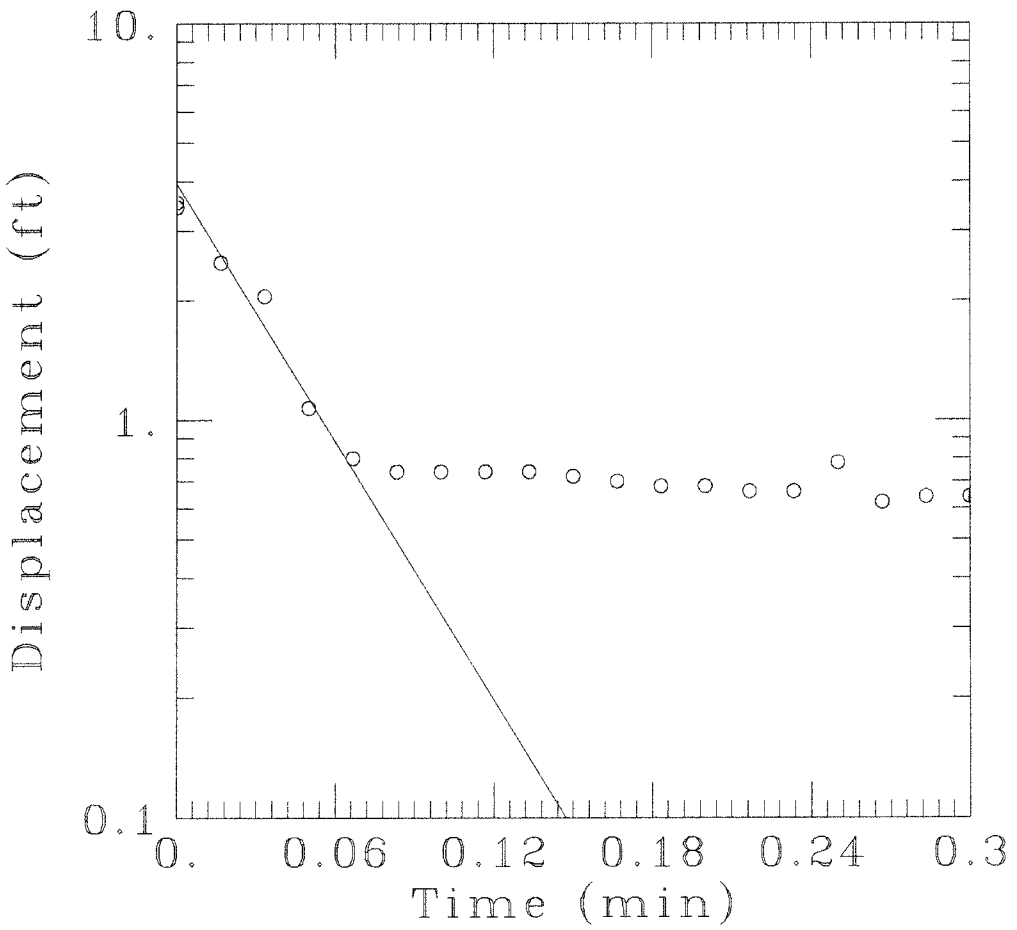
DISCOVERY BAY, AGUADILLA, PUERTO RICO

GROUNDWATER LEVELS AND PERMEABILITY ANALYSIS

MONITOR WELL NUMBER	WELL DEPTH (FT) (FT. BTOC)	WELLSCREEN LENGTH (FT.)	WELL STICK-UP (FT. AGS)	BEGINNING WATER LEVEL (FT. BTOC)	SATURATED LENGTH (FT.)	PERMEABILITY (FT./DAY)	ENDING WATER LEVEL (FT. BTOC)	SATURATED LENGTH (FT.)	PERMEABILITY (FT./DAY)
P-1	20.0	10.0	1.30	3.19	16.81	29.4	3.28	16.72	62.4
P-2	20.0	10.0	1.00	3.85	16.15	60.8	3.93	16.07	58.3
P-3	20.0	10.0	1.30	5.71	14.29	58.3	5.71	14.29	31.5
P-4	20.0	10.0	1.00	3.17	16.83	26.3	2.58	17.42	26.2
P-5	20.0	10.0	1.80	8.90	11.10	26.6	8.90	11.10	N/A
P-6	25.0	10.0	5.50	12.36	12.64	65.0	13.21	11.79	N/A
				AVERAGE =		44.4			44.6

HYDRO-ENVIRONMENTAL ASSOCIATES	Client: CORDECO NW
Project No.: 05-4131A	Location: AGUADILLA, PR

DISCOVERY BAY P-1 SLUG-IN TEST



DATA SET:
p1in
05/02/05

AQUIFER TYPE:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

TEST DATE:
04/26/05

TEST WELL:
P-1

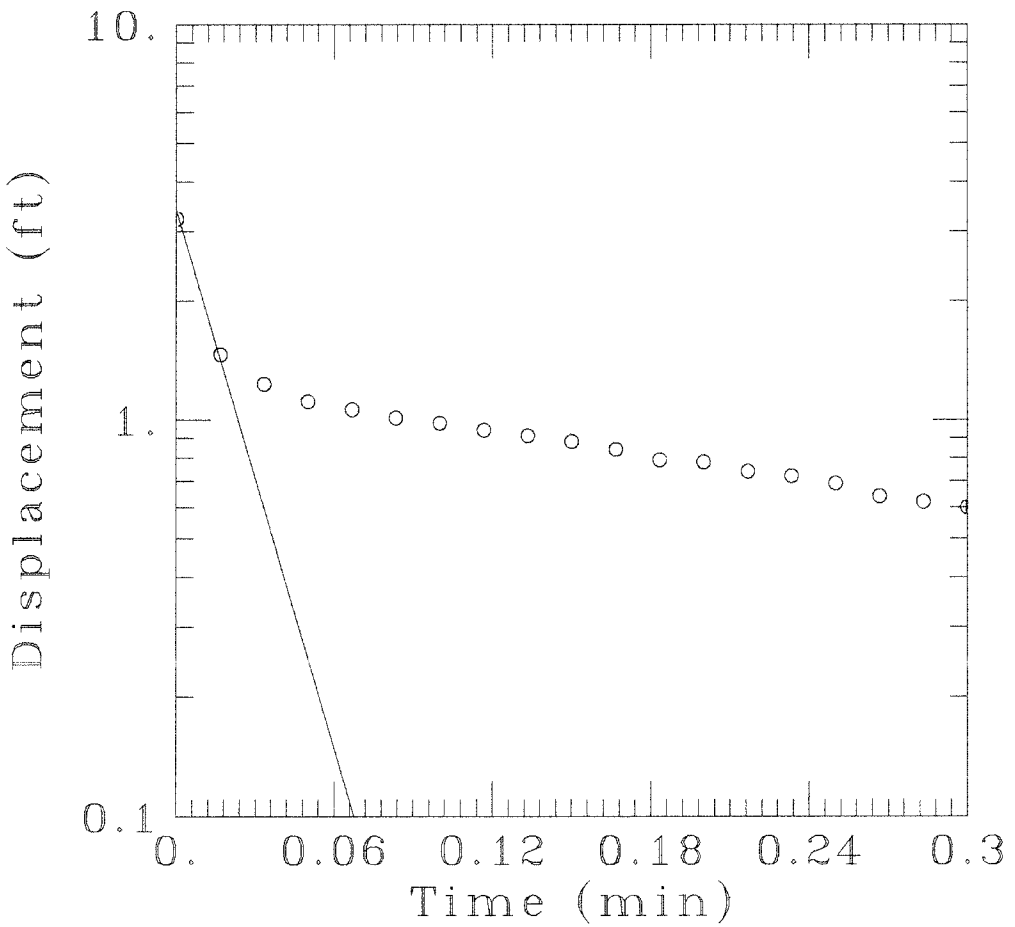
OBS. WELL:
P-1

ESTIMATED PARAMETERS:
K = 0.02045 ft/min
y0 = 3.938 ft

TEST DATA:
H0 = 3.54 ft
rc = 0.08 ft
rw = 0.25 ft
L = 10. ft
b = 50. ft
H = 15.51 ft

HYDRO-ENVIRONMENTAL ASSOCIATES	Client: CORDECO NW
Project No.: 05-4131A	Location: AGUADILLA, PR

DISCOVERY BAY P-1 SLUG-OUT TEST



DATA SET:
p1out
05/03/05

AQUIFER TYPE:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

TEST DATE:
04/26/05

TEST WELL:
P-1

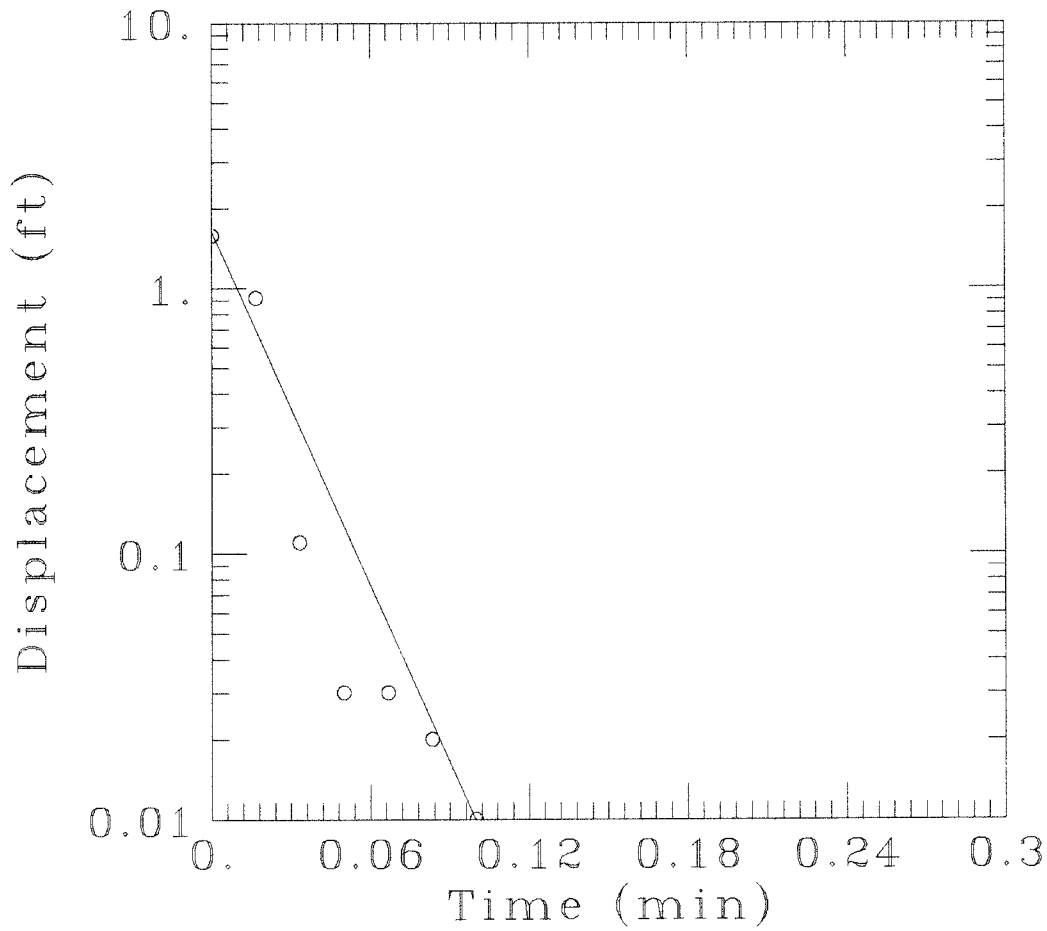
OBS. WELL:
P-1

ESTIMATED PARAMETERS:
K = 0.04333 ft/min
y0 = 3.388 ft

TEST DATA:
H0 = 3.22 ft
rc = 0.08 ft
rw = 0.25 ft
L = 10. ft
b = 50. ft
H = 16.72 ft

HYDRO-ENVIRONMENTAL ASSOCIATES	Client: CORDECO NW
Project No.: 05-4131A	Location: AGUADILLA, PR

DISCOVERY BAY P-2 SLUG-IN TEST



DATA SET:
p2in
05/02/05

AQUIFER TYPE:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

TEST DATE:
04/26/05

TEST WELL:
P-2

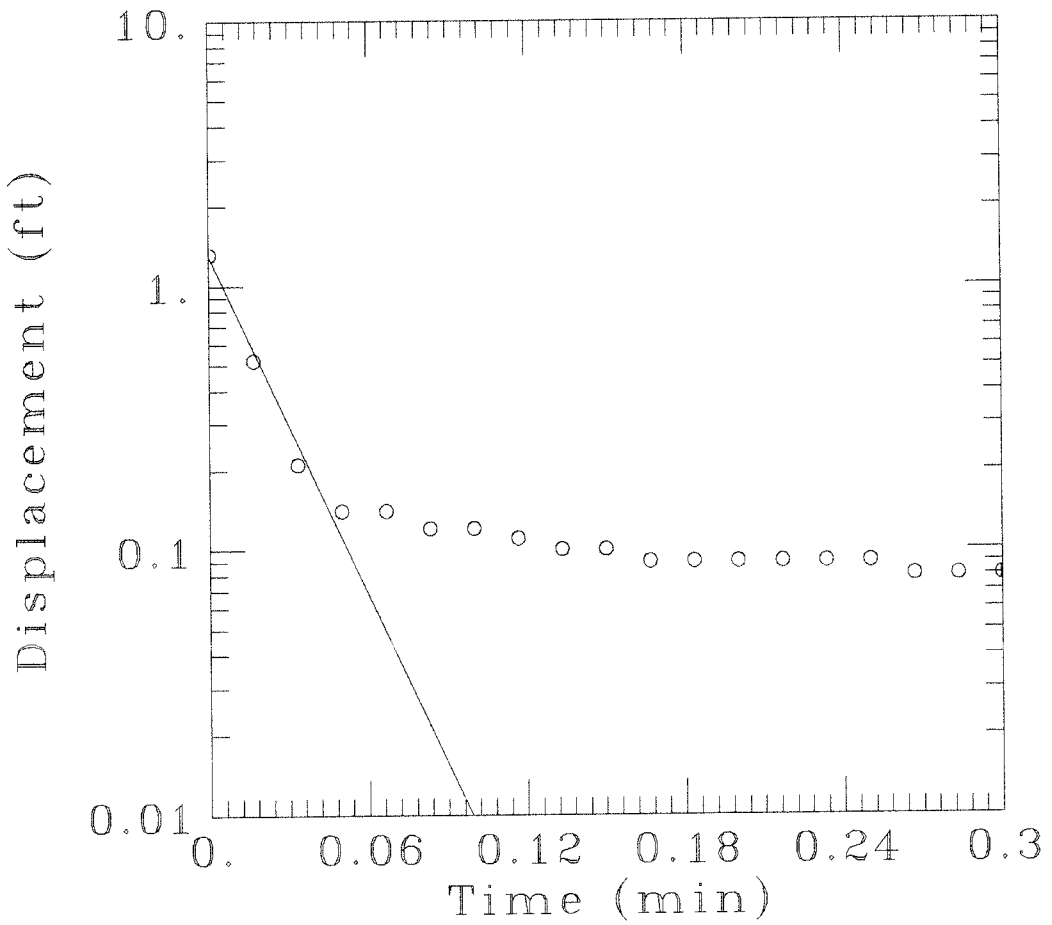
OBS. WELL:
P-2

ESTIMATED PARAMETERS:
K = 0.04222 ft/min
y0 = 1.64 ft

TEST DATA:
H0 = 1.58 ft
rc = 0.08 ft
rw = 0.25 ft
L = 10. ft
b = 50. ft
H = 16.15 ft

HYDRO-ENVIRONMENTAL ASSOCIATES	Client: CORDECO NW
Project No.: 05-4131A	Location: AGUADILLA, PR

DISCOVERY BAY P-2 SLUG-OUT TEST



DATA SET:
p2out
05/02/05

AQUIFER TYPE:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

TEST DATE:
04/26/05

TEST WELL:
P-2

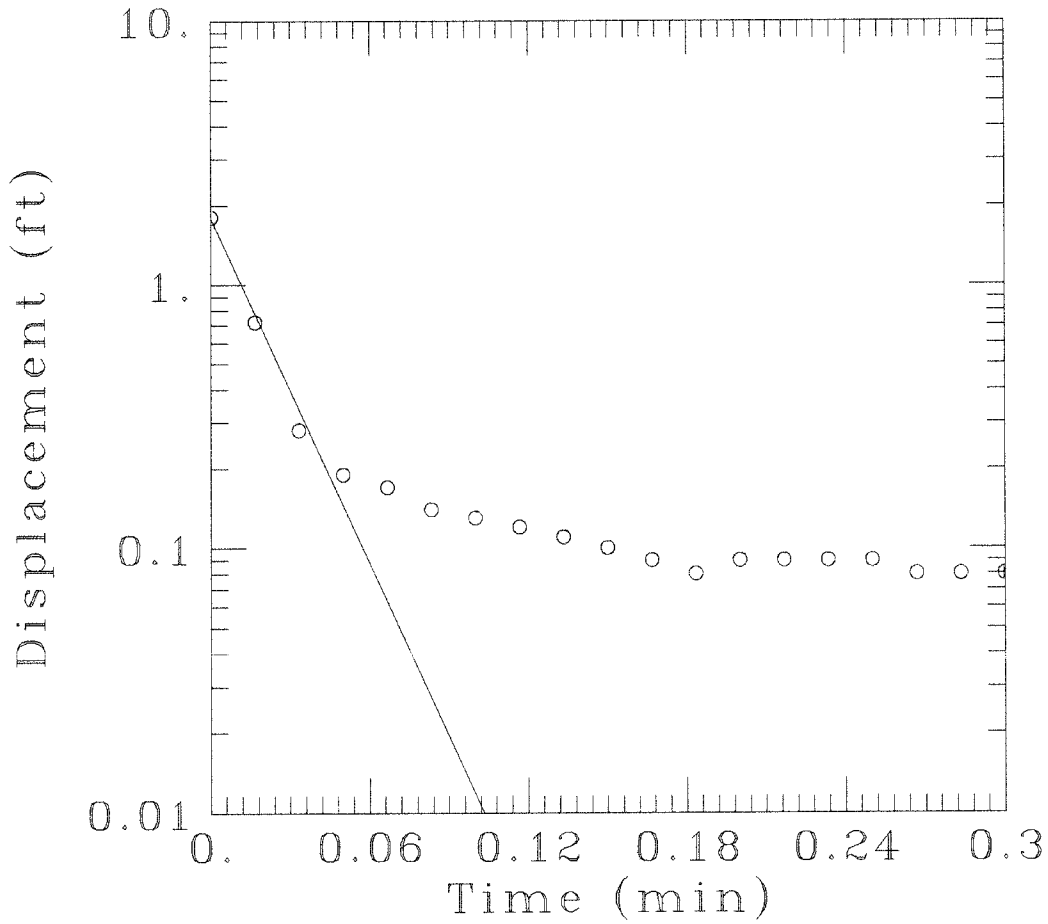
OBS. WELL:
P-2

ESTIMATED PARAMETERS:
K = 0.04047 ft/min
y0 = 1.294 ft

TEST DATA:
H0 = 1.31 ft
rc = 0.08 ft
rw = 0.25 ft
L = 10. ft
b = 50. ft
H = 16.07 ft

HYDRO-ENVIRONMENTAL ASSOCIATES	Client: CORDECO, NW
Project No.: 05-4131A	Location: AGUADILLA, PR

DISCOVERY BAY P-3 SLUG-IN TEST



DATA SET:
p3in
05/02/05

AQUIFER TYPE:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

TEST DATE:
04/26/05

TEST WELL:
P-3

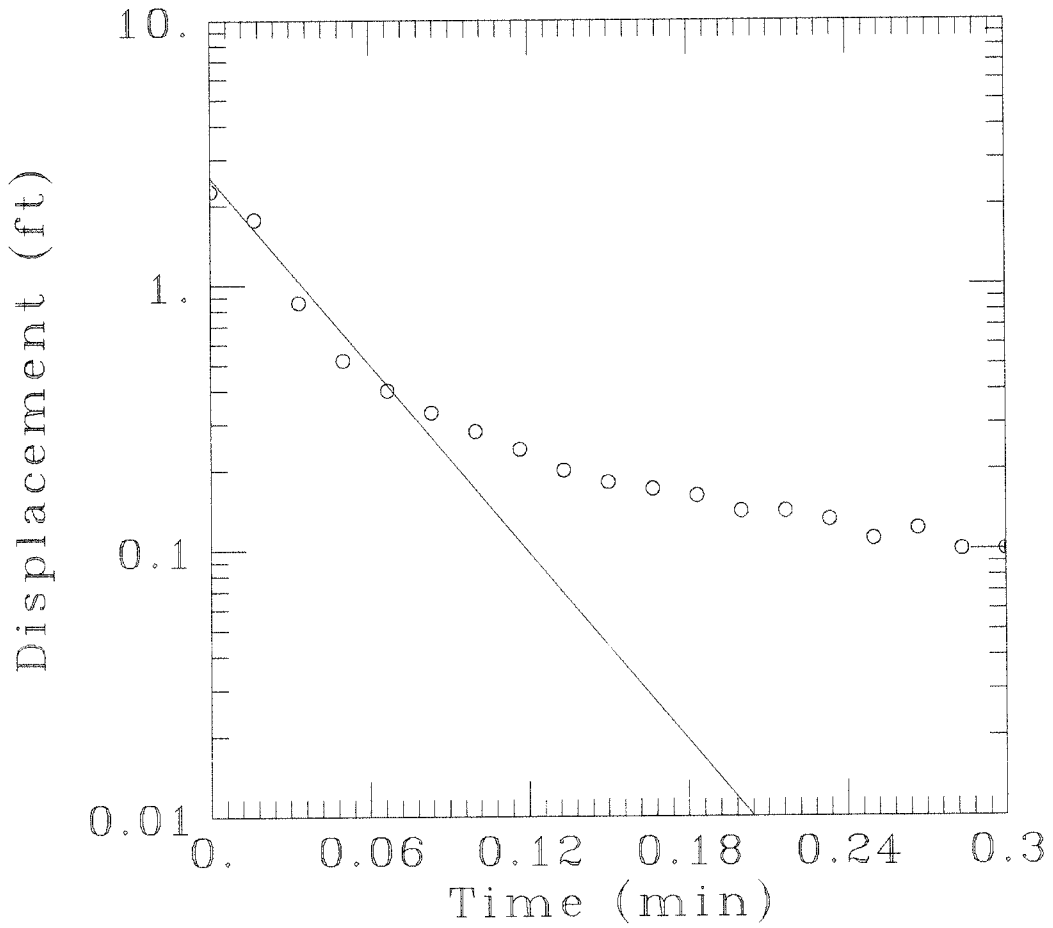
OBS. WELL:
P-3

ESTIMATED PARAMETERS:
K = 0.04055 ft/min
y0 = 1.786 ft

TEST DATA:
H0 = 1.8 ft
rc = 0.08 ft
rw = 0.25 ft
L = 10. ft
b = 50. ft
H = 14.29 ft

HYDRO-ENVIRONMENTAL ASSOCIATES	Client: CORDECO NW
Project No.: 05-4131A	Location: AGUADILLA, PR

DISCOVERY BAY P-3 SLUG-OUT TEST



DATA SET:
p3out
05/03/05

AQUIFER TYPE:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

TEST DATE:
04/26/05

TEST WELL:
P-3

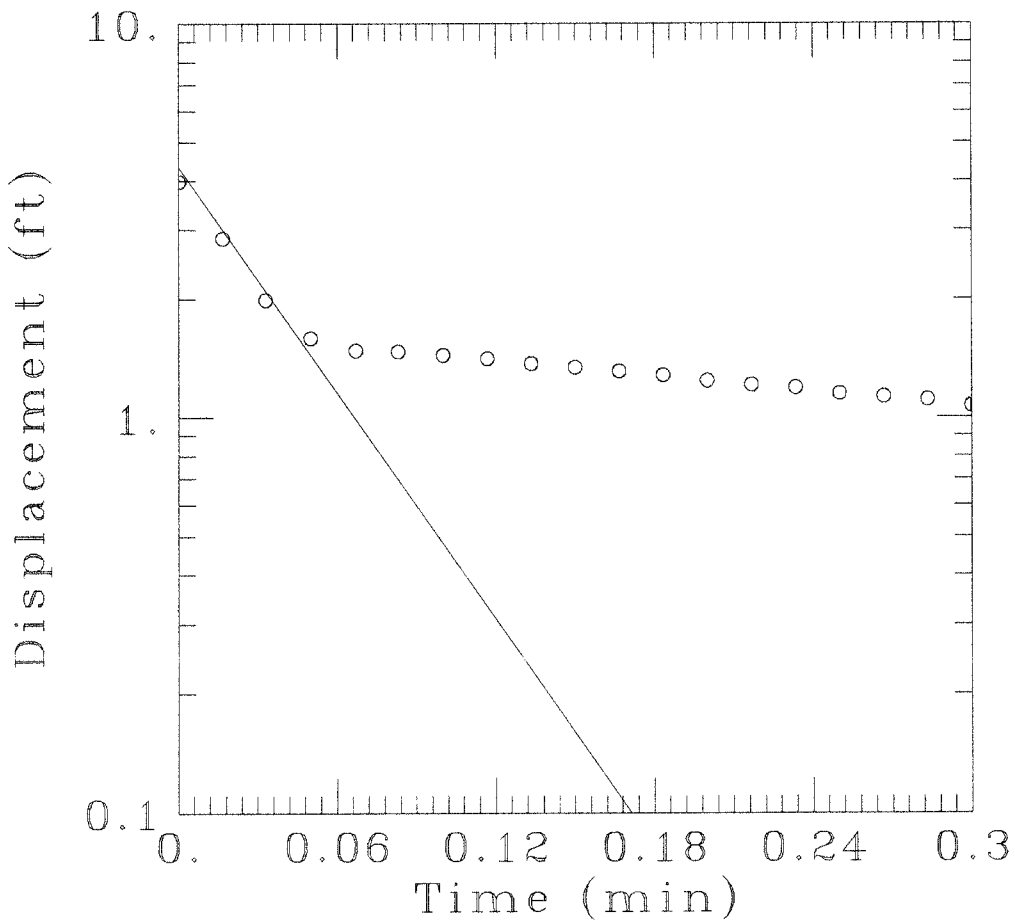
OBS. WELL:
P-3

ESTIMATED PARAMETERS:
K = 0.02189 ft/min
y0 = 2.553 ft

TEST DATA:
H0 = 2.26 ft
rc = 0.08 ft
rw = 0.25 ft
L = 10. ft
b = 50. ft
H = 14.29 ft

HYDRO-ENVIRONMENTAL ASSOCIATES	Client: CORDECO NW
Project No.: 05-4131A	Location: AGUADILLA, PR

DISCOVERY BAY P-4 SLUG-IN TEST



DATA SET:
p4in
05/03/05

AQUIFER TYPE:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

TEST DATE:
04-21-05

TEST WELL:
P-4

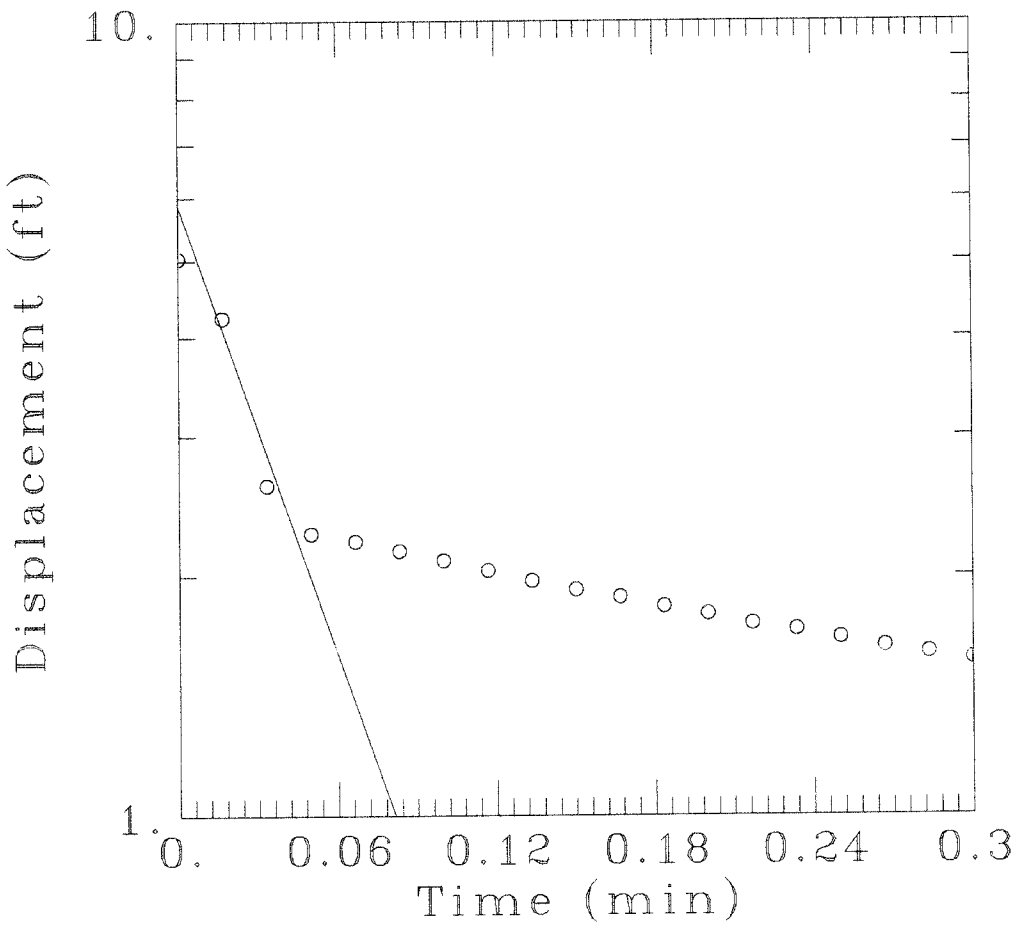
OBS. WELL:
P-4

ESTIMATED PARAMETERS:
K = 0.01829 ft/min
y0 = 4.33 ft

TEST DATA:
H0 = 3.97 ft
rc = 0.08 ft
rw = 0.25 ft
L = 10. ft
b = 50. ft
H = 16.83 ft

HYDRO-ENVIRONMENTAL ASSOCIATES	Client: CORDECO NW
Project No.: 05-4131A	Location: AGUADILLA, PR

DISCOVERY BAY P-4 SLUG-OUT TEST



DATA SET:
p4out
05/03/05

AQUIFER TYPE:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

TEST DATE:
04/26/05

TEST WELL:
P-4

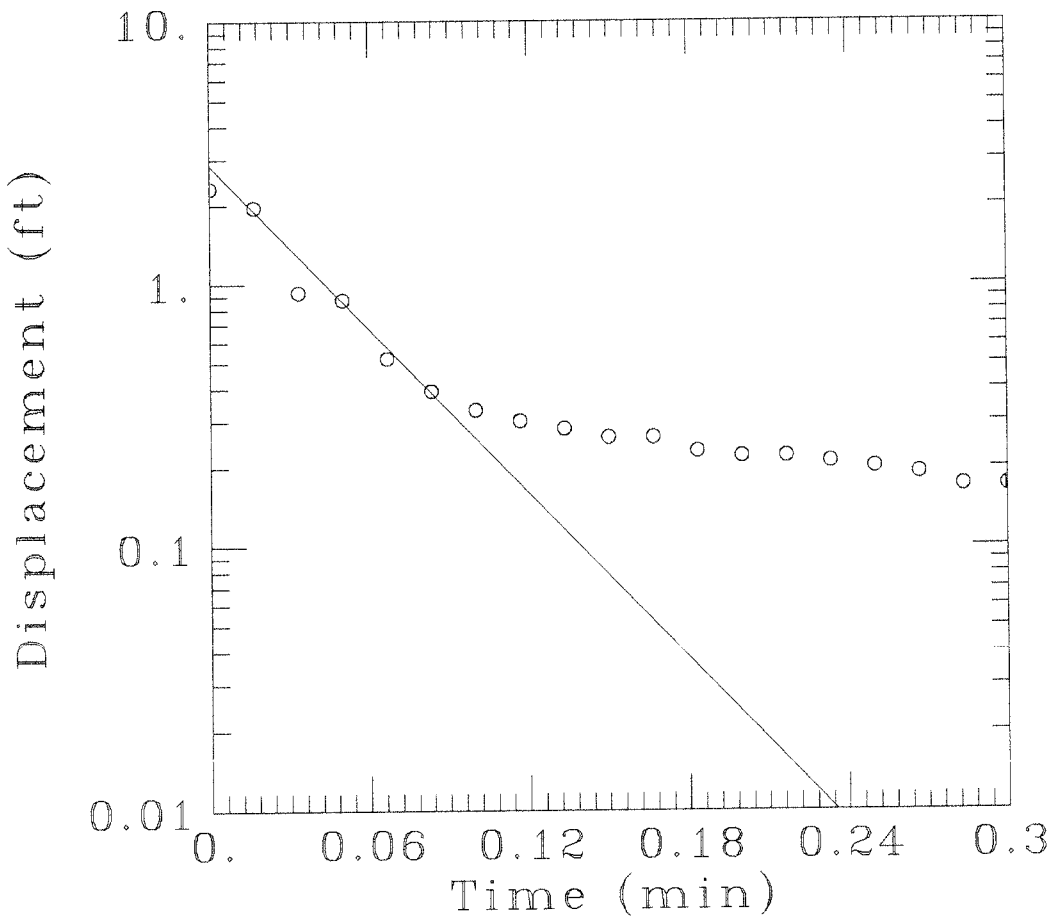
OBS. WELL:
P-4

ESTIMATED PARAMETERS:
K = 0.01818 ft/min
y0 = 5.872 ft

TEST DATA:
H0 = 5.03 ft
rc = 0.08 ft
rw = 0.25 ft
L = 10. ft
b = 50. ft
H = 17.42 ft

HYDRO-ENVIRONMENTAL ASSOCIATES	Client: CORDECO NW
Project No.: 05-4131A	Location: AGUADILLA, PR

DISCOVERY BAY P-5 SLUG-IN TEST



DATA SET:
p5in
05/03/05

AQUIFER TYPE:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

TEST DATE:
04/26/05

TEST WELL:
P-5

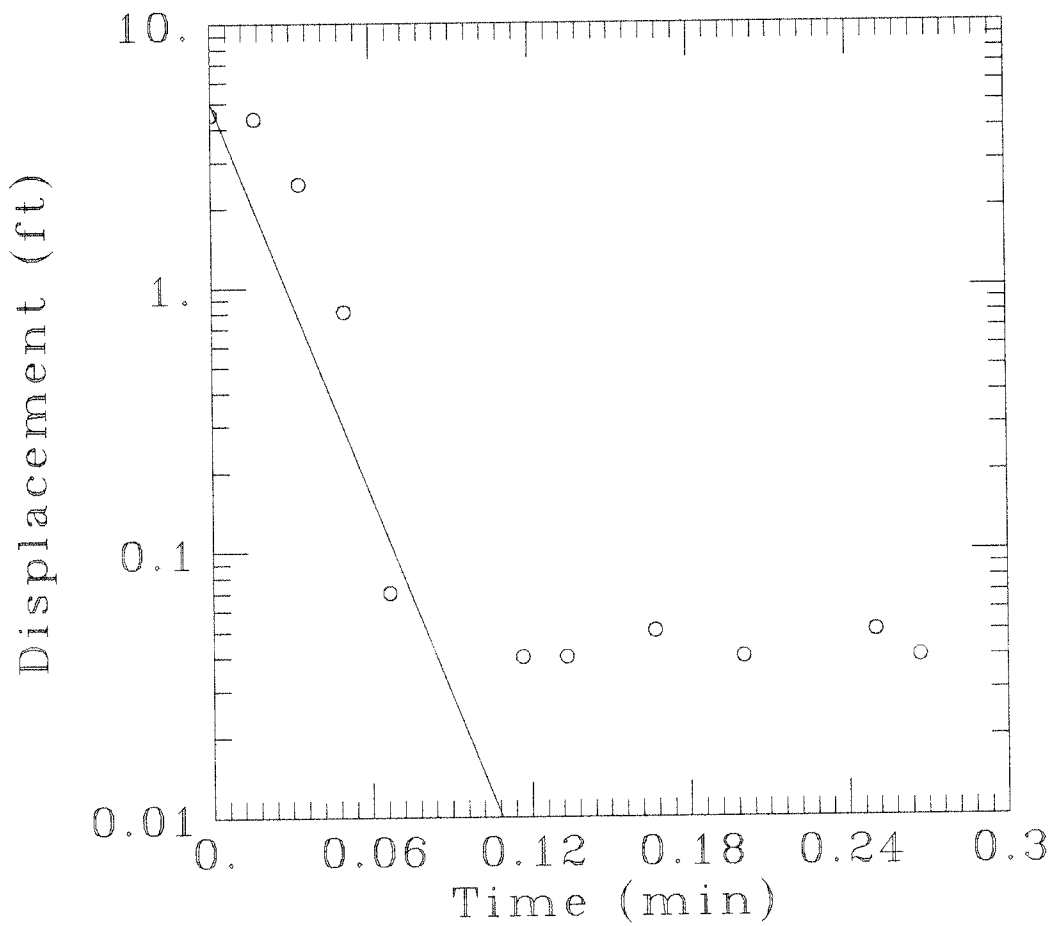
OBS. WELL:
P-5

ESTIMATED PARAMETERS:
K = 0.01849 ft/min
y0 = 2.835 ft

TEST DATA:
H0 = 2.32 ft
rc = 0.08 ft
rw = 0.25 ft
L = 10. ft
b = 50. ft
H = 11.1 ft

HYDRO-ENVIRONMENTAL ASSOCIATES	Client: CORDECO NW
Project No.: 05-4131A	Location: AGUADILLA, PR

DISCOVERY BAY P-6 SLUG-IN TEST



DATA SET:
p6in
05/03/05

AQUIFER TYPE:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

TEST DATE:
04/26/05

TEST WELL:
P-6

OBS. WELL:
P-6

ESTIMATED PARAMETERS:
K = 0.04514 ft/min
y0 = 5.012 ft

TEST DATA:
H0 = 4.52 ft
rc = 0.08 ft
rw = 0.25 ft
L = 10. ft
b = 50. ft
H = 12.64 ft