ESTUDIO HIDROLÓGICO

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ENVIRONMENTAL HYDROLOGY

STUDY

FOR PR 22 – EXPRESSWAY

HATILLO-AGUADILLA CORRIDOR

HATILLO- AGUADILLA, PR

FINAL REPORT

Submitted For

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I. INTRODUCTION AND PURPOSE

The PR Highway Authority (Authority) is proposing the extension of the Highway PR 22 (Hwy PR 22) from Hatillo to Aguadilla. There are several alternatives under consideration based on two basic alignments. The conversion to expressway of existing Hwy PR 2 is considered one of the alternatives. Other alternative under consideration is a cross-country route along the north central and northwestern slopes about a kilometer south from existing Hwy PR 2, crossing predominant karst topography. This alternate will be an extension of existing expressway PR-22. A corridor of 500 meters at both sides of the alignment is considered for detailed evaluation. A third alternative consists of the combination of the two basic alignments of the cross-country route and the conversion of expressway of PR-22.

The alternate route will cross several sensitive surface runoff and ground water basins. There are several major river channels, sinkholes, ground water wells, irrigation channels, and local drainage flow patterns typical of karst topography that will be affected by the proposed Corridor. The purpose of this report is to provide preliminary study results and recommendations for the development of hydrologic parameters to be considered in the design and construction of the cross-country alternative for the Corridor Hatillo-Aguadilla. In addition, information on sections along existing Hwy PR 2 directly or indirectly affected by major flooding events is provided.

II. SCOPE OF WORK:

The scope of work for the hydrologic portion of the project includes:

1. Develop, detailed inventory of surface runoff systems and local drainage characteristics along proposed Corridor. Develop hydrologic characteristics for these systems. This will include potential effects on existing flood prone areas along proposed routes.

2. Develop, in coordination with the project's geologist, an inventory of sinkholes along and in the vicinity of proposed routes. Develop information on the basin's characteristics for the sinkhole areas along the proposed Corridor. Develop potential flood prone areas associated with sinkhole surface runoff basins to estimate effects on the loss of storage capacity.

3. Develop structural and non-structural alternative to mitigate or minimize the lost of infiltration capacity associated with the construction of the expressway.

4. Collect available information and provide recommendation on floodable sections along existing Hwy PR 2. As part of the alternative to convert existing Hwy PR 2, there is a cost associated with flood proofing the expressway that needs to be considered.

III. Major Surface Runoff Basins

This section is dedicated to assess the potential effects on existing flood prone areas along the proposed Corridor of the cross country route alternative. The proposed project will go across the coastal channels of the Río Camuy and Rio Guajataca and will affect the northwestern portion of the flood plain of Río Culebrinas and Caño Madre Vieja in the vicinity of the intersection with Hwy PR 2 within the Municipality of Aguadilla. The Corridor will also go across two (2) small basins, Quebrada La Seca at Municipality of Hatillo at project beginning and Quebrada La Sequia at Municipality of Isabela.

The Río Camuy and Río Guajataca main channels will be intersected with a PR-22 vertical alignment that will provide significant structure clearance over flood levels. The road crossing on both rivers is characterized by deep channel cross sections. The flood prone areas of these rivers are confined to the deep channel in the vicinity of the proposed bridge structures. However, in accordance with applicable flood plain management regulations, and to address potential effects of proposed changes on vertical profile alignment during the design process, the one-percent chance exceedance frequency flood profile (the 100-year event) will be estimated for the Río Camuy and Río Guajataca in the vicinity of proposed highway crossings. The intersection with PR Hwy's 2 and 111 will take proposed Corridor into the flood prone area of the Río Culebrinas and Caño Madre Vieja. The potential effect of this intrusion into the flood prone area will be evaluated.

1. <u>Río Camuy</u>:

The Río Camuy is the first main river basin crossed by the proposed Corridor. The site for the proposed river crossing is a well-defined deep channel carved in the north coast limestone. Proposed highway vertical profile is about 60 meters above the Río Camuy channel invert. Figure 1 shows Rio Camuy Basin.

<u>Rio Camuy General Hydrology</u>

The Río Camuy surface runoff basin is divided into two areas: the volcanic terrain characteristic of the upper basin and the limestone terrain characteristic of the north coast slope (Reference 1.)

The volcanic terrain zone extends for about 35.6 square kilometers (Reference 2) from the upper part of the Río Camuy basin to about 12 kilometers downstream to where the river goes underground into a cave known as Blue Hole. During extraordinary rainfall events, ground water flow within the upper basin is not significant. However, downstream from the Blue Hole, all the excess rainfall collection and drainage is underground. The limestone terrain extends all the way down to the river estuary. Direct runoff and ground water are main drainage components within the limestone terrain. The drainage area boundary of the limestone zone is difficult to delineate because of the complex subsurface drainage patterns (References 1 and 3.) The Federal Emergency Management Agency (FEMA) developed an approximation of the limestone basin area. The total drainage area for the Río Camuy basin was estimated at about 83.1 square kilometers (Reference 3.)

As part of the improvements to the Hwy PR 2 (late 80's), The P.R. Highway Authority, developed a hydrologic study for a new bridge structure at the Río Camuy (Reference 2.) The study provides estimates on the surface runoff for the 100-year event. In addition, the Federal Emergency Management Agency (FEMA,) developed (late 90's) a Flood Insurance Study (References 3,) and provides estimates on surface runoff for the 100-year rainfall event for the Río Camuy at the Hwy PR 2 bridge structure. The proposed site for the bridge structure at Río Camuy is about 2.5 kilometers upstream the Hwy PR 2 bridge structure. Table 1 provides results from these studies in cubic meters per second (cms.)

Table 1

100-year Rainfall Event for Río Camuy at Hwy PR 2

Reference	100-year (cms)
PR Highway Authority	507
FEMA	911

The results from the FEMA, Flood Insurance study (911 cms) will be used to estimate the water surface profile along the Río Camuy channel for the 100-year rainfall event at the proposed bridge structure. The FEMA, study also provides an estimate for the discharge for the 500-year event. The Río Camuy 500-year event is estimated at 1,416 cms.

RIO CAMUY GENERAL HYDRAULICS

Using photogrametry information, various cross sections were developed to estimate the water surface profile along the proposed bridge crossing. The USA Corps of Engineers Computer model HecRas was used for this purpose. Final design of the route must consider a detailed hydraulic study since the result of this analysis is approximate with the intention of detecting and document any adverse potential effect of the proposed PR-22 bridge crossing on the flooding conditions of Camuy River.

The proposed road profile shows that bridge structure will be at an elevation of about 71 meters and the channel invert is at about 10 meters (MSL.) The preliminary hydraulic results of flood stages of the Río Camuy at the proposed bridge crossing are provided on table 2

Table 2

100-year flood stages for Río Camuy

Discharge (cms)	Stage (mts MSL)
911 (100-year)	13.75
1,416 (500-year)	14.89

The 500-year flooding event would elevate the river's water surface about 4.89 meters above the channel invert. However, the water profile would be about 56 meters below the bridge structure.

This is clear indication that the proposed bridge will not have any effect in the flooding conditions of the Camuy River in the vicinity of the bridge   Figure 2 shows bridge plan layout and proposed bridge section at Camuy River crossing.

2. <u>RÍO GUAJATACA</u>:

The proposed Corridor crosses the Río Guajataca channel about 4 kilometers upstream from the Hwy PR 2 bridge structure, and about 12 kilometers downstream from the Lago Guajataca Dam structure. The site for the proposed river crossing is a well-defined deep channel carved in the north coast limestone. Proposed highway vertical profile is about 118 meters above the Río Guajataca channel invert.   Figure 3 shows Rio Guajataca Basin.

<u>RIO GUAJATACA GENERAL HYDROLOGY</u>

Most of the surface runoff from the Río Guajataca basin is controlled by a dam structure managed by the Puerto Rico Electric and Power Authority (PREPA.)   The dam was constructed in 1928 for agricultural activities (irrigation) and power generation. Today, irrigation and water supply for several municipalities in northwestern Puerto Rico are the predominant uses for the Guajataca dam. The Technical Service Center, U.S. Department of the Interior, at the request from the PREPA, developed a Peak Flow Frequency Curve for the Dam (Reference 4.)   The hydraulic capacity and structural conditions of the dam structure's spillway was main concern for the Department of the Interior studies (References 4, 5 and 6.) The surface runoff associated with the most Probable Maximum Flood (PMF) was the discharge used for the evaluation of the spillway.   In accordance with the

Department of the Interior, the controlled section of the basin of the Río Guajataca is about 78.7 square kilometers including karstic topography within the area. The influence of the karstic topography would delay the surface runoff reaching the dam particularly during frequent rainfall events. However, the total drainage area was used for the estimates of the PMF studies. Due of the scarcity of flow data for the karstic zone the results presented in the study for the PMF can only be considered preliminary. However, the estimates presented for the one-percent chance exceedance frequency flood profile (the 100-year event) are considered with a large degree of confidence.

In 1978, the USGS developed a regional analysis for all of Puerto Rico (References 4 and 7.) The report presented regression equations to estimate 100-year peak flows based on drainage area and mean annual precipitation. In accordance with the Department of the Interior, for the Guajataca Dam drainage area, and with a mean annual precipitation of 2.41 meters determined from a map in the USGS report, the 100-year peak flow was estimated as 1,558 cubic meters per second (cms) The USGS report cautions that the regressions may not be strictly applicable to the karstic areas in northwestern Puerto Rico.

In 1996 Hurricane Hortense hit the eastern section of Puerto Rico and many new peak flows records were established at long-term gauge sites. An envelope curve drawn on a graph depicting peak discharge and related basin area produces information on maximum expected discharges for that event. The Department of the Interior (Reference 4) developed an envelope curve from the data on peak discharge from Hurricane Hortense to estimate the peak flow for the Guajataca Dam drainage area would have been about 1,841 cms. The frequency of this event was estimated between a 100-year and 1000-year return period. This estimate needs to be used considering that the karstic topography does not allow the same flood response to hurricanes and the envelope curve of recorded peak flows should not be used to judge any frequency curve analysis in this area.

The Puerto Rico Electric Power Authority (Reference 8) has developed several rainfall-runoff models for this surface runoff controlled basin. These models have provided peak flows for the 100-year event of 416 cms and 552 cms depending on the duration of the rainfall event. The rainfall-runoff models have estimated the PMF event between 2,407 cms and 2,804 cms. These events (the discharge) were estimated at a frequency between 5,000- and 10,000-years. Due to the lack of sufficient stream gauge or historic peak flow data, the Department of the Interior concluded that for the Río Guajataca basin a peak flow flood frequency curve can not be extrapolated beyond the 100-year with a large degree of confidence. It also recommended the use of the General Extreme Value (GEV) peak flow frequency curve to estimate the 100-year event and for less frequent events. The GEV frequency curve (Reference 4) yielded a 100-year discharge for the Río Guajataca below the dam structure of 792 cms. The estimate for the 100-year discharge is given within a boundary of 5 and 95 percent confidence limits. The upper limit of the confidence boundary is 853 cms. Figure 4 shows General Extreme Value (GEV) curve for Guajataca Dam.

Río Guajataca General Hydraulics

The upper confident limit of the GEV frequency curve (853 cms) developed by the Department of the Interior will be used to estimate the water surface profile along the Río Guajataca channel for the 100-year event at the proposed bridge structure. The results from the envelop curve developed by the Department of the Interior from the data on peak discharge from Hurricane Hortense to estimate the peak flow for the Guajataca Dam (1,841 cms) and the estimate for PMF of 2,804 cms will be used to develop a water surface profile along the Río Guajataca channel to assess the potential effect from this extraordinary events on proposed bridge structure.

The proposed bridge structure will be at an elevation above 128 meters and the channel invert is at 10 meters over mean sea level datum (MSL.) Preliminary results for stages at Río Guajataca at the site of the proposed bridge crossing are shown in table 3.

Table 3
100-year flood discharge and stages
for Río Guajataca

Discharge (cms)	Stage (mts MSL)
853 (100-year)	16.90
1,841 (Hortense envelop curve)	20.35
2,804 (Probable Maximum Flood)	22.77

The Probable Maximum Flood would elevate the river's water surface about 12.77 meters above the channel invert. However, the water profile would be about 105 meters below the bridge structure. Figure 5 shows bridge plan layout and proposed bridge section at Rio Guajataca crossing.

3. <u>Río Culebrinas and Caño Madre Vieja</u>.

The Río Culebrinas basin is located in the northwestern region of Puerto Rico. The headwaters of the river (Reference 3) lie in the western part of the Cordillera Central at elevation of about 450 meters. From here, the stream flows westerly for about 44 kilometers to its mouth where it discharges into the Bay of Aguadilla. The river has a drainage area of about 769 square kilometers. The Río Culebrinas and Caño Madre Vieja flood prone area in the coastal plain affect communities within Aguadilla and Aguada. The total discharge for the 100-year event was estimated by FEMA (Reference 3) as 4,063 cms at the Hwy PR 2 bridge structure. Figure 6 shows Culebrinas River Basin.

<u>Rio Culebrinas and Caño Madre Vieja General Hydrology and Hydraulics</u>

The Federal Emergency Management Agency (FEMA,) developed (late 90's) a Flood Insurance Study (References 3) and provides estimates on surface runoff for the 100-year rainfall event for the Río Culebrinas at Hwy PR 2 where proposed PR-22 –PR-2 intersections will be constructed. The Rio Culebrinas regional analysis for discharge computation was based on statistical computations of discharges records of 37 sites in Puerto Rico of more than 10 years of records regressed against basin characteristics. The analysis results in a discharge 4063cms for the 100-year flood and 5759 cms for the 500 year flood.

The Río Culebrinas and Caño Madre Vieja flood prone areas upstream Hwy PR 2 are interconnected. However, the Río Culebrinas, a significantly larger surface runoff basin, will control the water surface flood profile upstream Hwy PR 2, during the 100-year flood event. The northwestern section, just upstream Hwy PR 2, of the flood prone area of the Río Culebrinas and Caño Madre Vieja basins would intersect the Corridor. In accordance with the Federal Emergency Management Agency (FEMA,) Flood Insurance Rate Map (FIRM,) (Reference 9) the proposed intersection would be located part within the AE zone with a base flood elevation determined and part within the Río Culebrinas floodway zone. The portion of the intersection south of PR-111 from Sta 446+00 to Sta 458+00 at PR-2 is located in Zone II . From 458+00 to 462+50 at project end is located within Zone 1.

To minimize the effect in the flood prone area , the proposed project is considering a long bridge , trestle, at intersection with Hwy PR 2 and PR 111 between the municipalities of Aguadilla and Aguada. This allows for construction into the flood prone area with the recommendations of a required hydrologic, hydraulic and local drainage analysis of potential effects to neighboring activities. All construction within these areas must comply with PR planning regulation 13. Figure 7 shows Rio Culebrinas flood prone area at project site.
In accordance with the FIRM, about 0.5 kilometers upstream from Hwy PR 2 bridge at Río Culebrinas at intersection with PR-111, the water surface profile for the 100-year event is

about 9 meters MSL. The water surface elevation just at Hwy PR 2, is 8.5 meters (MSL.) Based on this elevation and the topography of the area developed for the project under consideration, a portion of the Hwy PR 2 , just south of the bridge structure for Caño Madre Vieja, in the vicinity of the proposed intersection is below the 100 yr flood profile. Therefore, the intersection with Hwy PR 2 should consider connection with the section of the highway above the 8.5 meters (MSL.)

In summary, the intersection of the proposed corridor with Hwy PR 2 and 111 will have to be constructed above elevation 8.5 meters at PR-2 intersection and above the 9 meters at the crossing of corridor with PR-111. Although the proposed elevated intersection "trestle bridge" will minimize the effect on the flooding conditions of the area, due to presence of piers obstructions, a detailed backwater study must be performed under the preliminary phase of the project for compliance with PR Planning Board Regulation 13. Figure 8 shows proposed intersection with PR-2 and PR-111 crossing at Culebrinas River flood prone area.

IV. Smaller Surface Runoff Basins - Regional Analysis.

The hydrologic analysis for the smaller surface runoff basins intersected by the proposed Corridor will be done using the US Geological Survey's suggested regression equations to transfer the magnitude and frequency data from gaged to ungaged sites(Reference 10)

In accordance with the USGS, the regression equations developed by Ramos-Ginés, differs from previous reports (by López and others 1970-79) by considering additional rainfall and flooding events data, improved analysis techniques, separation of flood-response regions. The USGS study presents estimates of the magnitude and frequency of floods at sites having 10 or more years of record and developed regressions equations based on flood-peak discharge and frequency data for 57 gaging stations in Puerto Rico for recurrence intervals of 2, 5, 10, 25, 50, 100, and 500 years. The equations consider contributing drainage area, basin's average depth-to-rock, and mean-annual rainfall as basin and climatic parameters. The equations consider contributing drainage areas ranging from 0.32 to 80 square kilometers.

There is some limitation on the use of these regression equations in the karst area due to the definition of contributing drainage area. For purpose of developing the regression equations, the USGS analysis, non-contributing areas such as sinkholes and drainage to caves were not considered. Two stations in the Rio Camuy were not included for the regression analyses due to the undermined drainage area typical of the karst area. However, within the northwestern region enclosed between the Río Culebrinas and Río La Plata, boundaries of the main section of the northwestern karst zone and area to be affected by the proposed Corridor there are fifteen surface runoff data collection stations (gages) considered in the development of these regression equations. Therefore, for the purpose of this preliminary analysis the USGS regression equations will be used for purposes of developing design parameters for the bridges and culverts intersecting small surface runoff basins.

1. QUEBRADA LA SEQUIA

The hydrology design parameters for the required hydraulic structure crossing the surface runoff basin of Quebrada La Sequia will be completed based on the US Geological Survey (USGS) regression equations. It was estimated a contributing area of approximately 1.00 square mile for the Quebrada La Sequia at the intersection with proposed PR-22 route. The area exhibit a Mean Annual Rainfall (MAR) of 80 inches. It is assumed that the upper karstic area where a high density of sinkholes detention areas and caves will not contribute to surface runoff as proposed by the USGS. Using the USGS regression formulas (ref 10) the estimated 100-year frequency discharge for the Quebrada La Sequia was 84 cms (3000 cfs). A typical cross section was developed from photogrametric data to estimate the water surface elevation at the site. The preliminary results for stages at Quebrada Sequia at proposed bridge crossing resulted in an elevation of approximately 96 meters. The proposed road and bridge elevation at this site is about 117, which is 11 meters above the maximum 100-year flood. Figure 9 shows proposed bridge area at Quebrada La Sequia.

2. Quebrada La Seca

Quebrada La Seca is located at the beginning of the project route. The Expressway will divide the existing watershed in two areas. The former local drainage pattern to Quebrada La Seca is along an existing road at the Corcovado community. The drainage area of upper watershed is approximately 85Ha (213 acres) (0.33square miles) that drains along the community road. At this area, the drainage of the upper watersheds will be designed taking consideration of the community location within the constructions area. Discharge runoff will be safely directed to downstream receiving point at Quebrada La Seca. Figure 10 shows Quebrada La Seca location.

VI. Man-made and Natural Conditions that May be Affected

The proposed Corridor will go through an area with an intensive land use. A significant number of dairy farms and associated rural communities depend of the availability of surface runoff water provided by the Guajataca dam and from ground water extraction (water wells.)

1. Canal Principal and Canal Moca.

Within the municipalities of Isabela and Moca, proposed Corridor crosses the main irrigation and water supply system for the northwest region of Puerto Rico. The Guajataca dam provides the storage capacity for these activities.

A diversion channel (Canal Principal) from the Guajataca dam, feeds about 16.43 cubic meters per second (58 cfs or 37.5 mgd) to a main distribution channel that nourishes Canal Moca to provide water for agricultural activities and for the water supply system for the municipalities of Isabela, Aguadilla, Aguada and Rincón. The PR Energy and Power Authority (PREPA) , manages and maintains the irrigation channels. The PR Aqueduct and Sewer Authority (PRASA) manage and maintain the water supply portion. There is a project on schedule to increase the hydraulic capacity of the water supply system to address increase water demands in the region.

The proposed route will cross through the system of channels intercepting various along the route. Six (6) points were identified where potential channel modifications or relocations are expected. The modifications might include channeling and or culvert crossings that had to be considered in the design phase of the project. The system must not be interrupted by the construction of the expressway that had to take this restriction in consideration. Coordination with PRASA and PREPA is required to complete any solution in this area. After performing the hydraulics studies to determine the required capacities of the alternatives, according to applicable regulations and with interagency coordination , this aspect is not a problem for the route. Figures 11 and 11A show the location of principal and secondary channels.

2. GROUND WATER EXTRACTION

In Puerto Rico, the source for the information on ground-water extraction is within two offices in the PR Department of Natural and Environmental Resources (DNER.) The office of "Franquicias" is the authorized entity under the DNER to grant surface runoff and ground water extraction permits for agricultural, industrial and domestic uses. This office keeps records of all the ground water extraction authorized by the DNER. The office of "Franquicias" keeps manual records of the original extraction permit request with information on the owner of the land, location (approximate location on photocopies of maps or sketches at different scales,) and water volume. The office of "El Plan de Aguas," also under the DNER was organized in accordance with the "Ley de Aguas de Puerto Rico" to develop surface and ground water management strategies. The office for "El Plan de Aguas" also keeps records of surface and ground water extractions in Puerto Rico with information on location (i.e. latitude and longitude,) well depth, and volume. For the first phase of this study a list of ground water wells permits located in the municipalities along the proposed cross-country route (between Hatillo and Aguadilla) was requested to both offices within the DNER. The offices of "Franquicias" and "El Plan de Agua" provided lists of about 80 wells with very few cases with corresponding information between the two lists in reference to well owners and locations

However, in accordance with the responsible staff, the information available on ground water wells is not updated by periodic field surveys/verifications. No information on accuracy of this data is available. The only way to establish the validity of this data is by performing actual field investigations to corroborate or recoustruct the available information in file.

As part of the efforts, a detailed field investigation on actual water wells located along the proposed cross-country route was performed. The detailed investigation started with the review of about 60 files of water extraction permits with physical address in the vicinity along the proposed project. All the relevant information on potential wells to be affected was collected and several owners (shown in the files) were contacted.

The cross-country route was walked to identify current activities associated with ground water extraction. A significant amount of dairy farming activities are located along the proposed Corridor. Most of the farming activities visited expressed high dependency on present ground water extraction and the good quality of the water available. Between the data collected in the files from the DNER and the field investigation, a total of 41 wells were visited to collect information on location (i.e. latitude and longitude,) and ground elevation. However, there is a possibility that some of the existing wells were not included due to lack of visibility or owners registered in the DNER's files were not located during this study time frame. The well locations must be verified during the final design phase where all affected wells will be located. The data of wells included is presented in table 4. Exhibit I shows detailed location of wells.

Table 4
Wells affected
Cross Country route

Municipality	Company	Owner	Use
Hatillo	Vaqueria Jose Luis Gonzalez	Jose Luis Gonzalez	A
	Vaqueria Lucho	Justo Mercado	A
	Vaqueria Los Campos	Francisco Ruiz Lopez	A
		Guillermo Toledo Rodriguez	A
	Adolfo Garcia	***Adolfo Garcia Amador***	***A***
	El Pirata	***Pedro Garcia***	***A***
	Carimary Dairy	Luis Sierra Toledo	A
	Reinaldo Dorta	Reinaldo Dorta	A
	Vaqueria Juan Dorta	***Luis J. Garcia Gonzalez***	***A***
	AAA	Bo.Capaez&Las Piedras	PRASA
	AAA	**Rio Camuy**	**PRASA**
Camuy	Vaqueria Taty Toledo	Alfredo S. Toledo Gonzalez	A
	Vaqueria Taty Toledo	Alfredo S. Toledo Gonzalez	A
	Vaqueria Tosado	Laury Jorge	A
	AAA	Pozo Talavera #1	PRASA
	AAA	Pozo Talavera #2	PRASA
	Vaqueria Vega	Luis Rene Delgado	A
	AAA	PR-119 La Pica y Cienaga	PRASA
	AAA	PR-119 La Pica y Cienaga	PRASA
	AAA	PR-119 La Pica y Cienaga	PRASA
	Eyramil Dairy	Luis Rene Delgado	A
	Vaqueria Soto Vidot	Soto - Bidot	A
	Goyo Toledo	Goyo Toledo	A
	Luis Rene Delgado	Luis Rene Delgado	A
	C-19 Teddy Alfonso	***Teodoro Alfonso***	***A***
	Luis Domingo Hernandez	Gabriel Perez	A
Quebradilla	Jose G Toledo Toledo	David Cruz	A
	USGS	USGS	Test
	Cacao Dairy	Jesus J Toledo Diaz	A
Isabela	Acquaright	Jaime R. Nieves Machado	I
	Farmer Inc.(Vaqueria Ramos)	Miguel A. Ramos Cruz	A
	Farmer Inc.(Vaqueria Ramos)	***Miguel A. Ramos Cruz***	***A***
	ACH Ornaments (Grama)	Adriano Chiesa Gonzalez	A
	Joglar Aggregates Corp.	***Antonio Joglar Moreno***	***I***
	Mundo Real (Gravero)	Santiago Varela	I
	Benitez Toledo Inc.	Carlos Benitez	A
	Jose M. Nieves (Grama)	Jose M. Nieves	A
Moca	Carlos Alfredo Dairy		A
Aguadilla	Vaqueria Alberto Toro	Alberto Toro	A
	Luis A. Cordero	Luis A. Cordero Mangual	A
	Bloques Barreto		I

Legend: A: Agricultural; (PRASA):Water Supply ; I: Industrial; Test : USGS

The Global Position System (GPS) technology used to collect information on location and ground elevation was the eTrex Vista personal navigator, manufactured by GARMIN International, Inc. With this instrument the average precision of the data collected on latitude and longitude for the ground water extraction activity identified along the proposed cross-country route is about 6 meters in any direction. This means that the real location of the well identified in Figure 12 to 12D can be actually located within a radius of 6 meters around the point identified in this plan view. As shown in these figures from the 41 wells seven (shown in bold) are outside the study fringe but were included due to their proximity.

During the design phase, the action to be undertaken for the affected wells will depend on the final evaluation and condition of the wells, but might include relocation and or closing of the facility. However, the relocation is the most feasible solution. It will require the proper soils studies to ascertain in general same conditions and yield of the former well location.

3. SINKHOLES.

Efforts were directed to identify sinkholes directly and indirectly affected by proposed alignment. The selection of sinkholes was based on all those directly affected within the preliminary R/W limits. This is the direct effect of expressway over sinkholes along the route.

Others sinkholes were selected based on importance and area coverage. Along the route, some major sinkholes system occurs at the reach along the north and south of the expressway cross-country road. The secondary systems were considered based on potential susceptibility to the existing and proposed discharges from the expressway. Some systems will be more susceptible to increased volume, others to increased discharge and others to both. Thus, any solution will include sound specific studies along the route to address final solutions that can be sustained with the applicable regulations and with the best engineering practice available.

Along the route, the predominant geology is composed of the karstic belt along the north coast and part of west coast of Puerto Rico. Along this belt, drainage is erratic being composed of high infiltration components and lower runoff response to rainfall events. Although this is typically the behavior of the area, it is not a rule, since some areas experiment high runoff rates due to the increased urbanization or local soil formations. This is particularly true for the route along the existing PR-2 where most of the route is densely populated.

Along the cross country road runoff is controlled in majority by the predominant soil characteristics. With the exception of Camuy and Guajataca River, Quebrada La Sequia and other minor creeks most of the drainage is internal by a combination of infiltration and storage. The karstic formation and soil type along the route will dictate the infiltration capacity and the sinkholes/depressions dictates the storage capacity. There is no specific regulations for developments at karstic and sinkholes areas. The basic for development route along the route will be focused in the mitigation of the effect on:

1. The reduction in sinkhole\depression areas along the route

2. The reduction of the infiltration\recharge to the underground system
3. The effect of potential increase in surface runoff due to the expressway
4. Control of pollutants or quality of discharge to the existing sinkholes receiving the discharge from expressway

The identification of the sinkholes affected by the route is included in table 5 and figures 13 to 13E. The table includes approximate areas of sinkholes to obtain the total area affected that requires relocation or expansion of existing sinkholes.

The actions to be undertaken includes

1. Relocation – The area affected will be relocated with specific characteristics according to the surface area affected and the average depth of the depression. This relocation will be located within the project fringe limits.
2. Compensation – The area of the sinkhole is partially affected and is required the expansion of the area of the existing sinkhole to compensate the affected area. Is similar to relocation but part of the existing depression is used.
3. Detention Pond - In some places where a community or major course of drainage is present and is expected to be affected the expressway.

The restoration or replacement of the reduced or eliminated storage along the route complies with the first goal of not to affect existing storage areas and in part with second goal of restoring recharge to underground system. The precise area-storage requirement and specific actions or combination of actions must be addressed on final design. The location presented at the maps is considered the most accurate at this point of the investigation. It will serve as a basis for estimate cost of the mitigation requirements.

Table 5
Sinkholes/Depressions
Area and location

SINKHOLE	LOCATION (STA) APPROXIMATE	SURFACE AREA (HA)	SURFACE AREA (ACRES)	AFFECTED AREA	ACTION
S1	8+00	0.17	0.425	50%	RELOCATION
S2-S3	16+00	0.06	0.15	100%	RELOCATION
S4	19+00	0.2	0.5	100%	RELOCATION
S5-S6	34+00	0.1	0.25	100%	RELOCATION
S7	78+00	0.1	0.25	100%	RELOCATION
S8	86+00	0.61	1.525	50%	RELOCATION
S9	89+00	1.13	2.825	50%	RELOCATION
S10 TO S14	94+00 TO 98+00	0.38	0.95	100%	RELOCATION
S15 TO S17	99+00	0.31	0.775	100%	RELOCATION
S18	104+00	0.5	1.25	25%	PROTECT
S19	104+00	0.18	0.45	100%	RELOCATION
S20 TO S21	110+00	0.48	1.2	100%	RELOCATION
S22	118+00	0.87	2.175	25%	RELOCATION
S23	118+00	0.23	0.575	100%	RELOCATION
S24	123+00	0.062	0.155	100%	RELOCATION
S25	144+00	0.03	0.075	100%	RELOCATION
S26-S29	148+00	0.35	0.875	100%	RELOCATION
S30	148+00	1.25	3.125	20%	RELOCATION
S31TOS39	156+00 TO 152+00	0.46	1.15	100%	DET.POND
S40TOS42	181+00	0.23	0.575	100%	RELOCATION
S43	210+00	0.16	0.4	PARTIAL	PROTECT
S43 TO S46	216+00	0.42	1.05	100%	JOIN TO S47
S47	216+00	0.18	0.45	PARTIAL	DETENTION POND
S48	246+00	0.06	0.15	PARTIAL	PROTECT
S49	250+00	0.38	0.95	100%	RELOCATION
S50-S51	258+00	0.32	0.8	100%	RELOCATION
S52-S53	262+00	0.23	0.575	100%	RELOCATION
S54	266+00	0.1	0.25	100%	RELOCATION
S55	298+00	0.03	0.075	PARTIAL	PROTECT
S56-S58	302+00	0.1	0.25	100%	RELOCATION
S59-60	308+00	0.15	0.375	100%	RELOCATION
S61	312+00	0.91	2.275	60%	COMPENSATION
S62	315+00	3.49	8.725	50%	COMPENSATION
S63-S66	322+00	0.22	0.55	100%	RELOCATION

Table 5.. cont
Sinkholes/Depressions
Area and location

SINKHOLE	LOCATION (STA) APPROXIMATE	SURFACE AREA (HA)	SURFACE AREA (ACRES)	AFFECTED AREA	ACTION
S67-S72	327+00	0.62	1.55	100%	RELOCATION
S73-S76	334+00	0.62	1.55	100%	RELOCATION
S77-S80	344+00	0.17	0.425	100%	RELOCATION
S80-S83	358+00	0.24	0.6	100%	RELOCATION
S84	350+00	0.12	0.3	100%	RELOCATION
S85-S87	354+00	0.1	0.25	100%	RELOCATION
S88-S90	358+00	0.11	0.275	100%	RELOCATION
S91-S93	360+00	0.26	0.65	100%	RELOCATION
S94-S96	364+00	0.24	0.6	100%	RELOCATION
S97-S99	367+00	0.64	1.6	100%	RELOCATION
S100	371+00	0.15	0.375	100%	RELOCATION
S101-S103	376+00	0.2	0.5	100%	RELOCATION
S104	378+00	0.81	2.025	100%	RELOCATION
S105-S108	382+00	0.55	1.375	100%	RELOCATION
S109-S111	386+00	0.27	0.675	100%	RELOCATION
S112-S114	388+00	0.46	1.15	100%	RELOCATION
S115-S116	390+00	0.47	1.175	100%	RELOCATION
S117	398+00	0.76	1.9	100%	RELOCATION
S118	400+00	0.14	0.35	100%	RELOCATION
S119	404+00	0.16	0.4	100%	RELOCATION
S120	438+00	0.15	0.375	100%	PROTECT
S121	443+00	0.39	0.975	10%	COMPENSATION
		22.082	55.205		

As shown in table 5 the direct effect of PR-22 construction along the cross-country route is the reduction of a minimum of 22 hectares (55 acres) of direct storage area. For this, the expressway construction considers various actions on the required areas. Final required areas must be determined during design and must include a detailed runoff analysis.

The second goal is the mitigation of the reduction in infiltration due to pavement construction. **For this purpose a total average width of approximately 40 meters times the estimated length of 46 km gives a total of 184HA (466 acres) of infiltration areas reduction. The 40 meters width used includes the expressway pavement and an additional fringe affected by the required cut and fill construction along the route. The precise affected area will be determined on final design phase.**

The restoration of infiltration capacities must considers the type of soil and the hydrologic groups directly affected by the expressway. Hydrologic groups are defined as A, B, C, or D soils according to their infiltration capacities. Soils A have the highest infiltration rate and soils D have the lowest. Table 6 shows corresponding soils along the route with estimate of the infiltration capacities. The proposed route crosses along various infiltration capacities zones according to the soils corresponding to the area . Figures 14 to 14L show the location of the PR-22 cross-country route in the corresponding hydrologic group classification. As noticed, the majority of the route affects soils of Hydrologic Classification B with a moderate infiltration rate in the order of 0.15 to 0.30 inches per hour if thoroughly wetted.

The solution for the infiltration reduction will be the establishment of infiltration areas combined with the relocated sinkholes and depression areas. The infiltration mechanism will be determined in the design phase but might consist of acceptable practices used in karstic regions. Some acceptable practices include infiltrations ponds, infiltration tanks, infiltration vaults, infiltration trenches and small infiltration basins. The use of any particular method depends on the infiltration capacity of the soils affected by the route.

The proposed corridor will include drainage structures to collect rainfall runoff and direct collected water to existing surface drainages or infiltration points at the relocated or existing sinkholes. For the purpose of quality control, the infiltration points will include pre-treatment systems to control sediments load and contaminants preventing the effect over the groundwater resources. These systems are typically composed by a storage area to collect the first inch of runoff, which will be retained under a specified period. From the system, an overflow is designed to pass the required discharge to a second storage where mitigation of discharge is achieved prior to final disposal through the receiving sinkholes or depressions . The final disposal might include direct mitigated discharge to receiving points, direct injection to underground, infiltration basins or a combination of them.

These systems are reliable to control pollutants to enter the underground systems if properly designed, maintained and operated. In this phase of Impact Statement, it is difficult to precise which alternative or combinations is the most feasible. However, the Expressway had to take account of this aspect to avoid affecting the sensitive sinkholes and cave system along the corridor. Some major systems including depressions clusters (groups) occur along the route especially between Sta 266+00 to Sta 400+00 with most of the major systems located south of expressway. The drainage pattern in the area is to the north and expressway runoff disposal will not affect the system located at the south. However, any discharge to them must be evaluated same as the rest of the systems and with all the recommendations of this study. Special considerations have to be given to the north major system and sinkholes clusters since they could be directly affected by storm sewer discharge from the expressway.

The policy for construction of the expressway in the kartsic zone might consider in general the following:

1. The construction of expressway must consider the protection of existing and future developments from flooding due to sinkhole overflow and backup.
2. Determine the extension of the storage areas of each sinkhole with specific flooding stages for a regulatory 100-year frequency event.
3. Determine the effect of the expressway and right of way location within the sinkhole storage area and restore any reduced volume.
4. Protect groundwater resources from contaminations due to pollution runoff into the sinkholes providing the best management practice along the route.
5. Provide the required filtering mechanisms or combination systems to mitigate the potential contamination of the groundwater resources.
6. The existing sinkholes and depressions areas can be used as surface runoff drainage if there is an existing discharge to the area providing that any increase in the quantity of surface runoff due to development of the expressway will not aggravate flooding problems in the area and or connected/adjacent sinkholes sub-surface systems. The mitigation system must be based on the requirements of the PR Planning Board Regulation 3.

Table 6
Soils classification and hydrologic group

Soil series	**Hydrologic group**	**Infiltration rate (in/hr)**
Soil Survey of Mayaguez Area		
Aceitunas AaC2, AbC2	B	0.15-0.30
Bajura Ba	D	0.0-0.05
Spinal Es	A	0.30-0.45
Guerrero Gu	A	0.30-0.45
Jobos JoB	A	0.30-0.45
San German SaD, SaE, ScB	D	0.0-0.05
San Sebastian SdF2	B	0.15-0.30
Tanama Ta	D	0.0-0.05
Soil Survey of Arecibo Area		
Algarrobo AgC	A	0.30-0.45
Espinosa EbB	B	0.15-0.30
Colinas Clay ClE2	B	0.15-0.30
Almirante Amb	B	0.15-0.30
Carrizales CeC	A	0.30-0.45
Bayamon BcB	B	0.15-0.30
Coto CtB	B	0.15-0.30
Matanzas MsB	B	0.15-0.30
Toa To	B	0.15-0.30
Limestone Outcrop Lo San Sebastian Association	B	0.15-0.30
Soler Limestone Rock SrD	D	0.0-0.05

VI. Flooding Along Existing Hwy PR 2 .

The conversion of Hwy PR 2 into an expressway category requires substantial improvement to sections currently affected by floods due to excess surface runoff or local storm sewer deficiencies. As a preliminary investigation, following are highlights for the PR-2 expressway conversion.

1. In accordance with FEMA (Reference 11,) The Rio Camuy 100-year flooding event will inundate the bridge structure and a section of about 700 meters of the existing Hwy PR 2 between the municipalities of Hatillo and Camuy. FEMA shows an approximate level of 5 meters at downstream face of existing bridge. The proposed bridge located upstream of the existing will be elevated over the 100 year flood in the area. Figure 15 shows general location of the proposed bridge over Camuy River.
2. In accordance with FEMA (Reference 12,) the Río Guajataca 100-year flooding event will not affect the proposed bridge structure. Figure 16 shows the proposed bridge location over Guajataca River.
3. In accordance with FEMA (Reference 9) the Río Culebrinas 100 year flooding event will inundate about 450 meters of the Hwy PR 2 , about 500 meters south from the intersection with PR Hwy 111 at the Municipality of Aguadilla.
4. The actual conditions of the local drainage for the Hwy PR 2 are deficient for purpose of constructing an expressway. Proposed expressway would have a significant increase on the volume and flow rate on the existing local drainage system and adjacent sub-systems. The construction of an expressway along the

existing Hwy PR 2 requires detailed evaluation and development of significant improvements to existing local drainage systems and peripheral sub-systems along the entire route.

5. The generally old and deficient storm sewer system of the existing PR-2 road due to the increased urban development along the route in the last 30 years presents the most important problem to be solved with the PR-2 conversion alternative.

6. With this alternative the PRHTA will have to invest great quantity of the funds to improve the existing storm sewer system along the route.

7. Mitigation studies in urban areas normally require detention ponds for the solution of the increased discharge. These ponds will require extensive urban land acquisition. Mitigation studies will be based on regulation 3 of the PR Planning Board.

Due to the conditions of drainage infrastructure, the extension of the required hydrologic and hydraulic studies, urban land acquisition, and the lack of planning coordination on the urbanization of the PR-2 in the past years, the conversion of PR-2 alternative is not recommended.

VII. CONCLUSIONS AND RECOMMENDATIONS:

The environmental hydrology study to evaluate the proposed route alternatives for the extension of the Highway PR 22 (Hwy PR 22) from Hatillo to Aguadilla resulted in the following conclusions and or recommendations. The entire document will be more specific, thus reading of particular sections is encourage.

1. MAJOR SURFACE RUNOFF BASINS includes Rio Camuy, Rio Guajataca, Rio Culebrinas and Caño Madre Vieja. Crossing of the expressway at these sites will not present significant effect on the existing flooding stages in the area. At the intersection with the Hwy PR 2, the connection with the section of the highway should be above the 8.5 meters (MSL). The intersection with PR-111 should be constructed with a vertical profile above 9 meters (MSL). A detailed analysis of the effect of the proposed intersection on current flooding and local drainage of the Caño Madre Vieja needs to be developed as part of the project design phase. For the portion of the road in Zone 1 in the Rio Culebrinas area (end of route), a final hydraulic study for compliance with planning regulation 13 is required.

2. SMALLER SURFACE RUNOFF BASINS includes Quebrada La Sequia and Quebrada La Seca. The crossing at quebrada La Sequia does not present major problems for road construction. At quebrada La Seca the flow pattern needs to be considered since the flow is directed through an existing road in the community. The effect of the road construction is minimized with sound hydrologic and hydraulic analysis, proper

conveyance of discharges through the community and safe discharge of runoff to the receiving point at Quebrada La Seca downstream.

3. Proposed route crosses along the area of CANAL PRINCIPAL AND CANAL MOCA which primary use is for water supply. Various points were identified that will require establishment of hydraulic structures. The water supply system must not be interrupted and the design must consider this restriction. During the design and construction phase, especial consideration should be given to the area of the irrigation and water supply systems known as Main Channel and Canal Moca. The construction of the road in this area is feasible if properly designed, managed and coordinated with PRASA and PREPA administrators.

4. Proposed route crosses along the area of ground water and extraction wells, which primary uses are for water supply and agricultural purposes. There are about 41 ground water wells identified within the entire zone. The ground water is used for agricultural, industrial and water supply or domestic activities. The affected wells were identified that will require relocation or closings depending of the actual condition.

5. SINKHOLES and depressions along the Karstic Belt present the most important hydrologic system crossed by the cross-country route. Primary affected and secondary sinkholes were identified along the road. One hundred and twenty one (121) sinkholes\depressions were identified directly affected by the road construction. The solution considers re-location or compensation of the affected area. A total area of 55 acres will be affected by the expressway construction that will require compensatory actions.

6. The expressway will affect the infiltration and recharge along a fringe of 466 acres of land. The road crosses soil of Hydrologic Classification (B) with infiltration rates of 0.15 to 0.30 inches per hour when thoroughly wetted. This is the basis for re-establishing the recharge capacity of the area. Infiltration areas will be properly designed to account for recharge restoration that will include a detention phase and a final infiltration phase. Quality control will be achieved by providing a combination of pre-treatment of the initial rainfall depth of 1 inch that can be combined with the mitigation of discharge system previously described.

7. Major systems or sinkholes with big drainage basins occurs mostly south of the expressway and will not be affected by the road construction. However, any sinkhole receiving existing and proposed discharges from the expressway at the south or at the north requires a mitigation system and follows the recommendations included herein.

8. The alternative or Conversion of PR-2 to Expressway is not recommended from the hydrologic point. It presents serious problems of infrastructure, drainage deficiencies, uncertainties on the existing systems, in part due to lack of development planning during the last decades along the route. Development of this alternative will required mitigation ponds that are associated to high urban land acquisitions and maintenance costs.

VIII. REFERENCES

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11. Feral Emergency Management Agency (FEMA,) Flood Insurance Rate Map (FIRM,) Community Panel Number 720000 0021 D, dated June 2, 1999.
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Exhibit I

List Of wells from Department of Natural Resources

PR-22 Corridor Hatillo-Aguadilla
Well Inventory (Field Work)

Municipality	Company	Owner	Use	Precision (mt.)	Longitude	Latitude	Elevation (mt.)
Hatillo	Vaqueria Jose Luis Gonzalez	Jose Luis Gonzalez	A	5.18	66.77718	18.46578	32.77
	Vaqueria Lucho	Justo Mercado	A	4.57	66.79197	18.46120	70.27
	Vaqueria Los Campos	Francisco Ruiz Lopez	A	4.57	66.79350	18.45857	84.91
		Guillermo Toledo Rodriguez	A	6.40	66.77877	18.46545	55.79
	Adolfo Garcia	***Adolfo Garcia Amador***	***A***	***3.96***	***66.81238***	***18.47772***	***39.63***
	El Pirata	***Pedro Garcia***	***A***	***5.79***	***66.81510***	***18.47650***	***29.27***
	Carimary Dairy	Luis Sierra Toledo	A	5.49	66.80115	18.46588	85.98
	Reinaldo Dorta	Reinaldo Dorta	A	4.57	66.79733	18.47195	51.83
	Vaqueria Juan Dorta	***Luis J. Garcia Gonzalez***	***A***	***6.10***	***66.79270***	***18.47353***	***50.30***
	AAA	Bo.Capaez&Las Piedras	PRASA	6.71	66.81497	18.47317	29.27
	AAA	*Rio Camuy*	*PRASA*	*8.23*	*66.82885*	*18.47292*	*5.79*
Camuy	Vaqueria Taty Toledo	Alfredo S. Toledo Gonzalez	A	5.18	66.84385	18.46062	99.70
	Vaqueria Taty Toledo	Alfredo S. Toledo Gonzalez	A	4.57	66.84075	18.45927	81.55
	Vaqueria Tosado	Laury Jorge	A	4.88	66.86235	18.45985	104.27
	AAA	Pozo Talavera #1	PRASA	8.23	66.86343	18.46163	112.50
	AAA	Pozo Talavera #2	PRASA	7.32	66.85968	18.46117	113.11
	Vaqueria Vega	Luis Rene Delgado	A	8.23	66.86560	18.45702	112.20

PR-22 Corridor Hatillo-Aguadilla
Well Inventory (Field Work)

Municipality	Company	Owner	Use	Precision (mt.)	Longitude	Latitude	Elevation (mt.)	
	AAA	PR-119 La Pica y Cienaga	PRASA	5.79	66.86817	18.45663	117.68	
	AAA	PR-119 La Pica y Cienaga	PRASA	5.49	66.87073	18.45647	109.76	
	AAA	PR-119 La Pica y Cienaga	PRASA	4.88	66.87340	18.45650	107.93	
	Eyramil Dairy	Luis Rene Delgado	A	4.57	66.87088	18.45353	103.66	
	Vaqueria Soto Vidot	Soto - Bidot	A	5.18	66.88703	18.45505	115.85	
	Goyo Toledo	Goyo Toledo	A	4.57	66.89093	18.45713	105.18	
	Luis Rene Delgado	Luis Rene Delgado	A	6.10	66.88065	18.45577	111.28	
	C-19 Teddy Alfonso	***Teodoro Alfonso***	***A***	***7.01***	***66.87208***	***18.44548***	***137.50***	
	Luis Domingo Hernandez	Gabriel Perez	A	7.01	66.89430	18.44712	138.72	
Quebradilla	Jose G Toledo Toledo	David Cruz	A	4.27	66.90785	18.45065	144.82	
	USGS	USGS	Test	3.96	66.92335	18.44442	160.67	
	Cacao Dairy	Jesus J Toledo Diaz	A	5.79	66.95365	18.44737	155.18	
Isabela	Acquaright	Jaime R. Nieves Machado	I	10.67	66.99638	18.46397	84.15	
	Farmer Inc.(Vaqueria Ramos)	Miguel A. Ramos Cruz	A	3.96	67.00975	18.46863	104.57	X
	Farmer Inc.(Vaqueria Ramos)	***Miguel A. Ramos Cruz***	***A***	***4.88***	***67.00772***	***18.45780***	***93.29***	***X***
	ACH Ornaments (Grama)	Adriano Chiesa Gonzalez	A	4.57	67.01282	18.46047	127.13	
	Joglar Aggregates Corp.	***Antonio Joglar Moreno***	***I***	***5.79***	***67.01635***	***18.47033***	***98.78***	
	Mundo Real (Gravero)	Santiago Varela	I	6.10	67.04138	18.45018	155.18	
	Benitez Toledo Inc.	Carlos Benitez	A	9.15	67.04423	18.44513	160.98	
	Jose M. Nieves (Grama)	Jose M. Nieves	A	4.88	67.04912	18.44665	164.33	
Moca	Carlos Alfredo Dairy		A	5.49	67.05968	18.44060	159.76	
Aguadilla	Vaqueria Alberto Toro	Alberto Toro	A	4.27	67.09272	18.43810	169.21	
	Luis A. Cordero	Luis A. Cordero Mangual	A	4.57	67.11907	18.43483	179.88	
	Bloques Barreto		I	11.28	67.14993	18.40097	20.43	

Legend: A: Agricultural; (PRASA):Water Supply ; I: Industrial; Test : USGS