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PORTADA

Foto oblicua del río Piedras en su confluencia con el canal Margarita que fluye paralelo al Expreso De Diego (visible en la foto) y se convierte en el Canal del Expreso (a la derecha). Originalmente los ríos Puerto Nuevo y Piedras no confluían, ambos llegaban independientemente a la Bahía de San Juan visible en el fondo de esta foto. Los terrenos entre la confluencia del río Piedras con el canal Margarita y la Bahía de San Juan eran manglares que han sido mayormente rellenados para acomodar la infraestructura portuaria de la ciudad, la cual es visible bordeando la ribera oriental de la Bahía. La zona ribereña del río es angosta y está rodeada de construcción urbana. Permiso para utilizar esta foto se obtuvo de Puerto Rico Historic Buildings Drawings Society y recomendamos la siguiente página cibernética para ver más fotos aéreas de la trayectoria del río Piedras: (https://www.facebook.com/media/set/?set=a.450891778316566.109458.145605908845156). Agradecemos la colaboración de Olga Ramos y Andy Rivera en la obtención de estas fotos.

CONTRAPORTADA

Detalle de la ortofotografía del 2007 de la zona costera de San Juan entre la Bahía de San Juan y los predios del Jardín Botánico de la Universidad de Puerto Rico. El canal del río Piedras está denotado en azul claro. El nuevo canal del expreso De Diego conecta al norte con el Caño Martín Peña y al sur con el canal Margarita y desemboca en la Bahía de San Juan. La zona portuaria evita que el río Piedras llegue a la Bahía como lo hacía históricamente. El río Piedras conecta con el canal Margarita y el canal del Expreso de Diego

EDITORIAL

Cuando el gobernador Carlos Romero Barceló firmó la carta del 4 de enero del 1978 al Cuerpo de Ingenieros de los Estados Unidos de América que aparece en el Apéndice 1 de esta publicación, desencadenó un proceso social ecológico con el potencial de alterar la fisionomía y funcionamiento de la ciudad de San Juan. Para el Cuerpo de Ingenieros el pedido del Gobernador estaba a tono con los objetivos de la Agencia, que con gran eficiencia y determinación diseñó un proyecto para la canalización del río Piedras. El Proyecto tomaría seis años para construir, a un costo de 253.5 millones de dólares y mejoraría el funcionamiento del río para resolver el problema de inundaciones en el sector Puerto Nuevo de San Juan. Nadie en el gobierno de Puerto Rico o en la sociedad de San Juan objetó la propuesta del Cuerpo de Ingenieros. Sin embargo, hoy, a 35 años de la carta del Gobernador y después de una inversión de sobre un billón de dólares, el proyecto de la canalización del río Piedras continúa un progreso que sólo ha logrado aproximadamente una tercera parte del trabajo propuesto. Importantes sectores de la sociedad y el gobierno expresan su preocupación con el proyecto mientras que la ciudad de San Juan aparenta estar más vulnerable que nunca a las inundaciones. ¿Qué pasó?

Este número de **Acta** trata de contestar esta pregunta por medio de un análisis crítico de los documentos oficiales que describen la planificación y desarrollo del proyecto de canalización del río Piedras, denominado río Puerto Nuevo por el Cuerpo de Ingenieros. El trabajo es una contribución del programa de investigación San Juan ULTRA (*Urban Long-Term Research Area*) al entendimiento del trasfondo histórico de un proyecto muy importante para la ciudad. La aspiración de este número de **Acta** es informar al gobierno, organizaciones no gubernamentales y a personas interesadas en el urbanismo sobre las ventajas y desventajas de los procesos de planificación a largo plazo.

Este proyecto de canalización de este río urbano levanta preguntas de enorme importancia para la ciudad. Por ejemplo, ¿cuál es el balance apropiado entre la infraestructura verde y la infraestructura gris en proyectos de control de inundaciones? ¿Cómo ejecutamos proyectos costosos que toman tanto tiempo que las premisas bajo las cuales se diseñaron dejan de tener vigencia antes de completar debido a los cambios sociales y ecológicos de una ciudad? ¿Qué procesos de planificación urbana y ejecución de este tipo de proyecto son los óptimos para evitar que caduquen y optimizar la adaptación del desarrollo de la infraestructura de una ciudad?

Esperamos que este número de **Acta** aporte a la discusión pública que debe acompañar proyectos como la canalización de ríos y quebradas en cualquier país.

Ariel E. Lugo
Editor

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AN ANALYSIS OF US ARMY CORPS OF ENGINEERS DOCUMENTS SUPPORTING THE CHANNELIZATION OF THE RÍO PIEDRAS[1]

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SUMMARY AND OVERVIEW

The United States Army Corps of Engineers (Corps) designed a Flood Control Project for the Río Piedras Watershed (identified in Corps documents as the Río Puerto Nuevo Flood Control Program) in response to a petition by the governor of Puerto Rico in 1978. Floods in the Metropolitan Area were causing significant losses in property and affecting the functionality of the city, particularly the Puerto Nuevo, Kennedy Expressway, and Bechara sectors; Winston Churchill Avenue; and other sectors including Quebradas Margarita, Josefina, Doña Ana, and Buena Vista. A significant fraction of vital urban infrastructure was vulnerable to flooding. Some 122 km of roads flooded in the watershed. The Corps estimated an average annual loss of $38.9 million from 1984 through 2035 due to flooding.

After a period of study and analysis, the Corps decided that the Flood Control Project would protect the watershed against the 100-year flood event to the extent that floodwaters would remain within the improved channels of the Río Piedras and its tributaries. The plan was to construct 17.7 km of concrete channels, improve natural channels, construct retaining basins upstream, improve or replace about 22 bridges, mitigate loss of mangrove area, and provide for improved recreation in the watershed. In 1984, the Corps estimated about six years of construction at a cost of $253.5 million with a positive benefit to cost ratio of 2.6.

By 1991, when a design memorandum was released, modification of the Flood Control Project involved eliminating five still basins and adding high velocity channels. These changes were motivated by additional urban development in the watershed, which did not comply with local regulations that prohibited construction in flooded areas. The Corps was compelled to design the Flood Control Project to

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[1]*Río Puerto Nuevo in the Corps Documents.*

account for maximum water discharge with the minimum channel width, which meant designing for critical flow water discharge. Concrete channels would have to be elevated to maximize water discharge during intense rainfall events. These protruding concrete structures would be fenced to prevent accidents and maintain public safety, and treated with materials, such as paint, that would soften the harsh contrast they would pose in the urban environment. The cost estimate for the Flood Control Project increased to $303.5 million, with the Project retaining a positive benefit to cost ratio of 2.4 and a proposed time of construction of 11 years. The Flood Control Project time horizon for planning purposes was initially 1980 to 2035 and in 1993 it was changed to 1993 to 2053. In either scenario, Flood Control Project life expectancy is 50 years.

After completion, the Flood Control Project will allow residual flooding to occur, in places to a depth of 2 meters. The San Patricio interchange will continue to flood due to structural limitations of the stormwater system at that location. After the channelization, the Corps estimates a 1.2 million dollar annual residual flood damage to structures and infrastructure in the watershed. Several alternative flood control measures such as retrofitting structures to make them flood resistant or removing some structures from particularly troublesome locations were discarded during the planning process due to high cost in favor of the preferred alternative relying on channel improvement.

During the planning process the Corps had to project historical trends to the future, so they ran hydrologic models to anticipate levels of flooding, and ran a physical model of the watershed to further anticipate the behavior of the region under extreme weather conditions leading to the 100-year flooding event. Other studies included environmental and cultural studies of the watershed, hydrodynamic water quality studies, geotechnical studies, socioeconomic studies, and others.

Today, thirty years after the original Survey Report was published (in 1984), Flood Control Project expenditures have reached about a billion dollars and flood control construction is in progress at the lower tidal reaches of the river without any indication as to when the Project will move upstream into the reaches that require construction of concrete channels that accommodate critical river discharge rates.

This paper has three objectives: 1) to provide a synopsis of the content of the reports, documents, data, and arguments used by the Cops to justify the channelization of the Río Piedras; 2) to evaluate the accuracy of predictions and assumptions used by the Corps to reach conclusions that justify the channelization of the Río Piedras; and 3) to make a case for the need to reassess the flooding problems in the San Juan Metropolitan Area with an eye to identifying solutions that are both effective and adaptable to evolving social and ecological conditions in the city. Our intent is not to propose any specific solutions to the problem of flood control in the city, but rather to emphasize that until the current course of channelization is thoroughly reviewed and potentially halted, other viable alternatives cannot be seriously debated and vetted for their efficacy.

The analysis of documents that we examine in this report uncovered many assumptions that the Corps had to make during the planning of the Flood Control Project, but which turned out not to be correct over the long-term. Both individually and on the whole, the invalidation of the Corps' assumptions raise questions about the hydrological and economic feasibility as well as the effectiveness of the proposed Flood Control Project. The following nine points are particularly relevant:

1. <u>Incorrect assumptions about human population, economics, and land cover</u>. The Corps assumed an increase in population within the watershed from 240,122 in 1980 to 325,000 by 2035, greater economic activity, and a land cover change from 75 to 100 percent developed land. In reality, population decreased, economic activity collapsed, and land cover is far from 100 percent developed.

2. <u>Not considering the stormwater infrastructure.</u> The Corps' analysis apprised them of the fact that San Juan's stormwater infrastructure was not functioning properly and lacked proper maintenance; nevertheless, they assumed that the stormwater infrastructure would function properly. Thus, the Flood Control Project was designed in isolation from the stormwater drainage system of the city and with the assumption that the stormwater drainage system of San Juan would be functional. A 2009 study for the Municipality of San Juan found that 63 percent of the drainage system was filled with sediments and/or garbage, 11 percent had storm and used or sanitary waters mixed together, and 3 percent were permanently sealed, which means that 77 percent of the stormwater infrastructure was not operational and only 23 percent was operational. Moreover, a significant fraction of the structures were either not included in the city's infrastructure blueprints or were in the blueprints, but not found in the field. The stormwater drainage system was not designed to handle large volume flood events, but for the river Flood Control Project to function properly the stormwater system has to convey water to the channels. If the stormwater system fails, the city will flood, particularly during high-frequency low-intensity events regardless of how well the channelized river and streams work.

3. <u>Asserting water quality would improve with channelization</u>. The Corps expected the water quality in concrete channels and in low reaches of the river to improve because channels do not generate sediments or pollutants and because of their improved flushing rates. Water quality would increase due to a decreased residence time of water within the watershed. This argument fails to consider the loss of water quality services by riparian systems and the continuous flux of sediments and pollutants from the upstream parts of the watershed, including urban runoff. Fecal bacterial counts are presently so high in the watershed, that it is an unlikely expectation that they will diminish by channelization. Moreover, much of the stormwater infrastructure carries sanitary waters mixed with urban runoff, thus further contributing to a water quality reduction on the channelized river and streams.

4. <u>Expecting that erosion and sedimentation would be minor issues</u>. The sediment production by the Río Piedras Watershed is high and the watershed will continue to

produce a large sediment discharge into San Juan Bay. Any reduction in sediment production within concrete channels (known as bedload) will have a small effect on the overall sediment load of the river system because bedload is about 15 percent of the total sediment discharge of the river. Before channelization, the sediment discharge of the river was 1,650,000 m^3/yr $\pm$ 40 percent. We could find no reason, argument, or data to justify the low post-channelization sediment discharge expected by the Corps (250,000m^3/yr). If the Corps is wrong in this estimate, the Commonwealth would have to pay a larger amount of money than estimated to maintain the channels after completion of the Flood Control Project.

5. <u>Incomplete assessment of the ecological values of the watershed</u>. The Environmental Assessments and Environmental Impact Statement for the Flood Control Project mostly focused on mangroves, some riparian areas, wildlife, and endangered species. The analysis failed to consider the environmental assets of the Río Piedras River itself. Recent studies have demonstrated the river system to be highly productive in fish biomass and to support a large diversity of migratory aquatic organisms, including a rare shrimp species thought to have been extinct, and a freshwater sponge species. The ecological role of riparian vegetation in support of water quality and in comparison to concrete channels was not assessed either. Furthermore, the disposal of fill within targeted areas of the city (some 20 ha) represent a future hazard for the city relative to potential effects of earthquakes on any infrastructure established on these filled-lands. This issue is not considered in a region with 29 percent of its area already artificially filled (over mangrove muds) and occupied by an urban population inhabiting and conducting business on a vulnerable infrastructure.

6. <u>Obsolete benefit/cost</u>. Decreased population and commercial activity in the watershed, plus dramatic increases in the cost of channelization, coupled by the extended time required to complete the Flood Control Project are bound to have an effect on the benefit/cost of the Project. In 1991, when the last benefit/cost estimate was made, the Flood Control Project cost was $303 million, but expenditures to date reach about a billion dollars. It is not known whether benefits have escalated in equal proportion to costs, particularly in light of the many abandoned businesses and structures in flood-prone areas.

7. <u>Not considering climate change</u>. The notion of climate change was not under consideration by regulations in the early 1980s when the Corps began to plan the Flood Control Project. At the time, notions of climate stability were common and thus agencies had no reason to question linear extrapolations of trends into the future. Today, the Corps is required to consider climate change when designing and constructing projects, even those in progress like the Flood Control Project. Climate change makes the future uncertain and requires a higher level of planning and anticipation than has been the norm for the Río Piedras Flood Control Project. Should the climate become more variable with stronger hurricanes, as anticipated for the Caribbean, the design of the Flood Control Project may not be able to cope with these future conditions. The 100-year flood may become more common, and

stronger floods could affect the watershed. Conversely, stronger droughts could strain water supplies, which would have to be conserved as opposed to discharging them at high velocities to the ocean.

8. Not considering sea level rise. All the planning and design of the Río Piedras Flood Control Project is based on mean sea level as defined by the National Geodetic Vertical Datum (NGVD) of 1929. At that time, sea level rise was not a factor considered in project design. Sea level rise is a consequence of global warming and the mean sea level of San Juan Bay increased at a rate of 1.65 mm/yr between 1962 and 2006. The rate of sea level rise could accelerate in the future. The Corps circular 1165-2-212 of 2011 ordered all projects to re-examine designs to conform to projected sea level rise. The circular recognizes that designs could become obsolete and non-functional if future sea levels obstruct channel discharge and causes backwater effects. To our knowledge the mandates in this circular have not been addressed in the Río Piedras Flood Control Project.

9. Not considering worst case scenario for channel discharge into San Juan Bay. The worst case scenario for the Flood Control Project is the coincidence of the 100-year flood event with an equally improbable hurricane tidal surge in San Juan Bay during a high tide. Such an event could create a significant backwater effect on the channels at the point where fresh and seawater collide. Such worst case scenarios are not normally considered when designing this kind of project because of the improbability of both occurring simultaneously. However, the likely passage of a category 5 hurricane, the uncertainties of climate change, and sea level rise, all increase the probability of such events. Because of the devastating consequences that the worst-case scenario would have on San Juan, we believe that event should be anticipated and tested in the modeling exercises.

The consequences of some of the failed assumptions could cause the Flood Control Project to not be cost-effective (1, and 4 to 9), while the consequences of others may negatively affect water quality (2 to 5) or the cost of sediment maintenance (2 to 4, and 7 to 9), while others could render the Project ineffective or prevent the Flood Control Project from accomplishing its goal of protecting the watershed from the 100-year flood event (1, 2, and 4 to 9). Therefore, we recommend that the whole design of the Flood Control Project as well as the approach to the flooding problem of San Juan be reassessed in light of the changing environmental, social, and economic conditions of the region.

Recent public and private statements by officials from the Corps at the University of Puerto Rico School of Education and in a meeting with the Secretary of the Commonwealth Department of Natural and Environmental Resources[1], other government agencies, and non-governmental organizations (both meetings attended by A.E. Lugo) have suggested that it is unlikely the Río Piedras Flood Control Project will be completed as planned in the 1980s and early 1990s. Thus, there is

[1]*This Department has changed names through the period covered by this manuscript, but we use throughout the current name.*

an excellent opportunity to re-assess the flooding problem of the city, seek novel solutions, and implement them through effective local governance that assures completion on a reasonable time scale.

From the above, there are lessons to learn in the governance of large public works that involve partnerships between the Federal and Commonwealth governments. Public works of the magnitude of the Río Piedras Flood Control Project involve at least eight responsibilities of the collaborating local parties, which the Corps made very explicit in the documentation that we examined. Number 5 indicates: "Hold and save the United States free from damages due to the construction and subsequent maintenance of the project, except damages due to the fault or negligence of the United States and its contractors." The Commonwealth is also required to observe sound land use and leadership to prevent encroachments or conditions that would interfere with the proper functioning of the Flood Control Project. There are local liability clauses associated with failure to act on these Commonwealth responsibilities.

As far as we can determine, the Commonwealth government successfully matched the federal investment by securing the lands needed for the Flood Control Project, but it is not clear how closely they monitored environmental effects and incorrect assumptions during project design. Also, the Commonwealth failed to establish an interagency and intergovernmental steering committee recommended by the Corps as a mechanism to assure proper coordination within and between government agencies. The failure of governance by both parties could affect the level of maintenance the Commonwealth is required to perform when the Flood Control Project is completed as well as the responsibility it has of dealing with project failure. The Corps is not responsible for project failure if the infrastructure of the city was not managed properly. This requirement alone assures that the Commonwealth will be responsible for any failures of the Flood Control Project.

Commonwealth government actions and inaction in their supervision of the Río Piedras Flood Control Project place communities and government financial resources at risk. It appears the government as a whole did not understand its liabilities and responsibilities when they engaged in this type of project. The consequences of governance failure are eventually borne by affected communities, taxpayers, and by a dysfunctional city that will continue to flood even during low-intensity high-frequency rainfall events. These prominent governance issues further warrant a total reassessment of flooding and flood control in the Río Piedras Watershed.

INTRODUCTION

The mission of the US Army Corps of Engineers (Corps) is to deliver vital public and military engineering services; partnering in peace and war to strengthen the Nation's security, energize the economy, and reduce risks from disasters. This includes dealing with flood control issues, which, because of the complexity and high cost of flood control projects, requires Congressional authorization if the Corps is to be involved in such projects. To obtain approval, they follow a lengthy procedure for analyzing, evaluating, designing, constructing, and maintaining facilities that address flooding issues and contribute to the navigability of the waters of the United States (see: planning.usace.army.mil/toolbox/process/chart-regs.pdf).

The Corps has completed, or has in progress, many projects in Puerto Rico (Table 1) and among those is the Flood Control Project for the Río Piedras River Watershed, which they identify as Río Puerto Nuevo in their documents (Box 1). This Flood Control Project, which we refer to as the Flood Control Project or Project, aims to protect the lower and middle portions of the Río Piedras River Watershed from the 100-year flood event and in so doing will transform the physiognomy of the city with the construction of both elevated concrete channels and earthen channels that traverse the watershed from San Juan Bay to the upper reaches of the river on a north-south trajectory through the heart of the urban mass of the city (Fig. 1).

This paper has three objectives. The first objective is to provide a synopsis of the content of the reports, documents, data, and arguments used by the Corps to justify the channelization of the Río Piedras. The second objective is to evaluate the accuracy of predictions and assumptions used by the Corps to reach conclusions that justify the channelization of the Río Piedras. A third objective is to make a case for the need to reassess the flooding problems in the San Juan Metropolitan Area with an eye to identifying solutions that are both effective and adaptable to evolving social and ecological conditions in the city. We do not present or propose solutions to the flooding problems of San Juan. Doing so will require a comprehensive and transdisciplinary process that is outside the scope of this manuscript.

We first present the synopsis of the Corps' documents, and follow each with an analysis of assumptions and justification for the channelization. We conclude with a recommendation for an updated assessment of urban floods in San Juan in light of emerging new social, economic, ecological, hydrological, and climatic conditions within and without the city.

Except where specifically stated, the information in this paper is taken from official documents of the Corps. Our evaluation of data and opinions in Corps documents will appear in this paper under the heading **Analysis**. In those instances where we incorporate our observations while presenting information from the Corps documents, we will use *italic font* so that the reader will understand the source of the material. The only deviation that we take from the official documents of the Corps is to use "Río Piedras" instead of "Río Puerto Nuevo" (Box 1). Also, we avoid as much as possible repeating information that appears in various sections of individual reports, or information that is repeated among reports. The information is captured the first time it appears and if it appears again in the documents it will not be repeated unless it is necessary to make a point. Our focus is on the alternative selected for implementation by the Corps, and thus we ignore alternatives that they rejected.

Our review of documents captures information that is relevant to understanding the social and ecological conditions and/or historical events within the Río Piedras Watershed. Also, we add separate sections to this report with information that supplements information not in Corps documents or expert points of view about the Flood Control Project. Our review is based on copies of reports and documents available to us, which means that the copies we examined may or may not be original or final documents, or at times appear undated. The materials we examined are on record at the International Institute of Tropical Forestry in Río Piedras, Puerto Rico.

The main headings of our report identify the document being reviewed and subsequent subheadings follow the same order as those of the report being reviewed. We begin with

Table 1. Completed and active projects of the US Army Corps of Engineers in Puerto Rico. Information is from Iván Acosta, Technical Engineer, Jacksonville District Office, 2014. A two billion dollar investment is estimated for these projects, with more funding pending for additional projects or phases of current projects.

Project	Investment (Thousand US Dollars)
Aguadilla Harbor	10,800
Arecibo Harbor	2,350
Boquerón WLR	3,400
Caño Martín Peña dredging	1,100
Juan Méndez	405
La Esperanza	2,000
Las Carolinas	335
Piñones PR 187	8,500
Portugués Bucaná	597,000
Puerto Nuevo Beach	2,000
Río Grande de Arecibo	27,000
Río Anton Ruiz	7,000
Río Bayamón	Pending
Río Cibuco	2,700
Río Culebrinas	4,500
Río Descalabrado	4,000
Río de la Plata	99,000
Río el Ojo de Agua	6,000
Rio Fajardo	6,100
Río Grande de Loíza	210,000
Río Grande de Manatí	20,000
Río Guamaní	6,000
Río Guanajibo-Mayagüez-San Germán	32,400
Río Guanajibo- Sabana Grande	3,850
Río Loco	7,900
Río Matilde	1,000
Río Nigua at Arroyo	8,500
Rio Nigua at Salinas	20,800
Río Patillas	3,000
Río Puerto Nuevo	750,000*
Río Orocovis	7,000
San Juan Harbor	55
San Juan Police Station	600
Yabucoa Harbor	350

*Several ongoing phases pending funding.

Box 1. Río Puerto Nuevo or Río Piedras?

The official documents dealing with the channelization of the Río Piedras seldom mention the river by its correct name. Instead official US Army Corps of Engineers documents refer to the Río Puerto Nuevo. When describing and quantifying the watershed of the Río Puerto Nuevo, the Corps documents include: the whole watershed up to the uplands in Cupey and Caimito, and tributary streams such as: Quebrada Margarita, Quebrada Josefina, Quebrada Doña Ana, Quebrada Buena Vista, and Quebrada Guaracanal. This description in fact is describing the watershed of the Río Piedras, not of the Río Puerto Nuevo.

On page 1 of the introduction to the Environmental Impact Assessment of 1984, one finds this text: "Upstream from the bridge of the De Diego Expressway the Río Puerto Nuevo is generally known as the Río Piedras." The document states that the Corps will use Río Puerto Nuevo to include the whole watershed. From here on, and with few exceptions that we note in the main text, there is no mention of the Río Piedras River in any other part of the Corps documents. It is unfortunate that the Corps elected to identify the Río Piedras River Watershed as the Puerto Nuevo River Watershed, and to dismiss the historical identity of the Río Piedras. Such a decision creates confusion and misleads the public as to what river is being channelized, as most people know the location of the Río Piedras, but have no idea where Río Puerto Nuevo is, particularly after all the engineering modifications to its channel.

We take exception to the phrase "generally known" when referring to the Río Piedras reach from the De Diego Bridge to the headwaters in Cupey and Caimito. That reach is the main stem of the Río Piedras, which has been officially known as the Río Piedras River for centuries. Lugo et al. (2011) conducted an analysis of official maps dating back to 1660 and showed that the Río Piedras and Río Puerto Nuevo are not the same. Moreover, the watershed of the Río Puerto Nuevo is smaller than that of the Río Piedras, and United States Geological Survey topographic maps and river watershed maps have always distinguished the Río Piedras as the main river watershed of the San Juan Metropolitan Area.

the Río Puerto Nuevo survey investigation (United States Army Corps of Engineers 1984), and subsequently, we present and summarize documents in chronological order of publication.

RÍO PUERTO NUEVO SURVEY INVESTIGATION

Syllabus

The survey investigation started in January 4, 1978 at the request of the governor of Puerto Rico (Appendix 1) with the purpose of investigating the flooding problems associated with high flows from the Río Piedras and its major tributary streams with a view to determining the need for, and feasibility of, improvements to solve the flood problems. Section 204 of the Flood Control Act of 1970 (PL 91-611) authorizes the Corps involvement in projects such as the one we are analyzing. Table 2 summarizes the characterization of the watershed as well as the costs and benefits of channelization that resulted from the Corps evaluation. The analysis proposed three alternatives for addressing the flooding problems, all involving channelization of the river. All three alternatives were estimated to

Figure 1. Map of the Río Piedras and Río Puerto Nuevo rivers with the proposed changes to their channels by the Flood Control Project of the United States Army Corps of Engineers (1984). The Caño Martín Peña is the mangrove-lined channel on the upper right corner of the map. The area shaded in blue represents the residual flooding that will occur with 100-yr Flood conditions after the Project is completed.

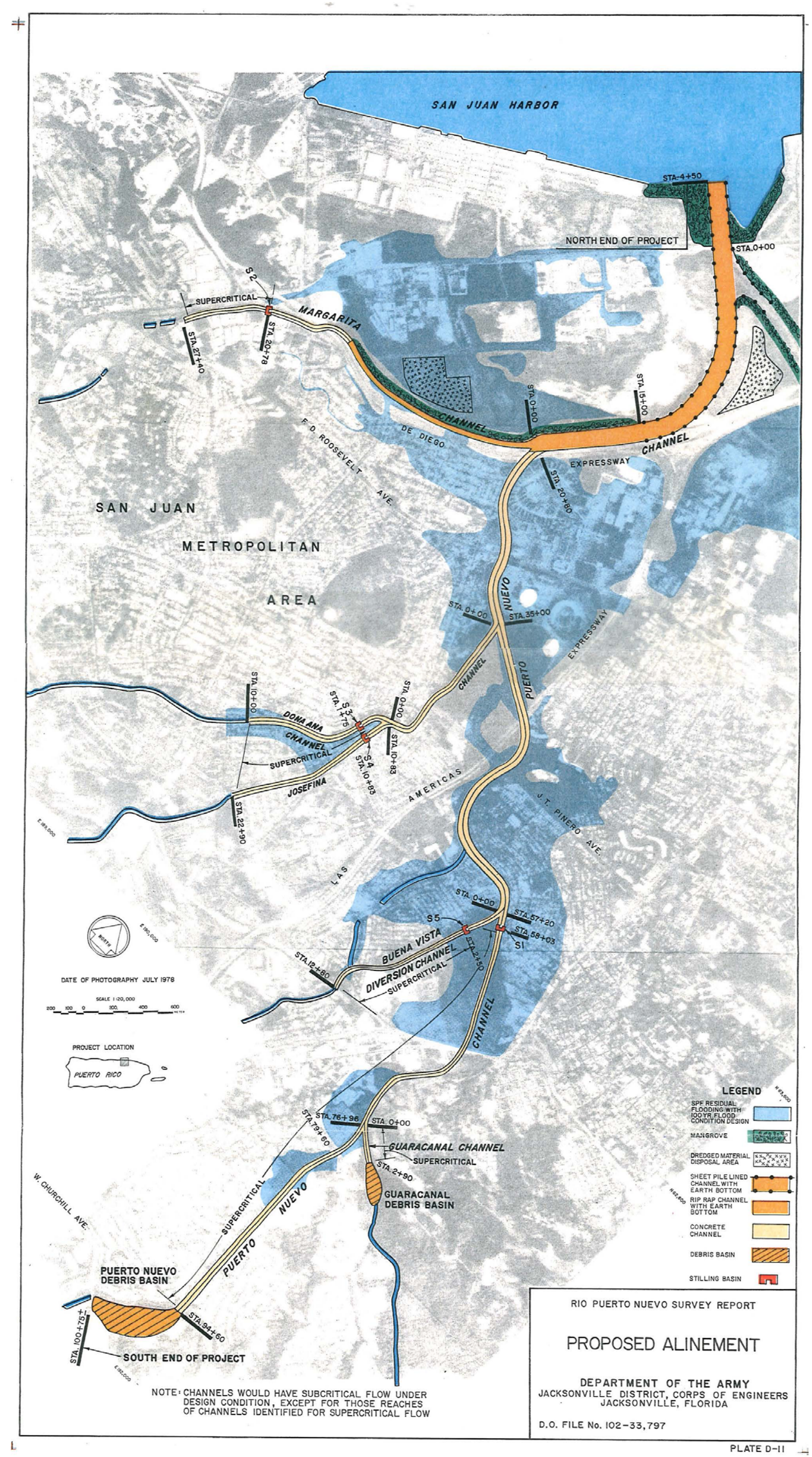

Table 2. Characterization of the Río Piedras Watershed condition and channelization costs and benefits by the United States Army Corps of Engineers (1984).

Watershed Element and Unit of Measure	Quantity
Watershed area (km^2)	62.8
Level of development (% of total)	75
Expected percent development by 2000	100
Population in the watershed	250,000*
Families affected by flooding	5,700
Commercial space flooded (m^2)	>325,000
Value of the property in the floodplain (billion $)	>3.0
Annual damages due to flooding (million $)	20
Annual damages into the future (million $)	38.9#
Area of mangroves that will be lost (ha)	13.5
Bridges to be replaced	22^
Length of main river channel to be improved (km)	10.4
Length if tributary channels to be improved (km)	6.0
Diversion of tributary (km)	1.3
Percent reduction in annual damages by the channelization	90
Estimated cost of proposed plan (million $)	253.5
Benefit/cost ratio	2.6/1.0
Federal share (million $)	186.4 or 164.7@
Commonwealth share (million $)	67.1 or 88.8@

*Represents 20 percent of the San Juan Metropolitan Area population.
#Due mostly to increased affluence.
^15 in major highways and avenues.
@Under 1984 federal policy and administration policy, respectively.

be 90 percent effective in reducing flooding damages, followed the same alignment, and had the same loss of mangrove area. The difference among alternatives was the degree of protection afforded by the proposed structures. Plan A addressed 25-year floods, plan B, 100-year floods, and plan C, the Standard Project Flood. The Standard Project Flood is a hypothetical maximum possible flood in the region. Plan B was selected because it maximizes net national economic benefits and is the most consistent with local rules and regulations (Fig. 1). Structures in plan B would be larger than those in plan A, but the alignment would be the same. Most of the improvements[2] consist of high velocity reinforced concrete rectangular channels. Also planned is a bicycle corridor along the right-of-way of the main river channel, and a mangrove mitigation plan.

Main Report (August 30, 1984)

P 1-4. The most important transportation facilities of the San Juan Metropolitan Area

[2]*The Corps uses "improvement" to mean what the project proposes to do to river channels. From a different perspective, say ecological, the actions are not necessarily improvements. Our use of Corps terminology does not imply agreement with the Corps.*

as well as the ports, recreational facilities, government offices, electric power and water utilities, and commercial buildings are located in the lower portions of the watershed. The lower reaches of the watershed includes over 10,000 single housing units, dozens of high-rise condominiums, over 1.5 km^2 of port facilities, one 508,000 kw electric power generating plant, the main Post Office, the Police Headquarters, National Guard facilities (*now abandoned*), the PR municipal and recreational facilities, and over 325,000 m^2 of commercial space. Other facilities indirectly affected are: PR Medical Center, Veterans Administration Hospital, The University of Puerto Rico Río Piedras Campus, and the State Penitentiary (*now abandoned*).

P 2-3. The areas that drew special attention with respect to flooding problems are included in Table 3. Figures 2 to 4 are maps of the watershed depicting the areas affected by the Standard Project Flood, including flood duration, depth, and velocity, respectively.

P 4-5. Table 4 contains the historical and ecological resources of the Río Piedras watersheds identified by the Corps as potentially affected by flooding.

P 5-6. Table 5 contains some projections into the future for the Río Piedras River watershed.

P 7-8. Table 6 contains estimates of historical and predicted flood damage to people and infrastructure in the watershed. In the event of a 10-year flood, floodwaters over 0.3 m deep would remain between 2 and 5 hours along the J.F. Kennedy Avenue from Bechara to the Municipal Public Works center and along the De Diego Avenue nearby the interchange with the De Diego Expressway. Sectors such as the Tres Monjitas and the Bechara-Kennedy industrial areas, Municipal Work Center, San Juan Municipal Sports Development, Las Américas Shopping Center Parking lot, Nemesio Canales housing development, and portions of Puerto Nuevo, University Gardens, and Ramón Nevares residential areas would be affected in some manner. In the case of the Standard Project Flood, floodwaters over 0.3 m deep would remain in those sectors and arteries for over 5 hours, and also over the De Diego Expressway, at a point between the De Diego Avenue and the De Diego Expressway bridge crossing. Floodwaters could also have velocities greater than 0.6 m/s. With continuing development after 1984, sectors that did not flood with the 10-year flood, would be inundated.

P 9. The construction of the bike path along the Río Piedras concrete channel would help satisfy the unmet demand for recreation in the watershed.

Table 3. Focus areas considered by the United States Army Corps of Engineers (1984) as the most problematic in the Río Piedras River Watershed.

- Río Piedras overflow between San Juan Bay and Winston Churchill Avenue
- Quebrada Margarita overflow from its junction with Río Piedras to the F.D. Roosevelt Avenue
- Quebrada Margarita between the Caparra Interchange and Garden Hills
- Quebrada Josefina and Doña Ana from the bridge on J.T. Piñero Avenue to 9 SE and 21 SE streets in Reparto Metropolitano
- Quebrada Buena Vista from the bridge on Américo Miranda Avenue to the bridge on PR 21.
- Quebrada Guaracanal (not very significant flooding in this stream).

Figure 2. Map of the Río Piedras and Río Puerto Nuevo rivers showing the duration of floods in hours as a result of the Standard Project Flood without the Flood Control Project of the United States Army Corps of Engineers (1984). The longer periods in blue exceed five hours.

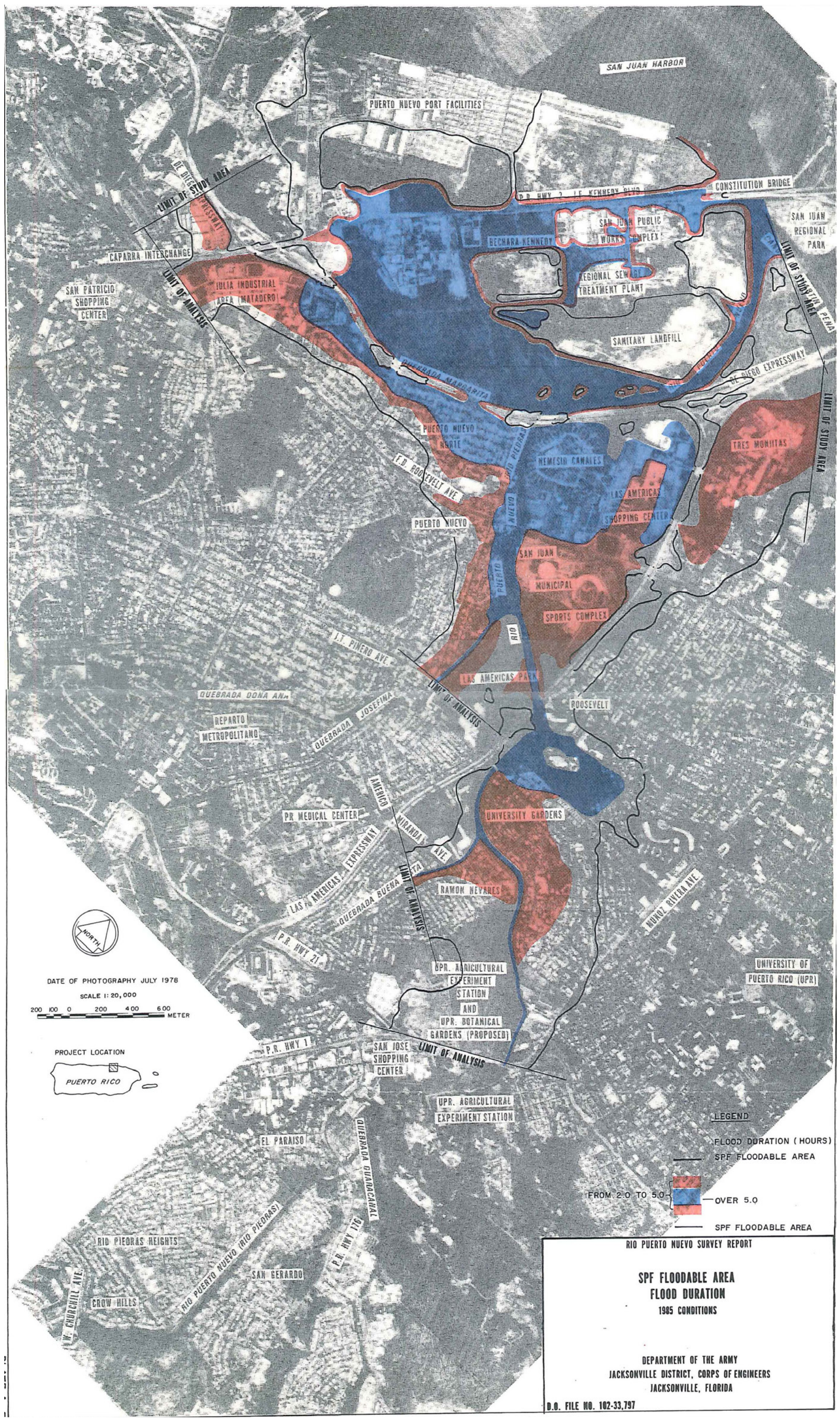

Figure 3. Map of the Río Piedras and Río Puerto Nuevo rivers showing the depth of flooding in meters as a result of the Standard Project Flood without the Flood Control Project of the United States Army Corps of Engineers (1984). The deepest predictions in blue exceed 1.5 meters.

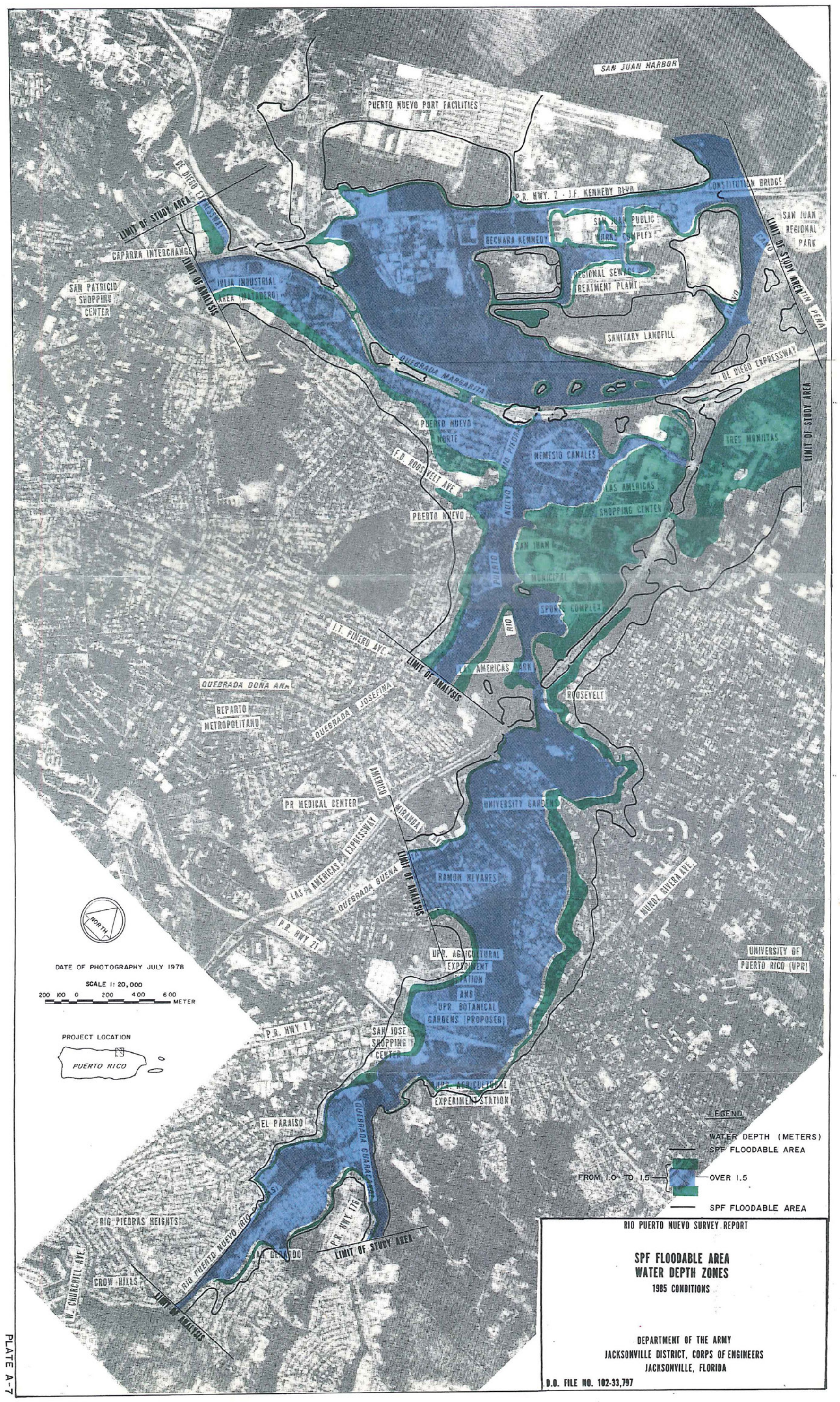

FIGURE 4. Map of the Río Piedras and Río Puerto Nuevo rivers showing the velocity of floodwaters in meters per second as a result of the Standard Project Flood without the Flood Control Project of the United States Army Corps of Engineers (1984). The fastest velocities in dark orange exceed 2.5 meters per second.

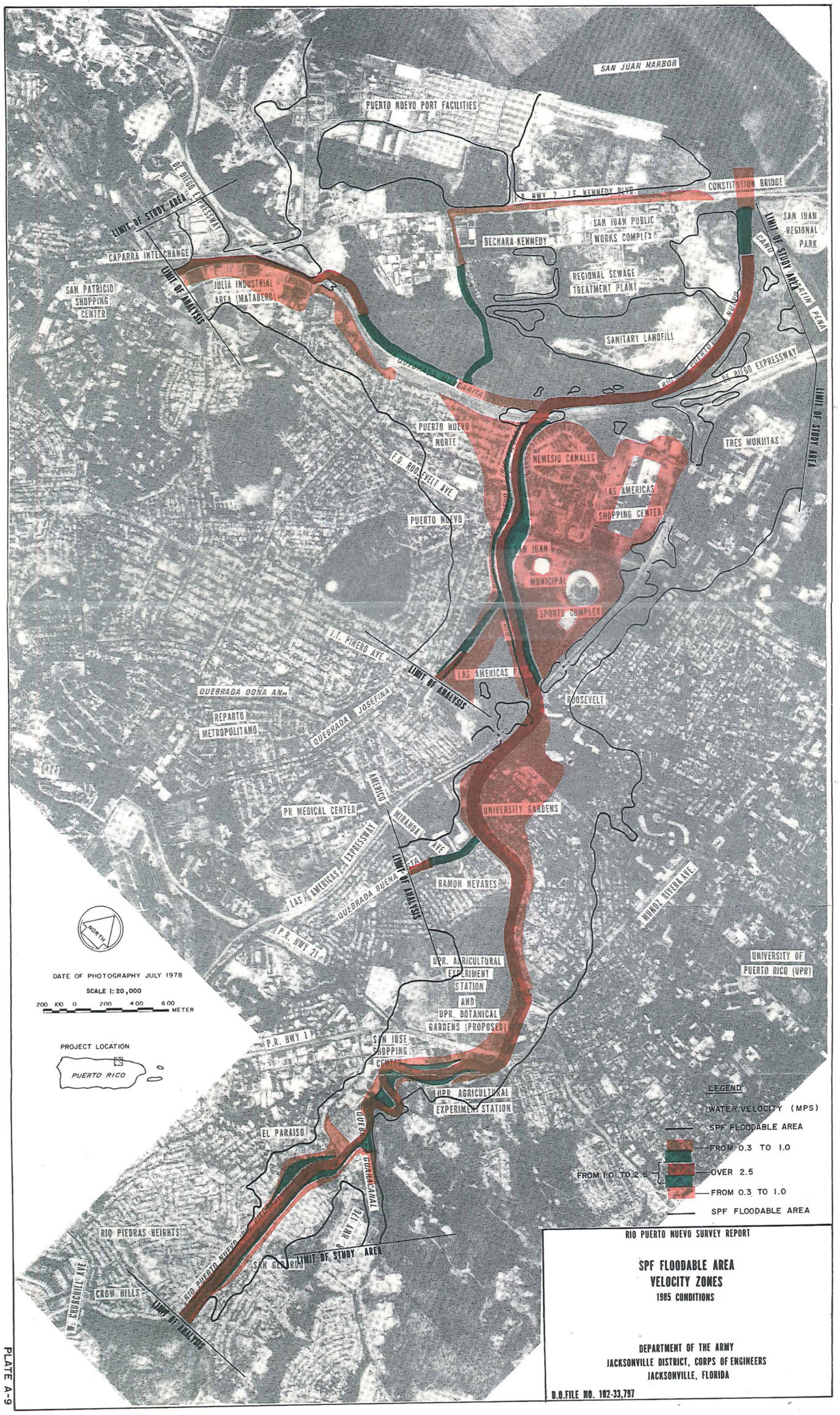

Table 4. Historical and ecological resources of the Río Piedras watershed potentially affected by flooding as identified by the United States Army Corps of Engineers (1984).

- Puente del General Norzagaray or Puente de los Frailes. Dates from 1855.
- Río Piedras Water Works.
- Area between De Diego expressway and the joint outlet to San Juan Bay between the Río Piedras and Caño Martín Peña- mostly mangroves, about 11.5 ha.
- Riparian vegetation along Quebrada Margarita, north of the De Diego Expressway near the Bechara-Kennedy area.
- The whole complex, and particularly the Constitution bridge area, harbors over 70 species of birds with observed concentrations of above 5,000 birds.

Table 5. Projections for the Río Piedras watershed according to the United States Army Corps of Engineers (1984).

- The population of the watershed is expected to rise from 240,122 in 1980 to about 325,000 by 2035.
- Land use will move by 2000 towards densification of commercial and recreational use in the lower reaches and increased residential use in the rest of the watershed.

Table 6. Estimates by the United States Army Corps of Engineers (1984) of flood damage to structures and people by historic (1970 and 1977) and predicted floods on the Río Piedras Watershed.

Flood	Sector affected	US Dollar Estimate
1970	932 families	3.2 million
1977	315 houses	600,000
1984*	Río Piedras sector alone	38 million
1984 100-yr flood	Río Piedras sector alone	90 million
1984 Standard Project Flood	Río Piedras sector alone	247 million
Average annual damages to 1984 conditions	Río Piedras Watershed	20 million
Average annual damages to 2035 conditions	Río Piedras Watershed	38 million

*Assuming the 1970 flood

P 10. The physical and environmental conditions of the study area point towards relatively costly flood control alternatives. The plan aims at meeting projected hydrologic conditions in 2035. These conditions assume the development of all lands that can be developed and currently vacant lands in the upper reaches of the river, as well as improvement of the natural channels of all streams where that development occurs. Completeness and integrity of the proposed flood control plans were other major criteria underlining the proposed flood control plan because of the high interrelation that exists between the river and its tributaries.

Costs and benefits associated with measures to improve local drainage systems are not considered in the economic analyses of the flood control plan. Economic criteria included the maximization of net benefits, discounting benefits and costs at the rate of 8.5 percent for a 50-year period (1985-2035), and included in the total annual cost figures the interests to be paid during the construction period, which was assumed to be six years.

P 11-12. The floodplain regulation number 13 of the Commonwealth was deemed unsuitable for the planning of flood control measures in the Río Piedras Watershed because lands inside the 100-yr floodplain have already been developed, thus precluding use of the regulation to curb development in these critical areas[3]. However, stormwater management is a viable non-structural measure that if implemented effectively in the watershed can improve the movement of floodwaters associated with low intensity and high frequency events. This non-structural approach requires improvement and maintenance of storm drainage systems. In undeveloped areas, future development should include detention ponds and other land development practices designed to increase infiltration[4]. These include avoiding alteration to remaining natural stream channels. Flood insurance could help mitigate flooding effects, but the high cost of premiums in known flood-prone areas may limit the value of this non-structural measure in the Río Piedras Watershed. The same is true for temporary floodplain evacuation in times of flooding. This approach requires an effective predictive system of floods, which is difficult because of the flashiness of streams in the watershed. Permanent floodplain evacuation is deemed too expensive (in the hundreds of millions for the 25-year flood events) to be feasible. Also deemed impractical and not cost effective was flood proofing with flood shields over building openings and/or raising structures for over 5,000 residential, commercial, industrial, and public buildings.

P 12-13. Modifying stream and river channels was the most feasible structural measure considered for this highly urbanized watershed. Floodwalls and levies were also considered. There was no room for additional reservoir construction and the Aljibe Las Curías reservoir did not have sufficient volume to exert any flood control for the region. Detention basins in the Agricultural Experiment Station were considered, but deemed not feasible in reducing floodwater movement under the existing Las Américas Expressway. Eliminated from consideration for a variety of technical, cost, and support reasons were the following approaches to flood control: permanent and temporary floodplain evacuation, upstream stormwater management in undeveloped areas, flood-proofing methods, and reservoirs. Also, no attempt was made to incorporate floodplain regulations and flood insurance methods in any alternative because they were assumed to be part of the "without" and "with" Flood Control Project conditions. The measures considered were channel modifications, channel diversions,

[3] *Regulation number 13 was enacted in 1961 after most of the development in the lower watershed had taken place.*

[4] *Regulation number 3, enacted in the mid 1970's, requires these measures as well as hydrological studies for flood mitigation as part of new construction permit processes.*

levees, floodwalls, and detention basins. The plan was aimed at the future (2035) because of the significant changes expected in the hydrology and hydraulics under most probable development conditions.

P 13-14. Table 7 lists the structural modifications suggested by the proposed flood control plan. All other types of structural alternatives were discarded because of cost, support, lack of feasibility or because they caused local flooding and/or drainage problems. For example, levees could reach 7 m in height, cause local flooding, and require realignment of infrastructure, and were unacceptable to neighborhoods. The detention basin at the Agricultural Experiment Station would have precluded the development of the Botanical Gardens due to technical and engineering obstacles associated with the construction of the detention basin. Besides the excessive bottom elevation required for the detention basin, a 6-m drop would be required for the proposed channel alignment upstream of PR 1 entering into the detention basin.

P 18-19. The risk of larger floods exceeding the proposed design for the 100-year flood is 45 percent with the risk of the Standard Project Flood being 2 percent. This would result in substantial residual flooding but with a low recurrence interval. The most significant adverse impacts are listed in Table 8.

P 21-23. Table 9 lists all the proposed improvements associated with the proposed flood control plan for the Río Piedras Watershed.

P 23-24. The following economic benefits are anticipated from the flood control plan:

- Eliminate frequent economic and traffic disruptions due to flooding.
- Valuable local, state, and federal property would no longer sustain flooding nor would their services be disrupted because of flooding.
- Some 25,000 persons and hundreds of small intermediate and large size commercial establishments would be directly and permanently protected from the overflow of the Río Piedras River and its main tributary streams.
- Also, 250,000 workers, students, and shoppers commuting and traveling daily through the floodplain would be protected from flooding as well.
- The proposed improvements would enhance the opportunities for development, redevelopment, and revitalization of large urban sectors within the core of the San Juan Metropolitan Area.

Table 7. Proposed structural modifications by the United States Army Corps of Engineers (1984) to streams and river of the Río Piedras River Watershed. The Corps uses the term "improvement" to mean structural change or modification.

- Channel improvement of the Río Piedras from San Juan Harbor to the Winston Churchill Avenue.
- Channel improvement of Quebrada Margarita from the junction with the river to the Caparra interchange.
- Channel improvement for Quebrada Josefina.
- Channel improvement for Quebrada Doña Ana.
- Diversion for Quebrada Buena Vista.
- Small traditional channels for existing channels of Quebrada Buena Vista and Quebrada Guaracanal.

Table 8. Most significant adverse impacts of the selected flood control plan for the Río Piedras according to the United States Army Corps of Engineers (1984).

- Loss of 13.5 ha of mangroves, 12.1 ha due to channel widening and 1.4 ha for location of a disposal site*.
- Need to replace 22 bridges, 15 of them in major highways.
- Risk of the 100-year flood control channel being overtopped by larger floods is 45 percent.
- Some 100 structures and buildings, mostly residential would have to be acquired to build the channel.
- The required excavation is 1,100,000 m^3 of dredged material for ocean disposal and 3,749,000 m^3 of unclassified and rock material to be placed in two upland sites. These sites cover 20.3 ha (page 23 of the Corps document).

*Replanting of 6 ha of mangroves along the lower channel of the river and Quebrada Margarita is proposed for mitigation.

- Use of the extensive and diversified existing infrastructure in the study area will be maximized.

The projected cost of construction of the Flood Control Project is $154 million. Real estate and bridges would absorb an additional $66.9 million. After adding interests on required construction funds, the total Project cost adds to $253.5 million. This includes $458,000 for the bicycle corridor, $10,000 for its operation and maintenance and $251,000 for the mangrove management plan.

P 24-27. The federal government will design, prepare detailed plans, construct, and fund the Flood Control Project. At no cost to the federal government, the Commonwealth will provide all lands, easements and rights of way, alterations and relocations to buildings, bridges, and public utilities. The Commonwealth is also committed to hold and save the federal government from damages due to the construction works, and to properly maintain and operate all works after completion of the Project, including establishing and enforcing regulations to assure effectiveness of the Flood Control Project to accomplish its objectives. The federal share for designing and constructing this project is $186.4 million and the Commonwealth share is $67.1 million.

The Department of Natural and Environmental Resources will be the sponsor and cooperating partner for this project. Part of its responsibility is to organize a steering committee of representatives from the Department of Transportation and Public Works, Municipality of San Juan, Puerto Rico Ports Authority, University of Puerto Rico, Department of Sports and Recreation, Puerto Rico Telephone Company (*now Claro Puerto Rico*), Puerto Rico Aqueducts and Sewer Authority, Puerto Rico Electric Power Authority, Puerto Rico Environmental Quality Board, Puerto Rico Planning Board, Department of Housing, Budget Office, and representatives of residents of the study area. This committee coordinates and programs the Project.

Environmental Impact Statement (EIS)

The Corps determined that the proposed Flood Control Project was consistent with the coastal zone management program.

A section 404 (b) evaluation report is not needed because none of the alternatives considered involve discharges into wetlands.

Alternative B was designated the National Economic Development Plan. It maximizes net

Table 9. Proposed improvements to the Río Piedras watershed by the United States Army Corps of Engineers (1984) as part of the Flood Control Project.

- **Main channel of the Río Piedras:** starts 450 m into the San Juan Harbor from the Constitution Bridge with a 120 m bottom width and the banks lined with concrete sheet pilings and mangroves. These sheet pilings extend another 1.5 km upstream the Constitution Bridge to the vicinity of the San Juan Municipality sanitary landfill area. The next 580 m up to the junction with Quebrada Margarita consists of a trapezoidal earth channel lined with riprap and mangroves. Bottom width of the channel at this junction is 120 m. From the Diego Expressway bridge to the Lomas Verde Avenue (7.4 km upstream) the improvement consists of a high velocity reinforced concrete rectangular channel with bottom width ranging from 55 to 12 m.
- **Also along the main channel** construction of a stilling basin just upstream of Quebrada Buena Vista and a debris basin at the uppermost section of the Flood Control Project in the vicinity of Las Lomas and Winston Churchill Avenues.
- All bridges along the 10.5 km improved main river channel, except the Constitution and De Diego Expressway bridges, will be replaced, but the historic Norzagaray Bridge will be preserved. At the historic bridge location, the channel will be diverted some 115 m to the west, and a new bridge over PR 1 will be built.
- Bridges to be replaced are: Roosevelt Avenue, Las Américas Expressway and its two eastern ramps, J.T Piñero, Notre Dame, and PR 176.
- Some 18 structures of different types will have to be relocated.
- **Quebrada Margarita:** From its junction with the main river to 1.6 km upstream it would have an earth trapezoidal channel with riprap and mangrove. For the next 1.4 km upstream to the vicinity of the Caparra Interchange the channel will be rectangular made of reinforced concrete, with a 25 m bottom width for most of the channel. The De Diego Expressway Bridge will have to be replaced.
- **Quebrada Josefina** will have a 2.3 km reinforced concrete rectangular channel from its junction with the main river to the vicinity of the Veterans Administration Hospital. The bottom width of the channel will range from 20 to 10 m. Bridges on J.T. Piñero and Américo Miranda Avenue will be replaced as well as three bridges on local streets. Forty-six residential structures would have to be replaced.
- **Quebrada Doña Ana** will be channelized for 1.0 km from its junction with Quebrada Josefina to 9 SE Street with a 10 to 7 m wide reinforced concrete rectangular channel. The bridge in Américo Miranda Avenue and three bridges on local streets will be replaced. Thirty-five residential structures will have to be relocated.
- **Quebrada Buena Vista** will be diverted along a 1.7 km reinforced concrete rectangular channel along vacant lands in the Botanical Gardens. The channel will start opposite Salamanca Street in University Gardens and end in a new bridge in PR 21. The channel will have a bottom width ranging from 12 to 7 m. Some seven houses will be displaced.
- **Quebrada Guaracanal** will have a 290 m transition section consisting of a 7 m wide reinforced concrete channel and a small debris basin.
- **The bicycle path** will extend from Lomas Verdes Avenue to the San Juan Regional Park along the main river channel.
- **Two boat ramps**, one near the San Juan Regional Park and the other at Las Américas Park, will be constructed.
- **Mangroves** between the Río Piedras, the Puerto Nuevo Port Facility, and Kennedy Avenue will be designated as a forest reserve.
- **Future planning** and design stages will consider enhancement of the Constitution Bridge mud flats as well as shape requirements for the mangrove planting along the stream channel.

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benefits consistent with the federal objectives of flood protection. It generated 13 percent more net benefit than the second ranked alternative C (protection for the Standard Project Flood event).

An area of conflict was the intention of the Commonwealth to align the channel following a 1973 plan, but the invasion of the channel by the San Juan Municipal sanitary landfill precluded that plan; thus, the alignment according to alternatives included in the EIS. Another area of conflict was the effect on the Constitution Bridge mangroves and mudflats. Mitigation actions were proposed to overcome this issue.

The connection of the Río Piedras and Caño Martín Peña is the result of construction in the late 1950's (page EIS-7). The Río Piedras is mentioned on this page.

Brown Pelican and Yellow-Shouldered Black Bird are two endangered species whose ranges encompass the project area (page EIS-8).

The lower end of the watershed is classified as a non-attainment area under the national ambient air quality standards since primary standards are exceeded (page EIS-9).

Channel construction would improve overall storm-water drainage and flow as well as increase tidal flushing activity and levels of dissolved oxygen. Sediment load should decrease because of reduced stream bank erosion along the length of the modified channel (page EIS-11).

Appendix A: Problem Identification

A-15. In addition to flooding by the Río Piedras, the watershed will be subjected to higher flooding frequency as a result of poor storm drainage infrastructure. The problem is attributed to limited capacity of the storm sewer systems, poor maintenance, backflow effects from streams, and by the erection of structures and roads on former wetlands and low lying lands, which do not permit adequate gravity flow towards existing drainage systems. Many drainage systems discharge into the Río Piedras at well below-bank level, thus assuring river backflow into neighborhoods during bank full discharge. There are inefficient local drainage facilities throughout the whole watershed.

A-16 to A-17. There are five distinct sectors where flooding occurs:

- Bechara-Kennedy sector is a track of 3.23 km^2 with 40 percent of the area dedicated to commercial and public use;
- Puerto Nuevo development has 2,026 single-family, reinforced concrete units and 120 small commercial outlets;
- Public oriented facilities sector and commercial area;
- University Gardens and Ramón Nevares developments
- Commercial and residential developments between PR1 and Winston Churchill Avenue.

A-17. Channels below PR 1 have a low drainage capacity. This results in long flood durations (0 to 2 hours, 2 to 5 hours, and over 5 hours for standard project and 10 year floods). These floods could have a depth of 0 to 1 m, 1 m to 1.5 m, and over 1.5 m. The 1.5 m depth area extent is quite large.

A-18. As of 1983, Las Curías dam was deemed unsafe and recommended for breaching and emptying (*today, the dam still stands*).

A-18 to A-19. The expectation was that by the year 2000 the entire watershed would be completely urbanized. At the time of the study it was 75 percent urbanized. Under future conditions, areas not flooded by the 10-year flood will flood. Examples would be Plaza Las Américas and Tres Monjitas industrial area.

Appendix B: Plan Formulation

B-7 to B-8. The construction practices in Puerto Rico (reinforced concrete with foundations over compacted soil) were not deemed amenable to flood proofing structures, as they could not be raised.

B-8. Channel improvements involve straightening and widening current structures. All bends, obstacles, and irregularities within the stream would be removed.

B-9. The right field of a baseball stadium built for the 1979 Pan American Games is located over a reach of some 200 m of the Quebrada Buena Vista channel.

Table 10 depicts the depth of residual flooding due to floods exceeding the 100-year flood with and without the proposed Flood Control Project. Figure 1 shows in blue the areas in the watershed that will experience residual flooding after the completion of the Project.

B-51. Changes in land occupation pattern in the watershed would not significantly affect the total cost of the Flood Control Project. They estimate only a 5 percent reduction in cost ($10.9 million) if the watershed is not developed as expected. This estimate is anticipated in spite of an increase of 30 percent in the peak discharge at PR 1 (13 percent at the De Diego Expressway Bridge) of the Standard Project Flood due to the additional development in the watershed. These increases in peak discharge would translate to an annual increase in damage of $6.2 million per year for the whole watershed.

Appendix C: Economic Analysis

Table 11 contains the kilometers of highways and streets subjected to flooding by river reach.

Table 12 contains the average value of structures and the average value of content inside structures for various residential sectors of the Río Piedras Watershed inside the Standard Project Flood.

Table 13 contains the structure and contents values for commercial establishments affected by flooding of the Río Piedras and tributary streams. The information is provided by river reach.

Table 14 contains the number of commercial and residential structures potentially affected by the 100-year flood of the Río Piedras.

Table 15 contains a summary of damages caused to structures and infrastructure as a result of the 1970 flood of the Río Piedras.

Table 16 contains the historical flood damages to residential areas during the flood of the Río Piedras in 1970.

Table 17 contains flood damages for single flood events of different frequencies for the Río Piedras by land use category using 1984 conditions and dollars.

P C-20. The increases in damages due to the Standard Project Flood are due to flooding of valuable properties that don’t flood with the 100-year event.

P C-23 to C-27. Table 18 combines data from several tables to illustrate the predicted flood damage for the Río Piedras Watershed for the year 2035 using data from the year 2000. The Corps assumes that by the year 2000 the watershed would have been fully developed.

Table 19 contains residual flood damage for various reaches of the Río Piedras Watershed using 1984 thousands of dollars. These residual damages, subtracted from the damages without the Flood Control Project, approximate the benefits of flood control on page C-31. On page C-32, the Corps provides estimates for the increased future value of lands flooded without the Project and then protected by the Project. These increased land values were counted as benefits to the Flood Control Project. The discount value used was 8.5 percent for a 50-year period.

Table 10. Depth in meters of residual flooding due to overflow of improved channels during floods that exceed the 100-year flood. Values apply to the year 2035. Data from the United States Army Corps of Engineers (1984).

Selected Area	Without Project	With Project
Las Américas Shopping Center	1.77	0
University Gardens	3.32	2.16
Reparto Metropolitano	1.45	0.64
Bechara-Kennedy	3.07	0
Julia Industrial Area	2.81	0.67
Puerto Nuevo Norte (east)	2.68	1.34
Ramón Nevares	2.32	0.67

Table 11. Kilometers of highways and streets subject to flooding in the Río Piedras Watershed according to the United States Army Corps of Engineers (1984).

Reach	km
1. Mouth of the river to De Diego Expressway	14
2. De Diego Expressway to Winston Churchill Avenue	87
3. Quebrada Josefina upstream of JT Piñero Avenue to 9-SE street Reparto Metropolitano	12
4. Quebrada Buena Vista from Américo Miranda Avenue to PR 21	4
5. Quebrada Margarita from Caparra Interchange to Garden Hills	8

Table 12. Average structure value and average content value by sector of the Río Piedras Watershed. Values are from the United States Army Corps of Engineers (1984) and expressed in dollars per structure.

Sector	Structure	Content
Puerto Nuevo Norte	43,000	11,000
Nemesio Canales	33,000	8,000
Puerto Nuevo Sur	44,000	10,000
University Gardens	77,000	21,000
Ramón Nevares	56,000	21,000
San Gerardo and El Paraíso	56,000	21,000
Reparto Metropolitano	53,000	11,000

Table 13. Structure and content value for commercial establishments affected by flooding due to the Standard Project Flood by reach of the Río Piedras and its tributaries. Values are from the United States Army Corps of Engineers (1984) and expressed in thousands of US dollars using 1984 prices.

Reach	**Stream**	**Structure**	**Contents**	**Total**
1 and 2	Río Piedras	195,690	170,946	366,636
3	Josefina/Doña Ana	3,544	2,458	6,002
4	Buena Vista	--	--	--
5	Margarita	24,816	34,998	59,814

Table 14. Number of structures affected by the 100-year flood by land use in the Río Piedras Watershed according to the United States Army Corps of Engineers 1984).

Stream	**Residential**	**Commercial**	**Others**
Río Piedras	3,878	298	17
Josefina/Doña Ana	901	26	2
Buena Vista	238	--	--
Margarita	10	19	1

Table 15. Historical flood damages by principal land use for the flood of 1970 according to the United States Army Corps of Engineers (1984).

Sector	**Residential**		**Commercial**	**Public Offices**	**Infrastructure**
	Number of Houses	**Damages (US dollars)**			
Puerto Nuevo Norte	455	1,556,000	35,200	28,000	14,000
University Gardens	131	159,458			80,000
Puerto Nuevo Sur	120	84,910	42,700	5,000	12,000
Nemesio Canales	137	361,170		65,000	
Ramón Nevares	89	132,000			
Cupey Bajo			325,280		150,000
Quebrada Josefina					50,000
Quebrada Margarita					40,000
Other Tributaries					50,000
Total	932	2,293,538	403,180	98,000	396,000

Table 16. Historical flood damage to residential areas in various sectors of the Río Piedras River Watershed by the flood of 1977 according to the United States Army Corps of Engineers (1984).

Sector	Number of Houses Affected	Total Damage (US dollars)
Puerto Nuevo Norte	100	224,700
Puerto Nuevo Sur	96	208,100
Nemesio Canales	41	60,300
University Gardens	78	122,600

Table 17. Flood damages for single flood events by land use category using 1984 conditions in the United States Army Corps of Engineers (1984). Damages are in 1984 thousand US dollars. Standard Project Flood is SPF.

Flood Frequency (years)	Residential	Commercial	Public	Industrial	Total
2	7,079	1,607	--	--	8,685
5	19,429	2,921	292	--	22,642
10	30,170	4,672	3,100	--	37,942
25	41,353	8,403	4,187	--	53,943
50	52,404	11,698	4,947	--	69,049
100	64,223	17,206	9,001	--	90,430
SPF	134,249	83,035	29,456	517	247,257

Table 18. Flood damage for single flood events for the year 2000 to 2035 in thousands of 1984 dollars. Conditions for year 2,000 are used for the year 2035. The Standard Project Flood is SPF and Q is Quebrada. Data for Q Margarita is upstream from Caparra interchange. Flood frequency is in years. Data are from the United States Army Corps of Engineers (1984).

Flood Frequency (years)	Río Piedras	Q Josefina/ Q Doña Ana	Q Buena Vista	Q Margarita
2	46,682	11,315	1,321	315
5	68,887	18,617	4,267	643
10	95,487	24,264	5,216	1,093
25	117,057	29,733	6,185	1,519
50	161,990	33,473	6,817	1,865
100	190,264	37,834	7,502	2,468
SPF	353,247	64,745	12,325	6,495

P C-33 to C-34. The Río Bayamón channelization project was completed between 1973 and 1974, and immediately the western bank was developed for residential use. This is an example of benefits, and is illustrated with a photo of the development in Photo C-9 in the document. Owners are willing to improve dilapidated structures in the flood areas once flood protection is available.

P C-35. In Río Yagüez, Río Bayamón, Río Humacao, and Río Portugués, the experience is significant intensification of development once the channels are improved. The value is about $50 million of new development in the Río Bayamón. This revives slumping construction industry.

Table 20 summarizes the costs and benefits of the selected channelization alternative. Estimates apply to the whole Flood Control Project.

Appendix D: Hydrology and Hydraulics

P D-1. Originally only the lower reaches of the Río Piedras was known as Río Puerto Nuevo. In this document, the name Río Puerto Nuevo was retained for the whole watershed.

Table 21 contains the catchment area of the various tributaries of the Río Piedras.

P D-3 to D-8. Historic floods include (from newspapers): May 23, 1958, November 12, 1961, October 12, 1963, and September 16, 1966. Data are available for the June 17 and October 6 floods of 1970, flood of February 15, 1979, August 31, 1979, and October 9, 1979. Notable storms of the 20th century at San Juan occurred on December 14, 1910, September 13, 1928, November 11, 1931, and August 15, 1944.

Peak discharge at 4.37 km upstream from the mouth at the J.T. Piñero Bridge (39.9 km^2 drainage) of the October 6, 1970 flood was 221 m^3/s and 283 m^3/s for the June 17, 1970 flood (this flood has a recurrence interval of 8 years and the October 6 has a recurrence interval of 5 years). During the flood of February 15, 1979, a two-year event, peak discharge at the PR 1 Bridge was 251 m^3/s, and it was 283 m^3/s at J.T. Piñero Bridge. This event was used to calibrate rainfall-runoff models of this study.

P D-8. Lack of adequate streamflow records made it necessary to develop hypothetical storms and apply rainfall-runoff simulation models to the Río Piedras watershed.

P D-11. They use Río Piedras instead of Río Puerto Nuevo (*only once*).

P D-12 to D-26. The watershed was subdivided into 24 symmetrical sub watersheds

Table 19. Residual annual damages for Río Piedras with and without the Flood Control Project due to the 100-year flood. Data are from the United States Army Corps of Engineers (1984) and values are in thousands of 1984 US dollars.

Reach	Stream	Without	With
1 and 2	Río Piedras	29,589	707
3	Josefina/Doña Ana	7,634	532
4	Buena Vista	1,455	-
Total		38,678	1,239

Table 20. Annual benefits, costs, and their ratio (benefit/cost or B/C) for the Río Piedras and tributary streams in thousands of 1984 US dollars. The ratio does not have a dollar unit. Data are from the United States Army Corps of Engineers (1984).

Item	Value
Río Piedras	
Benefits	45,125
Costs	17,669
Net benefits	27,456
B/C	2.6
Quebrada Josefina	
Benefits	7,316
Costs	2,722
Net benefits	4,594
B/C	2.7
Quebrada Buena Vista	
Benefits	1,523
Costs	769
Net benefits	754
B/C	2.0
Río Piedras and Tributaries	
Benefits	53,964
Costs	21,160
Net benefits	32,804
B/C	2.6

using a topographic map[5]. Las Américas and Tres Monjitas sectors discharge to Caño Martín Peña. The Bechara-Kennedy industrial area does not contribute much runoff to the Río Piedras because of the swampy conditions and construction of the landfill at the edge of the river.

Runoff volumes and peak rates of discharge were estimated using two rainfall-runoff models: the 1977 version of the Corps HEC-1 model and the MITCAT Catchment Model of 1978. These models are developed from the models used by the Soil Conservation Service, modified for urban conditions. The models use the antecedent moisture condition (AMC) that considers soil moisture estimated from rainfall in the antecedent five days. The model estimates the lags for water from excess rainfall to reach peak discharge at a location where the unit hydrograph is being computed. These lags were modified according to the percent of hydraulic length modified and percent impervious area in the sub watersheds. It was assumed that all areas designated for development would have their stream channels modified.

Model outputs for the 100-year flood are given in Table 22. For 2035, peak discharges are expected to be between 1.3 and 16 times higher than in 1980, except in sections 28 and 33, where they remain the same. Because of different assumptions and the use of different models, the predicted values are lower than reported by Flavio Acarón in a study that used lower development intensity (1973 data). Acarón generated a 200-yr synthetic rainfall to drive his model.

P D-41 to D-48. Peak channel discharge, water surface elevation, and channel velocity are given for many reaches and historical and predicted conditions, also channel capacity. The main causes of flooding along different reaches are (by reach):

Flooding from Los Húcares to PR 1 is due to lack of hydraulic capacity in the stream and to urbanization, which reduces infiltration and increases velocity of runoff to streams. In addition, lack of hydraulic capacity of bridges, constriction caused by the location of two Sears warehouse buildings on each bank of the river, and backwater effect caused by large flows of Quebrada Guaracanal at its junction with the river. Topography and location of large buildings along PR 176 near bridge crossings all impede the overbank flow from returning to the river and flows instead to the highway at

[5] *In the 1991 Design Memorandum, page 7 volume 1 of main report, the Corps used 18 sub watersheds.*

Table 21. Catchment areas of the main tributaries of the Río Piedras. The total area down to the De Diego Expressway bridge crossing is 62.84 km^2. Data are from the United States Army Corps of Engineers (1984).

Stream	Drainage Area (km^2)	Percent of the Watershed
Quebrada Margarita	9.3	15
Quebrada Josefina/Doña Ana	10.0	16
Quebrada Buena Vista	4.9	8
Quebrada Guaracanal	7.5	12
Quebrada Los Guanos	3.1	5
Quebrada Las Curías	4.3	7
Total	39.1	63

Table 22. Peak discharges in m^3/s for 1980 and 2035 due to the 100-year flood.

Section	Location	Discharge	
		1980	2035
	Río Piedras		
13	Above Guaracanal junction	442	643
16	PR 1	598	926
17	Above Buena Vista junction	620	943
21	Above Josefina junction	719	1,011
27	Above Margarita junction	878	1,127
35	Lower end	969	1,232
	Quebrada Guaracanal		
14	Above Río Piedras junction	215	337
	Quebrada Buena Vista		
18	Above Río Piedras junction	142	178
	Quebrada Josefina		
25	Above Río Piedras junction	263	360
	Quebrada Margarita		
28	Above Caparra Interchange	153	153
33	Above Río Piedras junction	241	241

speeds of 1 m/s, flooding areas that otherwise would not be flooded. Depth of waters over the bridge pavement can be 0.3 m. At PR 1 Bridge, 100-year floodwaters can spread laterally 0.7 km over the highway and inside the Experiment Station grounds and remain overland for a long period of time.

From PR 1 to Las Américas Expressway flooding is caused by lack of channel and bridge capacity and the damming effect of Las Américas Expressway. The expressway detains waters at up to 0.6 m depth for four hours in the case of the 100-year flood.

From Las Américas Expressway to San Juan Harbor the main cause of flooding is lack of adequate capacity in the streams draining the area. In addition, Puerto Nuevo Norte and Bechara-Kennedy industrial and commercial sectors are subject to frequent flooding due to inadequate storm sewers and lateral drainage facilities, which retard runoff to the primary streams. Flooding of Quebrada Margarita is critical in the De Diego-San Juan Harbor area. The sector bounded by J.T. Piñero Avenue and De Diego Expressway is heavily affected by overflow of the Río Piedras. At the fourth hour of the Standard Project Flood, Río Piedras and Quebrada Josefina had a discharge of 1207 m^3/s with a velocity of about 4.7 m/s while the channel can handle 774 m^3/s just below Josefina with a velocity of about 4.3 m/s, and 751 m^3/s through the De Diego Expressway bridge with a velocity of about 5.3 m/s.

Topographic conditions that explain the flooding:

- The hydraulic section of the Río Piedras between Las Américas Expressway and Quebrada Josefina junction is much less efficient than the hydraulic sections found downstream.
- The portion of the valley bounded by the De Diego Expressway and Las Américas Expressway slopes towards the interchange of these expressways. Water accumulated in this sector can find its way out only by means of three bridge openings, a small channel that discharges into Caño Martín Peña, and the local storm sewer system. This portion of the valley is 60 percent of the floodable area of the sector.
- Flows from Quebrada Margarita and backflow from Río Piedras into Quebrada Margarita affect Bechara Industrial area via the old Río Piedras channel.

Puerto Nuevo Norte and Nemesio Canales flood due to their storm sewer systems. The discharge of the Nemesio Canales storm sewer system into the Río Piedras is below bankfull level. When Río Piedras is bankfull, backflow into the streets of Nemesio Canales occurs. The storm sewer system of the eastern portion of Puerto Nuevo Norte discharges into Quebrada Margarita with invert elevations below mean sea level. A backflow from Río Piedras into Quebrada Margarita floods 20 NE Street of Puerto Nuevo Norte.

Flooding problems along reaches of Quebradas Margarita, Doña Ana, Josefina, Buena Vista, and Guaracanal occur due to the lack of hydraulic capacity of their channels and of the many bridges, which cross them. For Quebradas Margarita and Buena Vista, problems are aggravated by the existence of very long under-capacity culverts. Overflow waters return to the channels mainly through local storm sewer systems.

P D-49. Consideration of tides in the design criteria: To minimize construction activity and right-of-way requirements, a supercritical flow regime was considered for the steep upper watershed and a slope controlled subcritical flow design which maximized allowable velocities was considered for the lowlands. Design water surfaces profiles were developed to flow in-bank and to follow the general profile of natural ground. Concurrent tidal effects in

San Juan Harbor established starting conditions for the subcritical flow portion of the design. Peak tides would not be coincidental with peak storm discharges. The tide range in San Juan Harbor is small, with mean high tide of 0.18 m msl and mean low tide of -0.15 m msl. A tide level of 0.0 m msl was used for design purposes in order to prescribe flood control conveyance capacity while protecting against higher velocities associated with the drawdown effect during lower tide levels. Starting conditions at the upstream termini of the main channel and tributaries were established from critical depth in the natural upstream sections, then forewatering through gabion transitions into the design sections. All tributary junctions, except the Guaracanal junction, would consider subcritical flow conditions, where the momentum analysis would define upstream water surface profiles. Guaracanal junction will be supercritical.

P D-51. To minimize the impact on heavily urbanized real estate, hydraulic designs were developed to maximize channel velocities and minimize channel size, and yet conform design water surface profiles to the general slope of existing natural ground.

P D-86. The hydraulic design was developed to pass the 100-year flood within banks of channels.

P D-89. Residual flooding is flooding due to floods exceeding design capacity, flooding due to surface runoff exceeding the capacity of local storm sewers (their overflow), and ponding in low areas where channel walls project from the ground or when terrain adjacent to the channel is higher.

Appendix E: Geotechnical Studies

Contains detailed boring and soil analyses along the proposed channel alignment.

Appendix F: Design and Cost Estimates

P F-1. The proposed channels (Fig. 1) will be designed with sufficient capacity for dealing with the 100-year flood based on year 2035 hydrology. A minimum 5-m strip on each side of channels will be used for various maintenance purposes. A wire mesh fence will protect this strip of land.

P F-3. Average annual sediment yield from the watershed is estimated at 1,300,000 m^3 for 1980 and 250,000 m^3 for 2035. About 20 percent will be deposited in the channel and the rest will flow into San Juan Harbor. Periodic floods will flush most of the sediment from the channels. They estimate $150,000 per year in maintenance.

Detailed construction estimates given in numerous tables.

Appendix G: Recreation, Cultural, and Natural Resources

P G-1. By 1977 there were 616 ha of neighborhood and community parks in the San Juan Metropolitan Area, including a golf course, beach front, and many other recreation facilities such as baseball parks, swimming pools, and so forth. (For example, 80 volleyball courts, 357 basketball courts, 424 softball parks, 207 baseball fields, 35 handball courts, 45 tennis courts, 2 track and field sites, and 125 playgrounds for children).

P G-6. The estimate for recreation needs is 2 ha per 1,000 people, which means that the Río Piedras Watershed will need 840 ha based on the population estimate for 2035 (350,000 people) used in this study.

P G-9. They report approximately 200,000 bicycles in Puerto Rico, half in San Juan with a trend that increases monthly.

P G-21. Puerto Nuevo was under the jurisdiction of Caparra, the island's first settlement (1508-1520). In 1520 it was transferred to the jurisdiction of San Juan. Río Piedras was chartered in 1714 and Puerto Nuevo might have shifted to its jurisdiction.

P G-27. They mention and recognize the Río Piedras River.

P G-32. Tidal flushing of the channel will improve water quality. Water quality will improve in the tidal-influenced segment of the Flood Control Project area.

Appendix G, Annex A Environmental Assessment

P GA-1. This appendix recognizes the identity of the Río Piedras River.

P GA-3. There is little freshwater dilution of waters at the mouth of the river and Caño Martín Peña. The normal computed flow (*not defined in the document*) of the Río Piedras is 37 cubic feet per second, which is minimal compared to tidal flows.

Appendix H: Public Involvement

P H-4 to H-5. Contains a listing of all Commonwealth and federal government agencies, civil organizations, and general public involvement with the Flood Control Project. The USDA Forest Service was not included.

P H-17 to H-19. The USDA Forest Service was not listed among organizations with which the Corps coordinated the survey report and draft environmental impact statement.

ANALYSIS

This report presents a comprehensive overview of the flooding problems in the Río Piedras Watershed and provides a well-explained proposal to channelize the river and its tributaries to resolve the flooding problems associated with a 100-year flood event. The document provides detailed explanations of why particular approaches were selected and how the Corps came to conclude that the selected flood control alternative was the right one for the Río Piedras Watershed. Fundamentally, the Corps used hydrologic and economic arguments coupled with an analysis of the existing (1980's) and future (2035) watershed conditions to propose the channelization of the river and tributaries so that the region could handle a 100-year flood without experiencing channel overflow.

We recognize that the Corps has produced many additional documents in support of the Río Piedras Flood Control Project and that many of the limitations of this report could be resolved in later reports. Our intention is to pursue the issues we identify here in subsequent Corps documents to determine if they have been properly addressed.

Our analysis of the document uncovered a number of topics not considered by the Corps and we found that several assumptions, upon which the justification of the Flood Control Project was based, are no longer correct. The initial assumptions were based on social, ecological, and economic trends perceived to be correct in the 1980's but proven incorrect in the present. Thus, the Flood Control Project is designed for 2035 conditions that we know today are not possible. We start the analysis by examining those assumptions.

Incorrect Assumptions

The Corps assumed that by the year 2035 the Río Piedras Watershed would be completely urbanized (Fig. 5) and would have a larger population than in 1980 (Fig. 6). All of their economic trends were based on these assumptions, as was their design of the improved channels that would convey the 100-year flood event. Moreover, the Corps focused the solutions to the flooding problems to channel hydrologic insufficiency and overflow and did not address flooding due to poor infrastructure maintenance and storm sewer insufficiency. Nevertheless, Corps documents contain information that show the Corps to be aware of the deficient state of stormwater infrastructure in the metropolitan

Figure 5. Map of the Río Piedras Watershed and a portion of the Río Puerto Nuevo Watershed showing the United States Army Corps of Engineers (1984) projection of land use in the year 2000. Diagonal lines are residential uses. Blue is public use and orange is commercial Agriculture and forestry are at the top of the watershed.

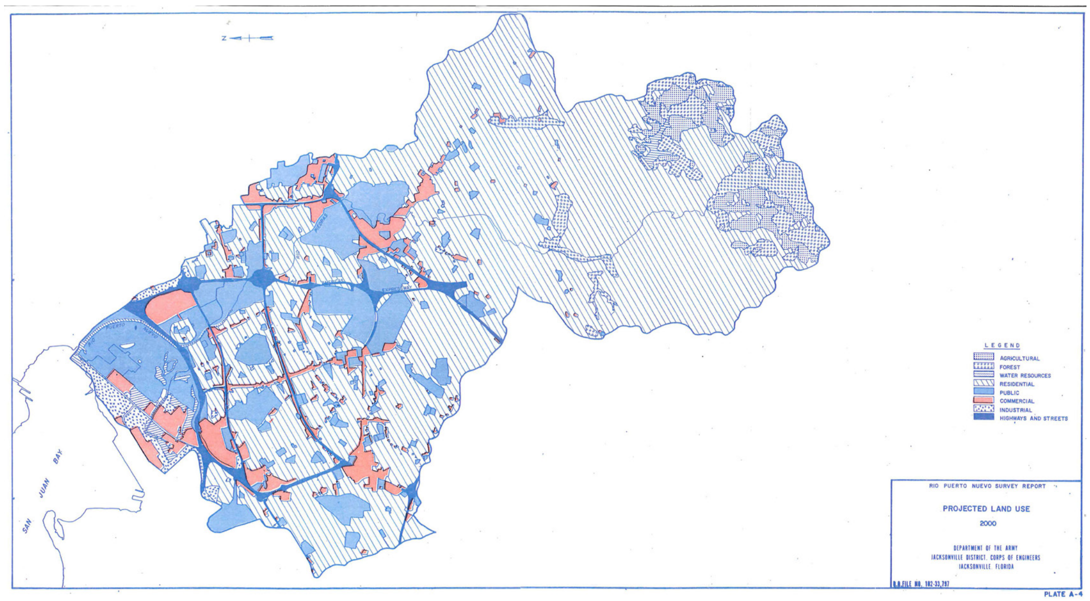
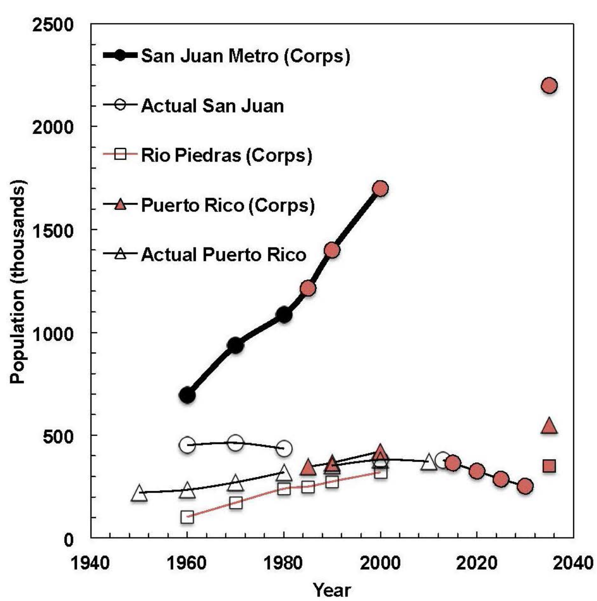


Figure 6. Changes between the 1960s and 2040 in the population of Puerto Rico, San Juan Metropolitan Area, San Juan Municipality, and Río Piedras. This graph is based on data in the report of the United States Army Corps of Engineers (1984), the U.S. Census, and the Commonwealth Planning Board. The Puerto Rico population numbers are divided by 10. Real points are extrapolations. The three red points for 2035 are extrapolations by the corps.



area (see page A-15 in appendix A of the Puerto Nuevo Survey Investigation and also below in the General Design Memorandum), a situation that invalidated their assumption that led them to only focus on the Río Piedras channel.

Today, all these assumptions have been proven wrong. The population of the watershed did not grow as expected because after 2000, Puerto Rico as a whole suffered a decrease in population (Fig. 6) and an increase in the abandonment of urban structures. In Fig. 6, the expected rising population numbers for San Juan Metro, the Río Piedras Watershed, and Puerto Rico as assumed by the Corps, contrasts with current negative trends for all those populations. The actual change in population density and abandonment of structures has led to a change in green cover for the Metropolitan Area, including the Río Piedras Watershed. Green cover in a 2004 satellite image approached 50 percent and the level of urbanization in the watershed was less than the almost 100 percent assumed by the Corps (Ramos González 2014; Fig. 7). These changes in population and land cover have economic implications that need to be considered to access the actual cost/benefit ratio of the Flood Control Project.

San Juan now floods more than it has in the past because its stormwater system cannot handle low intensity high frequency rainfall events. This is mostly due to insufficient capacity of its stormwater infrastructure and poor maintenance of that infrastructure (discussed in detail later in this report). It is possible that if the Flood Control Project were to be completed without addressing the stormwater infrastructure, the city would still not solve the flooding problem it faces, particularly with high frequency low-intensity rainfall events. The stormwater drainage system and its proper functioning need to be taken into consideration in tandem with the Flood Control Project.

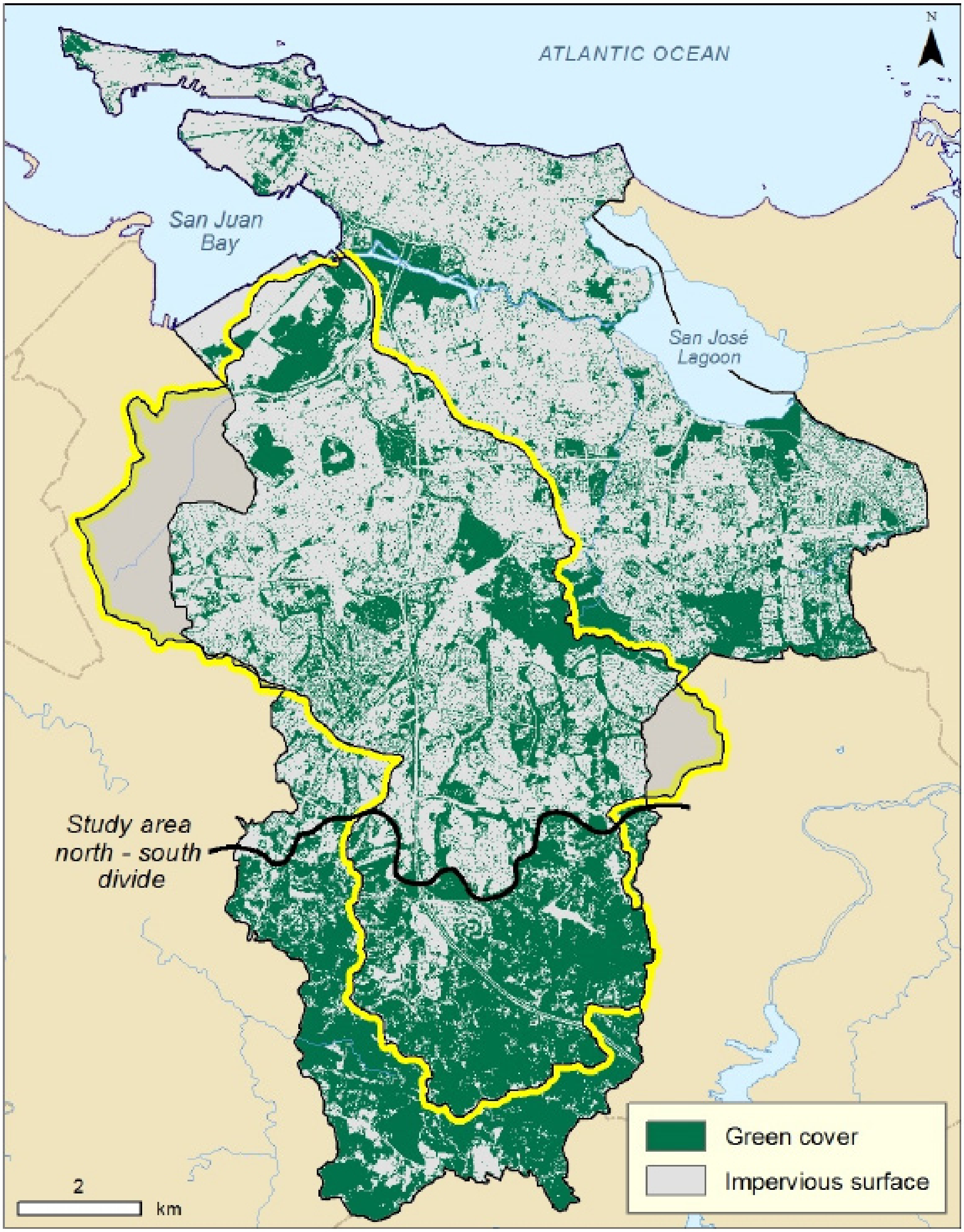
Asserting That Water Quality of the Río Piedras Will Improve With Channelization

The Corps expects water quality to improve because by lining river and stream channels with concrete, bank erosion would be reduced. Also, the improved channels are partially isolated from inflows of polluted waters that now flow unimpeded into streams. The question is how significant this reduction would be relative to the level of polluted waters that will continue to reach and pollute the stream and river system of the watershed. Three other factors contribute to the deterioration of water quality of river and stream waters. First, the removal of riparian vegetation eliminates the ecological service it plays in absorbing and removing pollutants from the water. Concrete walls do not provide this service. Second, another contributor to poor water quality in this watershed is the poorly designed and poorly managed infrastructure that processes storm runoff and human and city wastes before they get to river and stream waters. Finally, septic tanks are common in the watershed and they feed polluted waters to stream and river water. If these sources of pollution continue to pollute river and stream waters and there is less riparian vegetation to buffer the system, it is unlikely that channelization will improve water quality anywhere in the Río Piedras Watershed.

Expecting Erosion and Sedimentation to be a Minor Issue

The Corps assumed that bank erosion would disappear with concrete channels and that that it would reduce the sedimentation issue, which in turn would decrease maintenance costs associated with sedimentation. The Corps estimated an average annual sediment yield from the watershed of 1,300,000 m^3 for 1980 and 250,000 m^3 for 2035. They projected that about 20 percent of the post-channelization sediments will be deposited in the channel and the rest will flow into San Juan Harbor. Moreover

Figure 7. Green cover of San Juan based on a 4 m X 4 m resolution satellite image for 2002. The map is from Ramos González (2014). The yellow line outlines the Río Piedras watershed.



they expected that periodic floods would flush most of the sediment from the channels, and estimated $150,000 per year in maintenance.

The sediment issue is critical for the maintenance of the channels, particularly in the lower reaches of the river where sediments tend to settle. The Corps expects increased tidal flushing of sediments in the lower reaches of the channelized river towards San Juan Bay. We do not know how the Corps reached the conclusion that the sediment loads after the channelization would be reduced to only 250,000 m^3/yr. It is possible that they only considered bedload erosion and elected to ignore sheet erosion of soil, which is the principal source of sediment in the watershed. The question that must be answered is whether the annual flux of sediments from the Río Piedras towards San Juan Bay will be less, more, or the same in relation to historical values estimated by the Corps above and the implications of future sedimentation rates to the overall cost of maintenance of the canals. We do not have an answer to this question but Box 2 contains an independent estimate by Ferdinand Quiñones of the historical rates of sediment exports to San Juan Bay.

The estimate in Box 2 was an annual suspended sediment discharge of 1,650,000 tons for the year 2004, with an estimated error of $\pm$ 40 percent. Thus, the estimated 2004 annual suspended sediment discharge ranges from 2,310,000 to 990,000 tons, not including bedload discharge, which can be an additional 247,500 tons. Thus, as a conservative estimate we used 1 million tons of total sediment discharge annually into San Juan Bay, which is equivalent to 1,147,224 m^3/yr (using a density of 2,119 lbs. of sediment/m^3), a slightly lower value than estimated by the Corps for 1980.

Sediment removal from San Juan Bay is estimated to cost $15/$m^3$, which means that if all sediment discharge had to be removed the cost would be $17.2 million annually. However, the removal of sediments from the Bay depends on the depth of accumulated sediment on the Bay bottom. Dividing the annual sediment discharge by the area of the Bay (98 million m^2) and assuming that the sediment spreads out evenly, results in an annual depth of sediment accumulation of 0.117 m, or 1.4 m of sediments over 12 years. Ferdinand Quiñones estimates that every 12 years or so, the cost of dredging these sediments would be approximately $15 million.

The sediment discharge from the Río Piedras watershed, like that of other rivers in Puerto Rico, will vary widely from year to year (Lugo et al. 1980, Larsen and Webb 2009, Lugo et al. 2011). Annual discharge rates reported in Lugo et al. (2011) for the Río Piedras agree with the range reported island-wide by Lugo et al. (1980) and Larsen and Webb (2009), but are much lower than the Río Piedras estimates of the Corps for 1980 and Box 2 for 2004. The differences in estimates are significant and we don't know if they are due to changes in the quantity of sediment transport by Río Piedras or to the method used for estimating the annual discharge. Nevertheless, it is unrealistic to expect a low range of variability of the sediment discharge rate into San Juan Bay. Annual sediment discharge into San Juan Bay can either be 1, 2 or 0.5 million m^3 (all consistent with the estimates by the Corps for 1980, Box 2, and Lugo et al. 1980, 2011). However, it is difficult to justify the expectation of an annual sediment discharge of only 0.25 million m^3 as projected by the Corps for the year 2035. Particularly in light of the fact that the areas of the watershed where these sediments originate will continue to generate sediments and the Flood Control Project does not appear to have sufficient capacity to intercept these sediments before they reach the river channel. If the sediment discharge to San Juan Bay fails to abate to the levels suggested by the Corps, the cost of maintaining the channels and San Juan Bay after channelization is likely to be higher than anticipated by the Flood Control Project.

Box 2. Estimating the suspended sediment discharge at the Río Piedras USGS Hato Rey Gaging Station 50049100 for the water year 2004 (October 1, 2003 to September 30, 2004) by Ferdinand Quiñones.

La estación tiene un record de flujo desde el 1988. Escogí el 2004 pues es el que mejor record presenta y ocurrieron varias crecientes moderadas. Durante los años de huracanes el record es deficiente o no existe. Es muy trabajoso estimar estas descargas debido a la instrumentación que utiliza el USGS que varía la frecuencia de las medidas instantáneas de flujo, desde cada 5 minutos a cada 15, sin orden ni preferencia. Anteriormente existía un programa que hacía estos ajustes pero ahora no está disponible debido a que el USGS ha contratado al sector privado parte de estos servicios de cálculos de flujos y sedimentos diarios.

Lo que he calculado es un estimado con una desviación estándard potencial de + 40 por ciento. Esto se debe a varios factores:

1. Existen pocos datos de concentraciones de sedimentos suspendidos (SS) para flujos variados en la estación. Para mitigar esta falta de datos, desarrollé una correlación y regresión con los datos disponibles (Fig. 2-1).
2. Aunque la correlación luce "decente", la variabilidad es significativa a medida que aumenta el flujo (Q), lo que es normal en estos canales. De hecho, creo que los datos ilustran que hay dos regimenes de concentraciones de SS, siendo la parte alta cuando el agua sale de los bancos del cauce menos intensa. Pero para efectos del ejercicio, con esta regreción podemos obtener un estimado de la descarga de sedimentos.

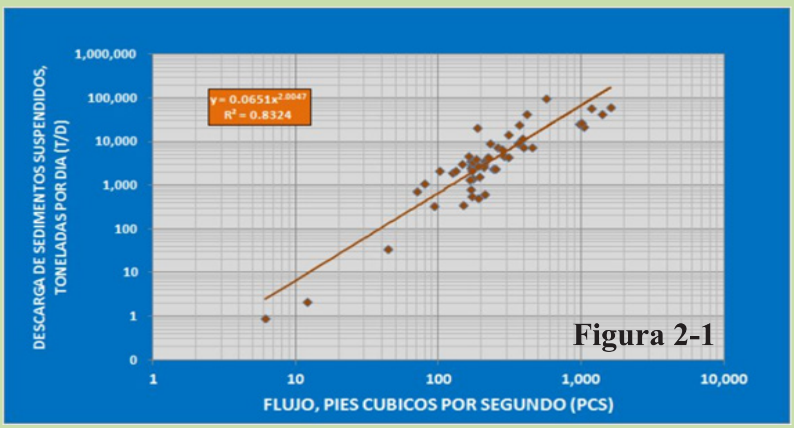


Figura 2-1

3. Con la ecuación de regresión de la Fig. 2-1 y los datos instantáneos de flujo (que el USGS no publica) calculé la descarga promedio diaria integrada con los valores individuales de la variables Q. La Fig. 2-2 representa los hidrogramas de SS (azul) y Q promedio diaria (rojo, como una guía, pues el cómputo integrado requiere los flujos instantáneos).

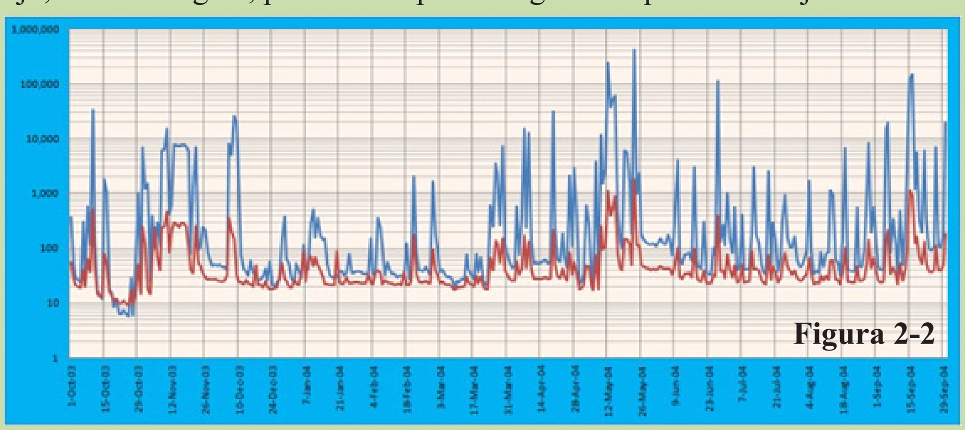


Figura 2-2

4. La suma de los valores diarios de SS para el año es de aproximadamente 1,650,000 toneladas (1,676,400 Mg). Esto no incluye el bedload, que de las observaciones de los depósitos de grava y arena que el Cuerpo de Ingenieros tiene que dragar de la Bahía de San Juan periódicamente, estimo que pudieran ser entre el 10 y el 15 por ciento de la descarga de SS. Si el error de cálculo fuera de un 50 por ciento, añadiendo bedload, estamos hablando de hasta 1 millón de toneladas (1.02 millones de Mg) en el 2004, año que no representó el de más lluvia y escorrentía, como se aprecia de la Fig. 2-3 combinada con la de El Señorial. En esta gráfica la línea roja es el promedio corrido de 30 días, que provee una tendencia bastante uniforme entre los años.

Figura 2-3

Analisis para estimar la descarga de sedimentos del río Piedras. La Figura 2-4 no refleja cambios significativos a través del tiempo, pero se notan cambios con las descargas minimas entre 1971 al 1980 (más bajas) y las del 1988-2013 (más altas).

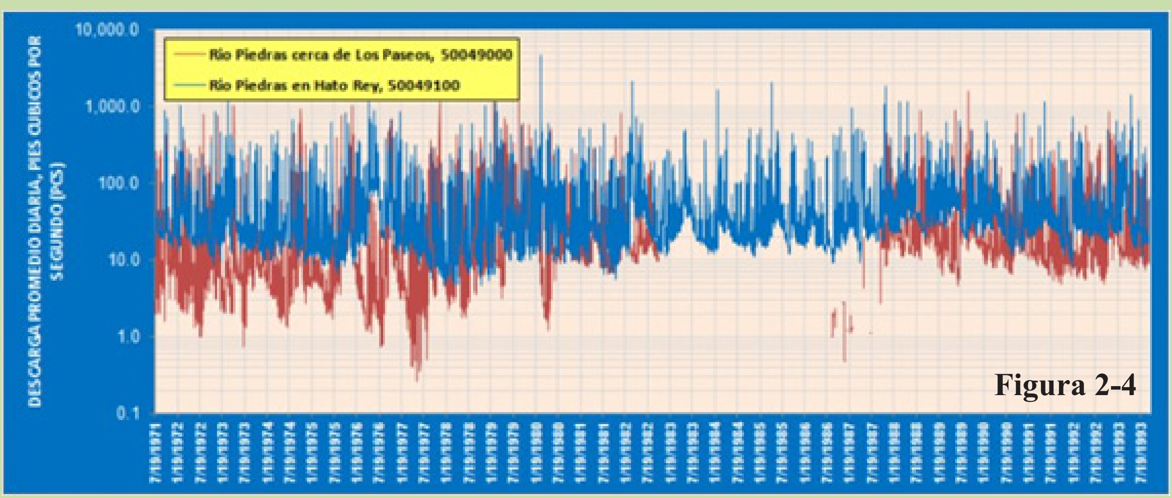


Figura 2-4

Incomplete Assessments of the Ecological Resources of the Watershed

The environmental analyses of the Corps focus on mangroves, freshwater wetlands, mud flats, birds, and endangered species as the main ecological resources of the Río Piedras Watershed. The river itself and its tributaries were never considered to have environmental or ecological value since the focus of the analysis was on their poor water quality and low hydrologic capacity. However, recent ecological work in the Río Piedras Watershed has surprised both the professional ecologists and the general public. The river, in spite of its low water quality, supports over 30 taxa of aquatic organisms both native and introduced. A shrimp species thought extinct, as well as a rare freshwater sponge, have recently been found in the river (Lugo et al. 2011). The river also harbors the largest fish biomass in all of Puerto Rico (Kwak et al. 2007). Moreover, the green areas of the city contain novel and native forests of great diversity and ecological importance (Lugo et al. 2011). At best, the environmental analysis of the Corps was incomplete and is now obsolete.

Obsolete Benefit/Cost Estimate

The benefit/cost ratio of the Flood Control Project has changed as a result of two socio-economic variables that have fluctuated in the watershed since the Project expenditures were first estimated. First, the population and economic activity levels in the watershed have changed considerably since 1984. These changes affect the benefits of the Flood Control Project. Secondly, the total cost of river alteration has soared dramatically as the projection for construction cost was $235 million in 1984 and today, in a public lecture at the University of Puerto Rico, Corps engineers reported an expenditure of $1,400 million for only the lowland phases of the Flood Control Project (Table 1 reports $0.75 billion). This expenditure is approaching ten times the anticipated total cost and the Corps has not yet begun the portion of the Flood Control Project involving supercritical flows of the main channel and most of the tributaries of the Río Piedras. If costs increased by greater than ten times the amount expected while the population and economic activity declines by an unknown factor, it is unlikely that the benefit/cost ratio will remain positive. This is an area that requires a new analysis.

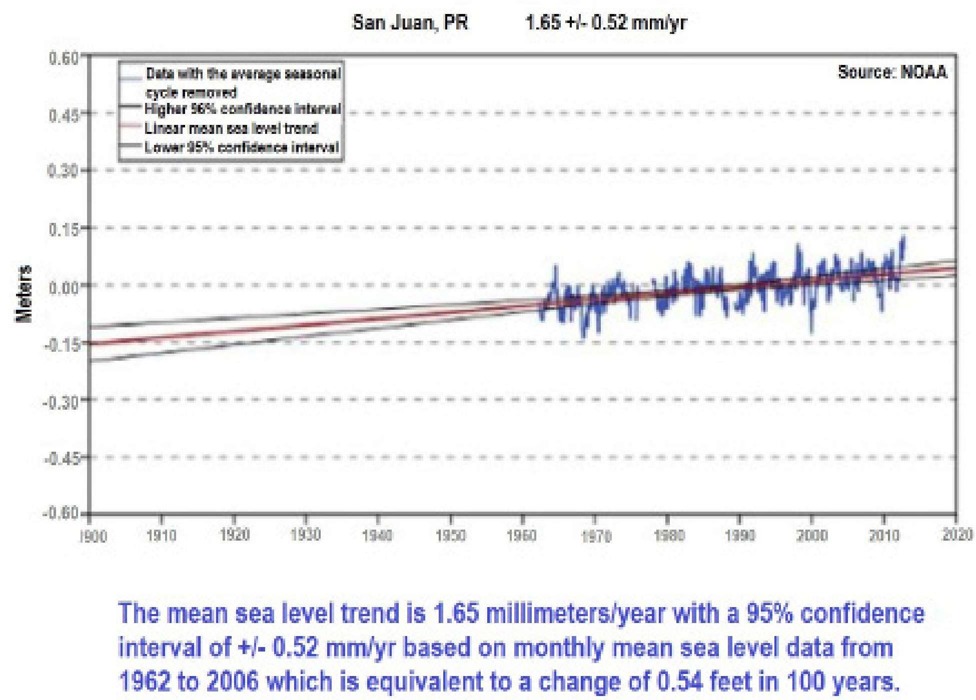
Not Considering Climate Change

At the time of Project design no one was thinking about potential changes in the climate as a result of human activity. Even today, the effects of a changing climate on the Río Piedras Watershed are difficult to quantify (Méndez-Lázaro, et al. 2014), but by 2035 some of the predicted trends could become a factor that affects the functioning of the proposed flood control system for the Río Piedras. For example, how would the improved channels function in a climate situation with more extreme events and increased frequency of hurricanes? What are the consequences of their failure to the people and infrastructure of San Juan?

Not Considering Sea Level Change

Sea level is increasing in the north coast of Puerto Rico just off the San Juan Harbor (Fig. 8). Between 1962 and 2006, mean sea level at San Juan Bay increased at a rate of 1.65 mm/yr or 0.54 feet (0.16 m) in 100 years. Sea level rise is expected to accelerate with climate change (Church and White 2006). At the time of the initial design of the improved Río Piedras channel, the assumption was made that the channel would discharge at msl and that higher tidal level would not occur simultaneously with channel discharge. If sea level increases, it is reasonable to ask about the consequent implications for river channel discharge. On September 18, 1989 with the passage of

Figure 8. Mean sea level trend at La Puntilla in San Juan Bay between 1962 and 2006. Data and analysis are from http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=9755371.



Hurricane Hugo some 30 miles east of San Juan, waters inside the Bay rose 2.77 feet (0.84 m). At present, the reach of the river where it connects to San Juan Harbor is below sea level, including the Martín Peña Canal and all the river reach with mangrove vegetation. Will there be a backwater effect in the lower river reach as fresh river water encounters a harbor tide higher than mean sea level in 1980 or higher than the value of 0.18 m (normal high tide) used for planning purposes in 1980? The possibility exists that the Corps hydrological design includes a safety factor that helps overcome sea level rise, but the documents we read were not explicit about this possibility. Later in this document we examine additional information about sea level and wave height during a tidal surge, as well as new Corps policies that require that the agency re-examine projects such as the Flood Control Project, in light of expected sea level rise and climate change.

Not Considering Worst-Case Scenario For Channel Discharge Into The San Juan Bay

The worst-case scenario for the proposed Flood Control Project will occur when the Río Piedras is in flood stage, say the 100-year flood, and the San Juan Harbor is experiencing a tidal surge due to a powerful hurricane during spring tides. When this happens, will the improved channel be able to discharge or will backwater effects flood Caño Martín Peña and all low lying lands along Quebrada Margarita? If present, how extensive will the backwater effect be? Later in this document we present the conflicting opinions of five expert hydrologists regarding the channelization of the Río Piedras and its likely performance during the worst-case scenario.

CULTURAL RESOURCES RECONNAISSANCE AND SURVEY REPORT

The cultural resources report (Weaver and Rodríguez Morales 1989) contains an archeological historical overview of Puerto Rico in the context of the Caribbean, as well as the methods used in the study of cultural resources in the floodplain of the Río Piedras. Results and their interpretation lead to the conclusion that there are no significant archeological, historical or architectural resources in the northern portion of the project area. Moreover, previous development activities preclude the presence of intact cultural resources in the area. However, buildings associated with a water filtration plant constructed around 1898 and associated with Hacienda San José represent values to be protected. The Norzagaray Bridge is also considered of historical value (P 71-75).

P 28. The Río Piedras begins in the hilly Morcelo sector and discharges into San Juan Bay at Puerto Nuevo. Usually, the river is 2 feet (0.6 m) deep but rises as high as 16 feet (4.9 m) in its lower reaches in times of flood. An old wooden bridge by the town of Río Piedras was often flooded. In 1831, Miguel de la Torre, governor, constructed a masonry bridge.

The most important road in the area during the first half of the 19^{th} century ran from Martín Peña Bridge to Río Piedras. In 1812 a road ran through Guaraguao Hills and Morcelo Mountain to Caguas. Another road connected Río Piedras to Bayamón on the west. In the second half of the 19^{th} century the San Juan to Ponce road was constructed and it passed through Río Piedras. In 1878, Río Piedras was bounded on the northwest by San Juan, Carolina on the east, Trujillo Alto on the southeast, and Bayamón on the west.

P 29. On June 4, 1951 a referendum was enacted for the consolidation of Río Piedras within the municipality of San Juan.

P 30-32. Central San José was in a critical economic position and was placed under a trustee. The mill closed in 1946. Lands were sold to small farmers. Sugar cane cultivation disappeared in Río Piedras. Many of the Hacienda San José lands were passed to the Experimental Agricultural Station founded in 1910. The *historic* Río Piedras Aqueduct is located on these lands. The water reservoirs were constructed in 1896 and pipelines leading to San Juan by gravity were installed between 1897 and 1898.

ANALYSIS

Past urban development in the San Juan Metropolitan area, including lands in the Río Piedras floodplain altered the historical footprint of the region. This process began with colonial settlement. Proposed river channelization led to this comprehensive analysis that uncovered a few remaining and historically important items, one of which is the *historic* Río Piedras Aqueduct that is partially threatened by the selected channelization proposal. The proposed Flood Control Project will not affect the historic Norzagaray Bridge.

GENERAL DESIGN MEMORANDUM, RÍO PUERTO NUEVO, PUERTO RICO[6]

In the transmittal memorandum of the General Design Memorandum of the Río Puerto Nuevo Project (United States Army Corps of Engineers 1991) drafted for the Commander of the South Atlantic Division, Colonel D.C. Salt, points out that floods greater than the 2-year event cause extensive flooding and that the proposed Flood Control Project that aims to protect against the 100-yr flood, has a project life of 50 years.

[6] *This report uses the English system of units in contrast to the 1984 report, which used the metric system of units.*

Syllabus

Portions of the channel design were physical-model tested by the Corps in their Waterways Experiment Station in Vicksburg, Mississippi. The authorized plan of 1984 was comprehensively revised here. They eliminated five stilling basins and used instead extended reaches of high velocity channel and high velocity confluence junctions. Total annual costs of investments are $30.6 million and annual benefits are $73.5 million, a benefit/cost ratio of 2.4. Total cost of implementing the Flood Control Project is $303,245,800 ($227.3 million federal and $75.9 million non-federal).

All elevations in the report refer to National Geodetic Vertical Datum (mean sea level of 1929).

P 1. The Department of Natural and Environmental Resources is the sponsor and Commonwealth of Puerto Rico representative of this Project.

P 2. Contains a list of 8 flood control activities where local cooperation is required. Number 5 indicates: "Hold and save the United States free from damages due to the construction and subsequent maintenance of the project, except damages due to the fault or negligence of the United States and its contractors." The Commonwealth is required also to observe sound land use and leadership to prevent encroachments or conditions that would interfere with the proper functioning of the Flood Control Project.

P 3. On this page there is a clear recognition that the watershed is traversed by the Río Piedras. Río Puerto Nuevo only occurs in the lower reaches of the Río Piedras River watershed, but they elect to use Puerto Nuevo for the whole watershed "for ease of reference".

P 4. Two baffle pier-stilling areas, two high-velocity flow junctions with tributary streams (Buena Vista and Guaracanal), and two upstream debris basins with side-overflow spillways were new modifications to the Flood Control Project. The De Diego Bridge will not have to be replaced because the physical model test showed that with the Project design, the bridge functions as is.

P 5. Policy dictates that economic analyses for projects that are up for construction approval must be no more than two years old. This caused them to update the economic analysis of 1985. Study update year is 1990, the base year is 2003 and the end of the planning period is 2053.

They found that over 7,500 residents and 700 commercial and public structures are subject to flooding. The Flood Control Project will provide benefits to 8,500 structures and facilities in the 100-yr flood plain. Table 23 summarizes the estimated Project benefits.

Hydrology and Hydraulics

P 6. The plan is to provide major outlet works for the Río Piedras[7] and four of its tributaries. Some new computations were made in this plan and the delineation of the watershed modified from the 1984 report.

P 8. The Río Piedras Watershed was analyzed using the HEC-1 model subdividing the watershed into 18 tributary catchments and sub-catchments. The model uses rainfall, infiltration, rainfall losses (evapotranspiration plus infiltration), land slope, soils, stream length, soil cover, land use, and lag time (derived mathematically from the above).

P 10. No spiral curves, invert banking, or warped transitions were incorporated into the physical models used to test the behavior of the Flood Control Project. Final channel design will be developed later and will include invert banking and modified spiral entrance and exit

[7]*This report actually uses Río Piedras for the upper portion of the channel.*

Table 23. Updated Flood Control Project benefits in thousands of US dollars according to the 1991 Design Memorandum (United States Army Corps of Engineers 1991). Estimates are based on interest rates of 8-3/4 percent and a 50-year project life.

Type of Benefit	Annual Benefit
Inundation reduction	36,551
Location	2,572
Redevelopment	1,677
Advanced bridge replacement	198
Intensification	3,600
Recreation	831
Income losses	120
Flood insurance overhead	64
Emergency	435
Benefits during construction	26,763
PL 91-646	1,003
Total	73,814

alignments for the curved portion of channels. The curves along the alignment create design problems due to the intense urban development that extends to the right-of-way, coupled with the requirements of channel design to handle large discharges. This issue will be resolved later in the Project development. Water surface profiles had to be elevated to account for some of the design issues associated with the effect of one curve in the channel on the next or previous curve.

Thirty bridges will need replacement; five passed the physical model test. Two debris basins are expected to protect channels from sedimentation in terms of functioning or damage to the concrete channels themselves.

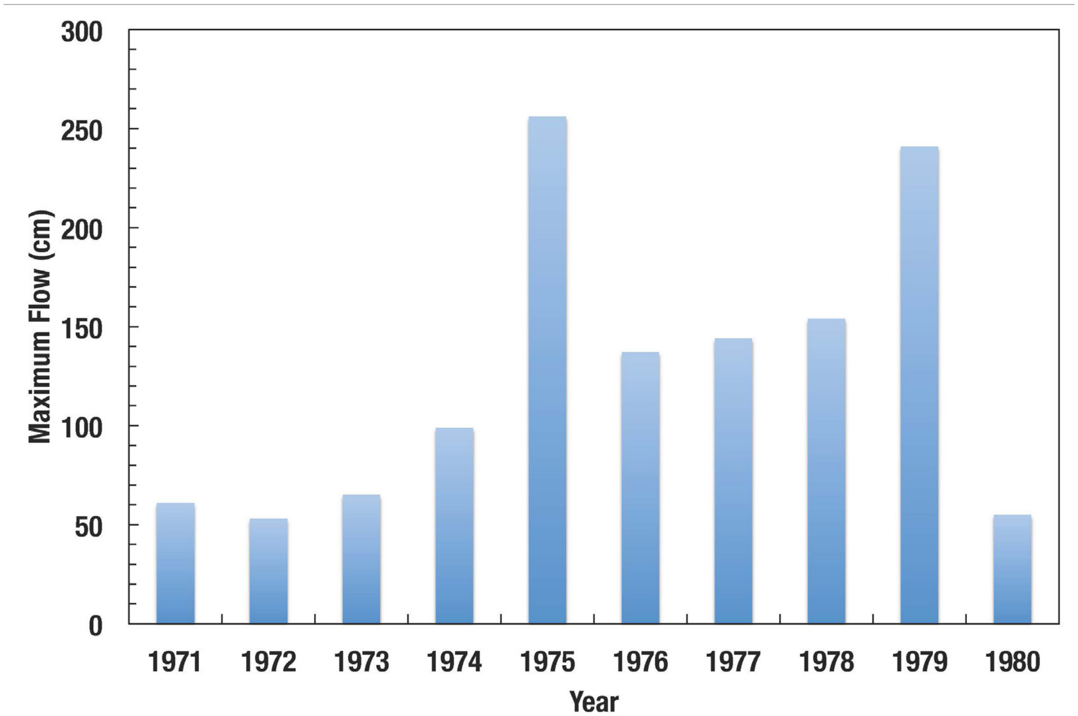
P 12-13. Among the details of channel design given is the precaution of assuming that mangrove resistance to flow will be high, thus the area of mangroves along the channels is assumed to have ineffective flow within the full channel cross section.

P 16-18. Margarita Channel will receive discharge from the culvert under San Patricio Shopping Center to contain and collect overland flow from adjacent parking areas. The design discharge at this location is much greater than existing bankfull capacity. Design discharge for the 100-yr flood event is 6,933 cfs (196.34 m^3/s) at the downstream side of the San Patricio Culverts. Because the culvert under San Patricio Plaza has only a 1,800 cfs (50.98 m^3/s) capacity, an expected 7,700 cfs (218.06 m^3/s) will be flowing in sheet flow into the area of the Caparra Interchange, and the PR 2 and PR 23 interchanges. Flow is expected to collect at the area of the Caparra Interchange. The commercial and warehouse area south of the Caparra Interchange will experience extensive flooding because the interchange is a watershed concentration point. Discharge not entering the culverts will flow out across the San Patricio Plaza in sheet flow, extending over 1,000 feet (305 m) wide. However, the Flood Control Project will not worsen the situation.

P 19. Three streams come together east of the intersection of Avenida De Diego and PR 21. At the PR 21 crossing, the culvert capacity is less than 1,700 cfs (48.14 m^3/s) but the 100-yr flood peak discharge is 4,122 cfs (116.74 m^3/s). The water will flow over PR 21 and to Avenida De Diego and Calle 54 before being recaptured by a secondary drainage system.

P 29-30. The channels are designed to hold more discharge than the maximum expected. This allows the Corps to claim benefits for floods greater than the designed flood (8 to 42 percent more in the lower reach, thanks to the trapezoidal design of the channel combined with a three-foot (0.9 m) minimum freeboard allowance). When modeling they assume that the secondary drainage system would provide the necessary conveyance. The published report available from the Waterways Experiment Station in Vicksburg, MS is: Río Puerto Nuevo Flood Control Project, Hydraulic Model Investigations, 1990. The historical maximum

Figure 9. Historical maximum flows (annual peak discharge) of the Río Piedras at río Piedras PR-1 bridge. Data are from the United States Army Corps of Engineers (1991).



flows of Río Piedras available to the Corps at this time are shown in Fig. 9.

Sediment Transport Study

P 32. This study led to the design of a teardrop shape debris basin with 104 acre-feet (0.13 hm^3) of water storage and 9.65 acres (3.9 ha) area. This is the Puerto Nuevo debris basin. The collection of sediments would protect the surfaces of concrete channels from abrasion and erosion due to the transport of sediments by discharge waters. They recommend a three-month monitoring schedule and after major events to assure trap efficiency. Annual cleaning is also recommended. There is a smaller debris basin on the Guaracanal creek, one to be constructed by excavation on the natural channel. It will store 50 acre-feet (0.06 hm^3) of water and cover 5.57 acres (2.3 ha).

Groundwater Study

P 33-35. Two reports from the USGS should be published in 1991. Preliminary results indicate that the total groundwater discharge of the Río Piedras Watershed is 14.7 cfs (0.42 m^3/s) and that the river accounts for 40 percent of the total discharge. The channelization might cause the groundwater level to rise to the surface in some places, thus requiring the installation of an under-drain system, which will be done to avoid differences in the underground water between pre- and post-Project.

P 37. The lower bulkhead channel that ends at San Juan Harbor experiences tidal action. It is a 1.65-mile (2.65 km) long section with design velocities from 4.3 to 14.3 feet per second (131.1 to 435.9 cm/s). It will be a 400 foot-wide (121.9 m) and 25-foot (7.6 m) deep channel.

P 40. 2.8 million cubic yards (2.1 million m^3) of excavated material will be disposed offshore. Other excavation material will be deposited in upland deposit sites (P 42, 44, 46 etc.).

P 47. Earthquakes were considered in the analysis (a loading factor of 0.1 seismic zone 3).

Design Considerations and Cost Estimates

P 73. The Flood Control Project consists of 11.2 miles (18 km) of the main river and its five tributaries; the replacement of 17 bridges (including two pedestrian); the modification of 8 bridges; the construction of 5 new bridges (including two pedestrian); construction of two debris basins with side overflow spillways; two stilling areas; and the relocation of a segment of De Diego Expressway. The majority of the Flood Control Project involves concrete channels for high velocity supercritical flows.

P 74. The wall elevation in the lower reach is at 0.0 feet (0.0 m). The relocation of two lanes of the De Diego Expressway is to avoid the sanitary landfill.

P 76. On reach 4, the proposed channel invert is 5 to 10 feet (1.52 to 3.05 m) higher than the existing channel bottom with a proposed channel invert ranging from 11.5 to 53.4 foot (3.51 to 16.28 m) NGVD.

P 79-81. Soil and water sample analyses indicated that the environment to which the channel structure would be exposed is an extreme aggressive marine environment. A saltwater wedge was found from San Juan Harbor to Canal Margarita. To mitigate the corrosion activity of this environment, prestressed pilings must be of superior quality, and mixing water should be of potable quality. Use of seawater would be prohibited. The text goes on to explain other requirements for the cement and conclude that the prestressed piles do not appear technically or economically feasible for this Project. They considered carbon steel sheet piles with additional concrete protection, but discarded this option because of maintenance requirements. Future design memorandums will develop a suitable solution that will also include seismic analysis.

P 87-88. A vibration-monitoring plan will be developed, and procedures to implement it correctly will be in place. Structures along the construction path would be inspected prior to construction to ensure they will not be impacted. Side streets to provide construction access to the channels are mapped.

P 88-89. Approximately 450,000 cubic yards (344,050 m^3) of concrete will be needed (including 150,000 cubic yards (114,683 m^3) of tremie concrete; *Wikipedia states: the **tremie** concrete placement method uses a pipe, through which concrete is placed below water level. The lower end of the pipe is kept immersed in fresh concrete so that the rising concrete from the bottom displaces the water without washing out the content).* Approximately 1.7 million cubic yards (1.3 million m^3) of fill and backfill would be required. Suitable off-site sources will be used for the backfill. Approximately 26,000 cubic yards (19,878 m^3) of riprap will be required. Stones weighing at least 165 pcf (2643 kg/m^3) should be used for riprap. The proposed channel improvements will require the excavation of about 6.5 million cubic yards (4.96 million m^3) of material. Little of this is suitable for backfill and must be disposed. About 2.8 million cubic yards (2.1 million m^3) from the lower Río Puerto Nuevo and 0.8 million cubic yards (0.6 million m^3) from lower Margarita channels will be disposed offshore. The remaining 3 million cubic yards (2.29 million m^3) will be disposed in upland disposal areas (one along the Puerto Nuevo the other along Margarita); they have a capacity of 3.3 million cubic yards (2.5 million m^3), assuming that 30 feet (9.1 m) of material is permitted.

P 90-91. Text contains a detailed discussion of the 84-inch (213 cm) Miramar Trunk Sewer

Table 24. Projected costs of the six contracts required for completing the Río Piedras Flood Control Project. Data are from the United States Army Corps of Engineers (1991). The amount includes the estimated cost as of 1990 and a contingency amount.

Contract Number	US Dollar Cost
1	59,366,500
2	96,544,500
3	34,394,000
4	45,624,000
5	27,736,000
6	39,618,800
Total	303,283,800

Table 25. Economics of recommended plan of the United States Army Corps of Engineers (1991) at 4-3/4 percent interest and in thousands of 1990 US dollars.

First Costs	
Total Project Cost	303,284
Interest During Construction	38,906
Total Investment Cost	342,190
Annual Costs	
Annualized Investment Cost	30,400
Operation and Maintenance	214
Total Annual Cost	30,614
Total Annual Benefit	73,465
Net Annual Benefits	42,851
Benefit to Cost Ratio	2.4

by the Constitution Bridge and the 90-inch (229 cm) San José Trunk Sewer that needs relocation.

P 95. The Flood Control Project will be constructed under six contracts totaling $303.3 million (Table 24). All construction will take 11 years, with the first contract advertised in FY 1993.

P 96. Land acquisition by the Department of Natural and Environmental Resources (not including river lands) will involve 153 parcels covering 457.1 acres (185 ha) and 54 structures for a total cost (not including severance) of $10,395,000. The combined federal/commonwealth cost of administering this acquisition is $1,003,000 and the relocation cost is $1,003,400 for a total of $15,966,800 including $3,193,400 in contingency.

Table 25 contains the economics of the Flood Control Project. The Project is financed 75 percent federal and 25 percent Commonwealth (P 97-98).

P 100. The revised total mangrove area to be removed is 16.1 acres (6.52 ha) plus 4 more acres (1.62 ha) at Quebrada Margarita. Some mangroves had been removed in 1987 when the Caño Martín Peña reach was expanded to include the Agua-Guagua project. Also the original mudflat by the Constitution Bridge were removed for the Agua-Guagua project and moved elsewhere in the estuary, such that the new mud flats are larger than the original. Mangrove mitigation will be at 1.5 to 1 ratio.

P 102. Aesthetic considerations include:

- The use of screening with berms, fencing materials, and vegetation to hide the channel from view wherever practical.
- The addition of colors and or pebbles to the concrete used in the channel walls to reduce its stark visual impact in areas where it cannot be successfully screened.
- Keeping the ground elevation and the channel walls as close to each other as possible to reduce the feeling that this channel is a barrier of some type.
- Careful selection of fencing materials used, where needed, to provide the necessary security and public safety while reducing the barrier effect.

P 107. Earlier pages contain more details of the bicycle path. The estimated cost is $464,000; the annual replacement and maintenance cost is $44,000, with annual recreation benefits of $831,000.

P 107-108. Contains a summary of departures from the survey report. The achievement of supercritical flow for the main channel was due to the use of a steeper slope by eliminating meanders and shortening the channel reach by excavating a new channel through the Botanical Gardens.

ANALYSIS

The 1991 General Design Memorandum updates the 1984 Survey Report to 1990. Costs increase but not significantly, the benefit/cost remains positive, and completion of the Flood Control Project was extended 11 years. The modification in channel design includes an increment in the length of channels conveying supercritical discharges, which causes the channels to be raised above the surface of the land; in some places significantly so. Aesthetic measures are suggested to avoid the impression that the channel is an eye sore on the urban landscape. The document lacks any information that would lead us to review the issues raised in the analysis of the Survey Report. However, in this document the Corps make the assumption in their modeling that the secondary drainage system of the city would "provide the necessary conveyance", i.e., that it will function properly. Yet, this system is notorious for its incapacity to provide the necessary conveyance during periods of high rainfall (Box 3). The significance of this erroneous assumption is that the city would be flooded to a greater degree than assumed by the models of the Corps.

ENVIRONMENTAL ASSESSMENT OF 1993

P 1. This is an updated assessment to account for the changes made in the design and update the implementation of NEPA to date.

P 6. The reconstructed mudflats do not function as well as the original. Hundreds of shorebirds are no longer observed there.

P 14. Dredging will increase depth and frequency of flushing in tidal reaches of the main river and the new Margarita channel, increasing habitat for salt water and estuarine organisms. The greater volume of water in the channels will assist in flushing contaminants out of the system.

P 16. The early estimate of 7.5 ha of mangroves was an error. It should have been 7.5 acres (3.04 ha).

P 26. Barbara Cintrón prepared the Environmental Assessment.

ANALYSIS

The Environmental Assessment of 1993 raises no new issues that require our analysis.

ANALYSIS OF FLOOD CONTROL PROJECT RÍO PUERTO NUEVO SAN JUAN AND GUAYNABO PUERTO RICO

This document (United States Army Corps of Engineers 1993) is an environmental assessment and finding of no significant impact (FONSI) by the Corps for the channelization of the Río Piedras. Barbara Cintrón prepared the document. Basically the document contains the same information as the Environmental Assessment reviewed above, but with the formalities of a FONSI. It is dated May 1993 and the document supports the Design Memorandum of 1991.

HYDRODYNAMIC AND WATER QUALITY MODEL STUDY OF SAN JUAN BAY ESTUARY

P 1-10. The study by Bunch et al. (2000) reports on the results of two models developed to assess the hydrodynamics and water quality of the San Juan Bay Estuary (Estuary). The

Box 3. 2009 study of the flooding problem in the Municipality of San Juan.

CSA Architects and Engineers, LLP (2009) conducted a comprehensive study of flooding in San Juan and determined the causes of flooding in numerous streets of the city. This study is the most recent available to us on the subject and it provides a recent and realistic overview of the stormwater infrastructure of the city. They examined 4,247 stormwater structures and found that 63 percent were filled with sediments and/or garbage, 11 percent had both storm and used or sanitary waters mixed together, and 3 percent were permanently sealed, which means that 77 percent of the stormwater infrastructure was not operational and only 23 percent was. Moreover, a significant fraction of the structures were either not included in the city's infrastructure blueprints or were in the blueprints, but not found in the field (Table 3-1).

The list of identified problems with the city's floodwater infrastructure includes the following:
Combined systems (mixing of sanitary waters with storm flow waters)
Filled or obstructed systems
Sealed structures
The size of pipes (mostly 12 inch [30.5cm] pipes) was insufficient to handle storm runoff or a large pipe can be connected to a smaller diameter pipe
The size of structures was insufficient to handle storm runoff
High water table does not allow runoff
Unknown discharges (either origin or discharge point not known)
Excessive paving raises streets above the runoff infrastructure
Several types of obstructions:
Sanitary structures crossing stormwater structures
Potable water pipes within the stormwater pipes
Excessive debris accumulation
Excessive garbage accumulation
Excessive vegetation growth
Collapsed pipes
Collapsed structures
"Home made" structures
Obstructions at the point of stormwater discharge
Water catchment areas larger than the discharge capacity of stormwater infrastructure
Poor condition of structures (parrillas)
Poor condition of gutters.

Table 3-1. Geographic condition of stormwater infrstructure in San Juan (CSA Archietects and Engineers, LLP 2009). The X means no data. When a barrio is repeated, a different sector of the barrio is under consideration **(continuación Box 3)**.

Barrio (number and location)	Combined	Obstructed	Sealed	Not in City Blueprint	Not Found in the Field
1. San Juan-Santurce	283	1422	97	233	112
2. Hato Rey-Puerto Nuevo-Oriente-Río Piedras Pueblo	193	902	34	264	42
3. Sabana Llana-Oriente Cupey-Río Piedras Pueblo	2	157	7	108	14
4. Puerto Nuevo-Cupey-Monacillos Urbano-El Cinco	0	207	13	43	18
5. Cupey-Los Paseos	0	1	0	4	X

models were used to evaluate management alternatives for the Estuary. To do so, they conducted bathymetric surveys, collected hydrodynamic field data and water quality data, and ran models of water quality and hydrodynamics. The models were indirectly coupled without feedback. Coupling of the models was not necessary because temperature and salinity, which affect water density and thus hydrodynamics, were included in the hydrodynamic simulations. Physical processes in the hydrodynamics model included tides, wind, density effects, freshwater inflows, turbulence, and the effects of the Earth's rotation. The water quality model included the following variables: temperature, salinity, dissolved oxygen, phytoplankton, dissolved organic carbon, particulate organic carbon, particulate organic nitrogen, dissolved organic nitrogen, nitrate + nitrite nitrogen, ammonium nitrogen, particulate organic phosphorus, dissolved organic phosphorus, total inorganic phosphorus (partitioning dissolved and particulate phases), chemical oxygen demand released from sediments, total suspended solids, and fecal coliform bacteria. Much of the dynamics of the model are based on experience in northern temperate estuaries such as the Chesapeake Bay.

Scenarios tested were:

- 1a- Baseline or present conditions
- 1b- and c- Channel expansion in Caño Martín Peña
- 2- Filling dredged material borrow pits (mostly San José Lagoon)
- 3- Channel expansion Canal Suárez
- 4- One-way gate at Canal Suárez
- 5a- Reducing un-sewered loads to Caño Martín Peña
- 5b- Removal of pump station loads at the Baldorioty de Castro outfall in northern Laguna San José
- 6a and b- Limited combinations of the above scenarios.

The Estuary is a 240-km^2 (215 km^2 land and 25 km^2 water) area with a population of 700,000 people. Stormwater is collected and pumped directly into the Estuary through a total of 12 pump stations that have a combined maximum capacity of over 900,000 gpm or 56.8 m^3/s. Benthic production is no longer possible in many of the lagoons and channels of the system due to increased water turbidity and eutrophication.

Solid waste disposal is a problem along the Caño Martín Peña. The system is characterized by strong salinity stratification in canals.

P 91. The Río Piedras discharged 8,000 cfs (226.6 m^3/s) on June 9, 1995, during the interval in which the models were tested and simulated.

P 126. The model reproduced the salinity stratification and patterns. However, salinities in the Estuary tended to be higher than those of the model output.

P 131-132. The whole Estuary is at or below sea level, with the Caño Martín Peña discharging at a higher elevation than the bottom of San Juan Bay (Fig. 10, top). The salinity of the system during the summer of 1995 ranged mostly between 10 and 38 ppt at San Juan Bay. Caño Martín Peña had the lowest salinities with a range from 35 to freshwater (Fig. 10, bottom).

P 169. For their scenario runs, they used the approved changes to the San Juan Harbor channel (11.9 m deep) and Puerto Nuevo flood control channel (7.32 m deep).

P 189. Scenario 1c is the best for increased flushing of Martín Peña Canal and San José Lagoon. The combination of scenarios 1c and 2 offers the best hope for improving water quality in San José Lagoon. Scenario 6b gave the best water quality by combining dredging Martín Peña Canal, filling borrow pits, and removing un-sewered loads (with the inclusion of the pumping station loads removed).

ANALYSIS

The results of the simulations confirm the known functioning of the Estuary. The bottom of the Estuary is below sea level and through the simulation interval always maintained some level of salinity with the exception of the stations at the Río Piedras and the outlet of Caño Martín Peña, which spiked to freshwater conditions during periods of high freshwater discharge. The Estuary tends to stratify with freshwater lenses flowing over saltwater wedges that prevail in deeper portions of the Estuary where tidal flushing is reduced. Water quality deteriorates with reductions in tidal flushing. No simulation considered sea level increase due to global warming.

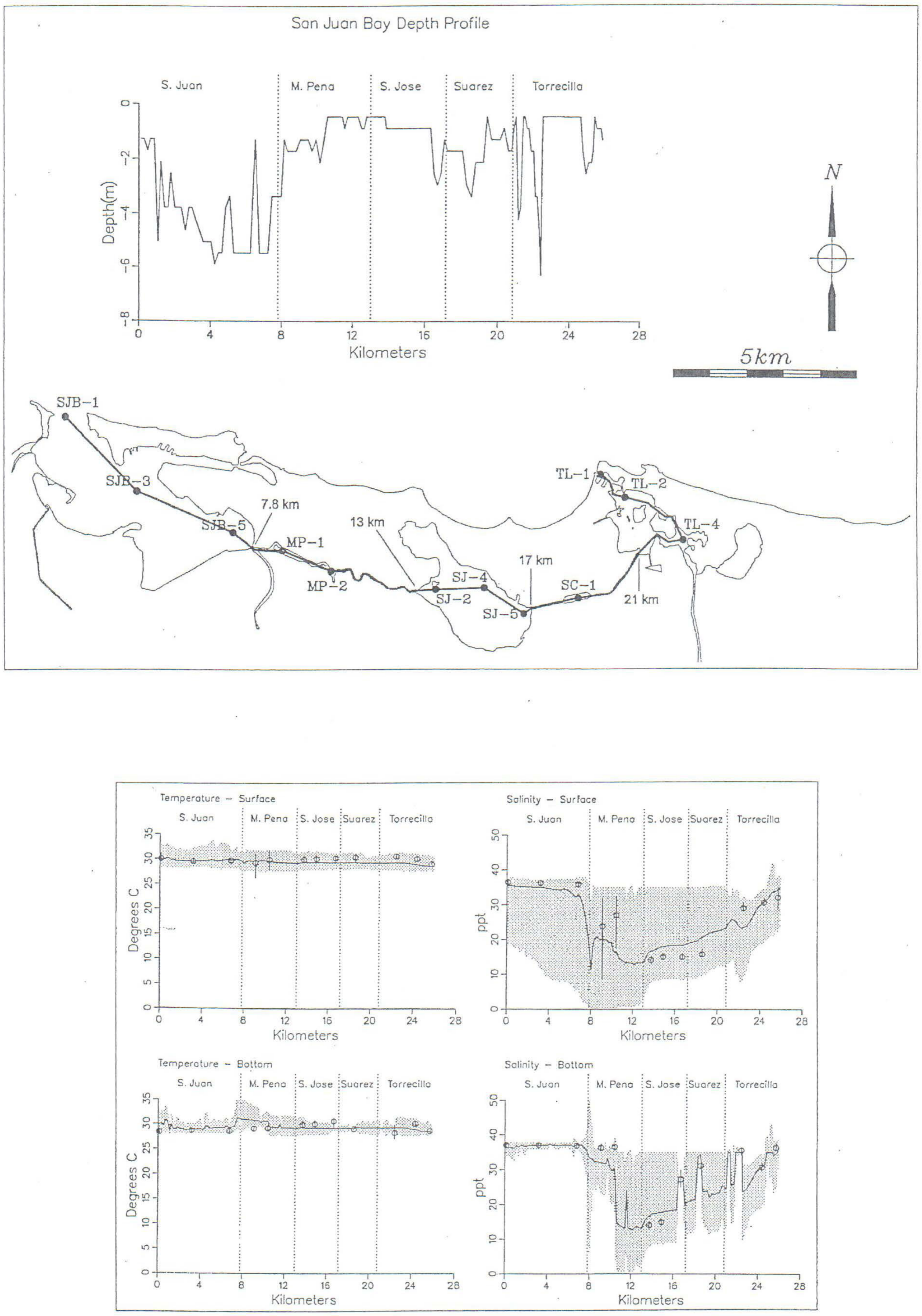
RECONNAISSANCE REPORT, CAÑO MARTÍN PEÑA ECOSYSTEM RESTORATION

P 1. This report (US Army Corps of Engineers 2004) is prepared in response to a U.S. Congressional Resolution and aims at restoring flows and water quality in the Caño Martín Peña. The drainage area of the Caño is about 4 square miles (10.36 km^2). The focus of the study is on the eastern 2.2 miles-long (3.54 km) section of the 4-mile-long (6.44 km) Caño.

P 7. The San Juan Harbor Project has had U.S. Congressional Authorizations dating back to 1917. The wetlands adjacent to San Juan Bay and along the Caño Martín Peña were used as disposal sites for material that was dredged from the San Juan Harbor, affecting or eliminating more than 80 percent of the original mangrove acreage in this area. Most of the filled area adjacent to San Juan Bay was then developed for the construction of port and storage facilities. The channels and depths maintained by the Corps in San Juan Bay are given on this page.

P 7-8. In 1982, the Commonwealth asked the Corps to design Agua-Guagua. The Commonwealth had relocated people living along the Caño during the 1960s and 1970s at a cost of over $125 million. The Agua-Guagua Project began construction in 1984 and was completed in 1988 at a cost of $20 million. They dredged and disposed in the ocean over 1.3 million cubic yards (0.99 million m^3) of material. This material was excavated from a 200-foot (61 m) wide and 10-foot (3 m) deep channel. The Agua-Guagua Project was inaugurated in 1991. Quebrada Juan Méndez Flood Control Project is also described.

Figure 10. Depth profiles of the bay and lagoons of San Juan (top) and measures of their temperature and salinity (bottom) From Bunch et al. 2000.



P 10-11. The San Juan Harbor Project in the 1920s led to the development of the wetlands along the Caño Martín Peña. The filled areas along the Caño were used for the establishment of substandard housing. Housing lacked basic utilities such as storm and sanitary sewer systems. Infrastructure was inadequate for the proper solid waste collection system. Thus, thousands of homes discarded their refuse into the canal. Trash has been detected up to 9 feet (2.74 m) below the surface of the canal and both banks. Raw sewage is discharged into the canal from direct sources, leaking septic tanks, and the sewer system. Encroachment into the channel has increased the frequency and intensity of flooding.

P 12. Some of the dredged pits on the lagoons such as Torrecillas and San José are as deep as 33 (10) to 60 feet (18.3 m). Dredging have occurred for securing sand and fill material for the development of residential areas and service facilities.

P 14. They propose to rehabilitate the Caño Martín Peña with a rectangular channel 200 feet (61 m) wide and 8 feet (2.44 m) deep. This requires an excavation of about 750,000 cubic yards (573,416 m^3) of mixed material at a cost of about \$60 million. Two bridges need replacement (\$12 million), utilities need replacement (\$10 million), recreation facilities will be established (\$2 million) and lands must be acquired at a cost of about \$36 million for a total of \$120 million at 1999 prices.

P 15. They propose the establishment of 67 acres (27.1 ha) of vegetation (mangroves and other wetland species) along the Caño.

P 17. The Corps assumes that before construction, the Commonwealth will eliminate sewage discharges into the Caño, replace bridges and utilities, and acquire lands. There is a list of ten constraints that suggest the difficulty of resolving the problems facing the Caño Martín Peña.

P 18-19. The next step is a feasibility study estimated to cost \$575,000.

ANALYSIS

The environmental situation facing the Caño Martín Peña is dire and affects underprivileged people. These communities were forced to where they reside by the socio-economic dynamics at play at the beginning of the 20th century, many of which continue today. The filling of wetlands by the Corps and also by the local population facilitated the establishment of a subpar housing development. At the time, wetlands were not valued and the economic imperative of the San Juan Harbor led to disposal of sediment material in areas that today could require millions of dollars to rescue communities from chronic flooding. Ironically the Corps is the agency called in to repair the environmental damages that it caused beginning in 1917.

CORRESPONDENCE INDUCED BY THE FIDEICOMISO DE CONSERVACIÓN

Context

The Fideicomiso de Conservación (Fideicomiso) is a non-profit non-governmental organization that among its many conservation projects is restoring the historic Río Piedras Aqueduct. This Aqueduct was built in 1894 and at one time served the Metropolitan Area. With the development of alternative water resources for the region, use of the Aqueduct was discontinued and abandoned in the late 1980s. The Río Piedras Aqueduct is the only Spanish-era structure of its kind remaining in Puerto Rico or the United States. During the process of restoration of the whole facility, the Fideicomiso obtained historical designation for the Aqueduct and in 2007 it also registered the site in the National Register of Historic Places with the name "San Juan Water Works". This designation included all Aqueduct facilities and the last remaining natural meander of the Río

Piedras. This is the first time a natural feature receives such a designation. The Flood Control Project proposed a river re-alignment that affects portions of the historic Aqueduct, which led the Fideicomiso to engage the Corps by mail and face-to-face meetings seeking alternatives. Also, the Fideicomiso needs a Corps permit to restore a weir or small dam on the river from where the Aqueduct drew water for the Metropolitan Area.

The Fideicomiso was not the first entity to formally raise questions about the Flood Control Project. Earlier, University of Puerto Rico President Antonio García Padilla had been the first to do so, when he realized that the University Botanical Garden lands were to be affected by the channelization. He went as far as proposing alternatives to channelization that would have a lower impact on the Botanical Gardens. Ironically, in an October 10, 1984 letter by then University President Ismael Almodovar, the University of Puerto Rico endorsed alternative B (the selected alternative) in the Survey Report. In September 5, 1984, the State Historic Preservation Office wrote to the Corps regarding the Río Puerto Nuevo 1984 Survey Report. They recommended the preservation of the General Norzagaray Bridge, the Río Piedras Water Filtration Plant, and the old buildings associated with the waterworks. All were structures potentially eligible for inclusion in the National Register of Historic Places. In May 19, 1992, the same Office wrote to the Corps to agree with postponing a detailed study of the Aqueduct area until after 2002 when work in the area would be scheduled. The State Historic Preservation Office made it clear that accepting postponement of detailed studies did not imply they endorsed working in the area without completion of the studies.

Finally, two of Secretaries of the Department of Natural and Environmental Resources (the Commonwealth agency responsible for co-leading with the Corps the Flood Control Project), also engaged the Corps in correspondence seeking changes to the project design. The dialogue among Commonwealth Department of Natural and Environmental Resources, the University of Puerto Rico, the Fideicomiso, and the Corps sheds light on the Flood Control Project and its future.

December 15, 2008

Letter to the Corps from the Secretary of the Department of Natural and Environmental Resources, Javier Vélez Arrocho: This letter is sent by the Department in its role as the sponsor of the Corps Flood Control Project and refers to contract number 5, which deals with the reach affecting lands where the Río Piedras Aqueduct is located. The Secretary asks for authorization to conduct a feasibility study to modify existing authorized channel design to protect and preserve the ecological value of the watershed. The Secretary notes that there is time to do so as the Flood Control Project schedule calls for implementation of this part of the Project 15 years into the future. The Secretary also mentions the Fideicomiso's restoration effort with the Aqueduct.

We have no record of a response to this letter.

June 2, 2009

Letter from MP Engineers of Puerto Rico to the Fideicomiso. In this letter the consulting firm MP Engineers provides the Fideicomiso with alternatives to the Corps channel alignment and design for the reach around the Aqueduct. These designs and conceptual approaches are compatible with Aqueduct restoration and flood control in the area *(it is not our objective in this report to discuss their characteristics and feasibility).*

October 28, 2009

Letter from the Secretary of the Department of Natural and Environmental Resources to the Corps: On this date, then Secretary Daniel

Galán-Kercadó wrote a letter similar to the one sent by Javier Vélez Arrocho (above). He mentioned the previous letter by date (December 11, 2008) and supported the effort of the Fideicomiso.

Undated (November 20, 2009 in file designation)

Letter from the Corps to the Secretary of the Department of Natural and Environment Resources: This undated letter addresses Contract # 5 in the vicinity of the Aqueduct, and the proposed modification of the authorized Río Puerto Nuevo Project. The Corps notes that at the time of their design, the Aqueduct was abandoned and damaged by floods. The topography and hydraulic characteristics of the area make it impossible to construct a flood control channel without impacting the old settling pools of the Aqueduct. The future of the Authorized Río Puerto Nuevo Project above the Bechara and De Diego Bridge sectors will depend on Congressional funding. Therefore, they feel there will be sufficient time to analyze or develop a plan to deal with the proposal of preserving the Río Piedras Aqueduct. Two areas of concern are (1) that without the Authorized Río Puerto Nuevo Project the segment of population upstream of the Old Aqueduct will be left without flood damage protection and (2) the required design changes to the Authorized Río Puerto Nuevo Project. The current design is based on a supercritical flow concept with high water velocities to protect the bridges below. Also, the potential to remove two of the upstream debris basins from the project area may cause increased impacts from large rock and debris to the downstream infrastructure and communities. Therefore, a 16-acre (6.48 ha) debris basin would have to be provided in the University of Puerto Rico Botanical Gardens between the Aqueduct and PR 1. These changes require Congressional authorization.

August 24, 2012

Letter from the Fideicomiso to the Corps: The Fideicomiso informs the Corps that the Aqueduct was included in the National Register of Historic Places in 2007 and their plan to restore the site to full historic value. The potential conflict of the restoration activities within the Aqueduct with the channelization of the river is explained in the letter, as is the high investment required by the Fideicomiso for a restoration project. The Fideicomiso asks if the Corps intends to prepare either a General Reevaluation Report or a Limited Reevaluation Report for this Project, as normally done when significant time passes between authorization and beginning of construction of flood control projects. Such reports would allow the Corps to comply with Section 106 of the National Historic Preservation Act, and allow the Fideicomiso to better assess the risks of investment in the restoration of the Aqueduct.

September 11, 2012

Letter dated from the Corps to the Fideicomiso: This letter is in response to a letter dated August 24, 2012 from the Fideicomiso to the Corps. Here the Corps indicates that the Flood Control Project started construction in 1995 and that it will continue to be a long and challenging process as the urban landscape of metropolitan San Juan develops and the hydrology of the watershed changes.

The Corps also state that they are in the early stages of preparing a Post Authorization Change Report that will address the rising costs of the Flood Control Project and may affect the construction schedule further. As communicated to the Fideicomiso in 2008, this phase of the Flood Control Project (the one affecting the Aqueduct) may not be needed or minimized as they address the hydraulic needs of the river.

November 28, 2012

Letter from the Fideicomiso to the Corps: On October 31, 2012, Officials from the Fideicomiso met in Jacksonville, Florida with Officials from the Corps to further discuss the Project's effect on the Aqueduct. By letter of November 28, 2012, Executive Director Fernando Lloveras San Miguel explains the historical value of the Aqueduct site and the need to restore and protect the weir located on the main reach of the Río Piedras. He also explains the Fideicomiso's intent to restore all elements of the site to their full historical value at a cost of millions of dollars. Full restoration of the Aqueduct site depends on the redesign of the improved Río Piedras channel.

Lloveras also shared a Memorandum for the Record summarizing the meeting and asked for their concurrence. According to this Memorandum, points made by the Corps were:

- No flood control work is anticipated for the area of the Aqueduct for at least 15 years.
- In previous discussions the Corps had indicated that box channels are now rarely, if ever, viewed as an appropriate design currently in practice.
- Due to changes in the watershed, it is possible that the upstream portions of the Flood Control Project may never be constructed.
- If the Project does proceed to the Aqueduct area, watershed changes will likely require a redesign and preparation of a General Reevaluation Report or Limited Reevaluation Report.
- A Post Authorization Change analysis currently in progress indicates the channel would have an adverse effect on the restored weir and ponds.
- The Corps recommended that the Fideicomiso apply for a permit for the restoration under the normal permitting process.
- The Corps expressed concern about the effect of the restoration on the flood control hydraulics and hydrology analysis

The Fideicomiso delivered letters from the Commonwealth Department of Natural and Environmental Resources expressing concurrence with their position to protect the historical river reach and weir from channelization.

December 17, 2012

The Corps replied to the above Fideicomiso letter by stating for the record that:

- Concrete box channels are effective when real estate and other features restrict the use of other cross-sectional areas to convey flows.
- The Corps is not clear on what watershed changes would limit future construction of the Flood Control Project; funding (Federal and non-Federal) is what would limit the future of the Project.
- The Corps is not aware of any analyses underway or included as part of the Post Authorization Change Report that would indicate that the Flood Control Project would have a definitive impact on the restored pond and weir.
- At this time the pond and weir are not restored and they don't know what the Flood Control Project design will be in 15 years.
- The Corps can say in the Post Authorization Change Report, that as presently designed, the Project may adversely affect the historical ruins and that they will avoid or minimize effects to the elements that contribute to the site's significance.

January 24, 2013

The Fideicomiso responded to the Corps by acknowledging receipt of the response from the

Corps to their Memorandum for the Record and by adjusting the Memorandum accordingly.

September 18, 2013

The Fideicomiso, joined by the Secretary of the Department of Natural and Environmental Resources and the Executive President of the Puerto Rico Aqueduct and Sewer Authority, writes to the Corps requesting clarification on the status of their Reevaluation Report and whether the Flood Control Project will or will not affect the Aqueduct. The letter, reproduced here as Appendix 2, contains a description of the restoration project and announces the intention to file for a Joint Permit application.

ANALYSIS

The letter exchange record summarized above is informative and illuminating. The Corps recognizes that the changes in the conditions of the watershed since the Flood Control Project was presented in the 1984 Survey Report and reiterated in the Design Memorandum of 1991 have changed dramatically. The designation of the Aqueduct and river meander in the Register of Historic Places complicates the planning process because the Project must address section 106 of the National Historic Preservation Act. Project costs have increased and hydraulic conditions have changed in the watershed. A Post Authorization Report is under development and that report can alter considerably the scope and extent of the Flood Control Project. What we do not know today is how thorough the Post Authorization Report will be and whether it will or not address the issues we raised as missing from the analysis or regarding the wrong assumptions used by the Corps since 1984. Regarding the timing of the report and its relationship to the Aqueduct, the Corps appears unable to provide a date for completion and has indicated in several documents reviewed above that there is sufficient time to address all issues because construction is far in the future. Nevertheless, if the report is delayed to the time closer to construction, the time available for adjustments and mitigation of effects is also diminished. Waiting for contract 5 to be executed and delaying the disclosure of impacts by that contract will adversely affect private investments in the watershed.

FLOOD INSURANCE STUDY OF 2012

P 1-2. The Federal Emergency Management Agency (2012) published a flood insurance study for all of Puerto Rico including the Río Piedras Watershed. The Corps was the contractor for the Dec. 1990 (completed in 1988) Río Piedras Watershed portion of the study.

P 13. The flood sources for Río Piedras were: Canal Puerto Nuevo, Río Piedras, Caño Martín Peña, and Quebradas Margarita, Doña Ana, Josefina, Guaracanal, Cepero, and Juan Méndez.

P 20. Has a short blurb on the Río Piedras Watershed.

P 39. Another blurb on the historic floods of the Río Piedras.

P 54. Another statement on water resource modifications in the watershed. Levees along the Puerto Nuevo Canal are not considered to provide protection from the 1-percent annual chance of flood.

P 78. Data on river and stream discharges in the watershed, same data as included in the Corps Survey Report of 1984.

P 98. Cross sections for Río Piedras Watershed are for 1978.

P 118-119. Manning's *n* value, which represents the average topography roughness of the floodplain, is used for modeling purposes. For the Río Piedras Watershed, all streams were assigned a channel n of 0.020-0.035 and overbank *n* of 0.016-0.200. For Caño Martín Peña, the respective values were 0.035 and 0.250.

P 122-123. A 0.9 m breaking wave is the minimum size wave capable of causing major damage to conventional wood frame and brick veneer structures. The coastal zone of Puerto Rico was mapped to include the level of waves higher than 0.91 m (V zone) and lower than 0.91 m (A zone at inland locations) as well as the V-A boundary. Transects corresponding to San Juan Harbor are numbers 42 to 50 (P 126).

P 134. Surge stations were also located around the Island and the ones corresponding to the San Juan Harbor were numbers 84 to 108 (P 137). For these stations the stillwater[8] elevation above mean sea level with a 1 percent annual chance of occurrence were estimated through modeling.

P 144. Stillwater elevations for the 1 percent annual event at surge stations 84 to 108 were in m msl: 1.4, 1.4, 1.6, 1.7, 1.5, 1.2, 1.5, 1.7, 1.6, 1.5, 1.4, 1.4, 1.3, 1.2, 1.1, 1.1, 1.0, 1.1, 1.1, 1.0, 1.0, 1.1, 1.0, 0.8, and 1.0, respectively. At the 0.2 percent annual probability some elevations doubled. Modeling was based on historical data.

P 165-167. Elevations for 1 percent annual chance still water, wave set up, and maximum 1 percent annual chance wave crest are given for San Juan in meters msl.

P 304-305. Information on the Río Piedras based on studies in the Corps Survey Report of 1984.

ANALYSIS

This report dated June 2012 uses old data for the Río Piedras Watershed, data already reviewed above in the Corps reports. However, this report contains information not discussed in the Corps 1984 and 1991 reports concerning the height of stillwater and damaging waves during storm events with 1 percent annual chance of occurrence. Under these conditions, San Juan Bay will be over a meter higher than msl with damaging waves another meter above. The question is, will a channelized Río Piedras discharge into San Juan Bay under these conditions or will there be a backwater effect? We have not found an answer to this question in Corps reports, so we posed the question to expert hydrologists (below).

WHAT SOME EXPERTS SAY

Over a period of about a month in November 2012, one of us (A.E. Lugo) had an informal exchange of e-mails with five expert hydrologists and coastal scientists working in Puerto Rico. We asked them to consider the channelization of the Río Piedras in relation to sea level change, storm surges, and the unlikely worst-case scenario when both San Juan Bay and the Río Piedras would experience higher than normal high waters. Would the river channel discharge or would backwater flood the low areas of San Juan, including Caño Martín Peña? The messages address both the question posed and/or other issues associated with the flooding problems of the Río Piedras. Below we present the opinions of those we consulted. Because these were informal exchanges, we maintain their identities anonymous and edited their remarks to hide identities and for grammar. We maintain the language used by the expert in the message. A.E. Lugo keeps the original messages.

Expert 1

(Nov. 11, 2012). Increasing pervious areas and detention ponds are solid Best Management Practices; however, given the intensity and volumes of tropical rainstorms, they should be less effective in the tropics than in temperate areas.

[8]*The surface of the water if all wave and wind action were to cease. Stillwater level does not include wind-driven waves at heights above the stillwater level, nor the run-up wave that penetrates inland.*

Most detention ponds are designed to hold the 5-year storm and have very little effect on large events.

One problem is finding areas to hold more water. This situation is even worse in the tropics, along with problems of vegetation clogging, mosquitoes, and maintenance. Many areas are developing stormwater management utilities to maintain them because of chronic failure in the past. They can be designed for new developments but retrofitting urban areas is hard (however, I know a place on the Río Piedras that could work).

Increasing infiltration is a good idea; but the high rain intensities and clay soils of the tropics limits the effectiveness of permeable parking lots and surfaces. These may work in the light rains and sandy soils of temperate regions, but not in the humid tropics without building an expensive subsurface.

Thus, the best solution for the humid tropics may be: 1) increasing vegetation; 2) good riparian management, which includes wide floodplains without people.

Expert 2

(Nov. 11, 2012). How the system works: hydraulic heads will be transmitted along the connecting channels of the system with maximum water elevations controlled by the tide at the entrance of the harbor. The inlet of the bay is very small compared to its volume, and the volume of water from a 100-year storm is small compared to the volume of the bay. If left alone, the system will behave as predicted in the COE (*Corps of Engineers*) model and partially validated in our studies. Water will back-up into the Río Piedras due to its low elevation relative to the bay, with hydraulic heads dissipating toward the low areas of Puerto Nuevo towards the west, through Laguna del Condado through the San Antonio Canal, and through Caño Martín Peña to San José. Eventually, as the system reaches a peak on a tidal event combined with a flood, large areas east of Torrecillas and Piñones lagoons will flood as it has happened forever. This flooding cannot be changed unless major water-containing dikes are built. Remember that several hundred years ago all these areas were wetlands due to this hydraulic balance, which in reality has not changed much. The hydraulic control points at different locations in the system will maintain a maximum level that can be predicted, and has been the basis of the proposed water works.

(Nov. 8, 2012). I think that the key to the control in the flooding in the basin[9] is a combination of works that involve widening the lower reaches of the channel of the Río Piedras, and diking to protect the areas now urbanized. If we had space upstream of the urban areas to detain the peak of the floods through large detention basins, this would reduce big time the peaks of the floods downstream. Recent aerial photos show there is no such space as it is difficult to find non-urbanized areas in the basin to do this. The COE model has been reviewed to death, and it seems reasonable, and perhaps it offers the best design solutions to alleviate the problem.

The effectiveness of the detention of floods in a basin (such as the Río Piedras) depends not only on the availability of land, but more so on the Time of Concentration (Tc) for the peak of the flood at the particular location. How long it takes for the peak to reach a point. If we had large parcels in the upper basin, the effect could be meaningless in terms of flood attenuation through detention since most of the runoff would be generated downstream. The areas that were wetlands several centuries ago were the lower basin natural detention ponds. The most current FEMA maps show the areas in the lower basin within the 100-year flood zone and the

[9]*In this section the consulted experts use "basin" to mean "watershed".*

residential areas that flood periodically. Now, look at the data from the USGS station at *Expreso Las Américas* from 1970 to 2011, where annual peaks are listed. It tells me that these peaks are not extremely high, and it does not take much to flood these areas in the lower basin due to the flatness of the channel and valley combined with the backwater from the San Juan Bay and probably compounded by sedimentation of the lower reach of the channel. But mostly, it is the slope where there is no energy to move the water against the tide in the bay. Maximum peak was 11,000 cfs (311.5 m^3/s) in 2010 when there were lots of storms. This is equivalent to 733 cfs/sqmi (8.01 m^3/km^2). In comparison, the historical known peak discharge at Río Grande de Loíza at Caguas was in 1996 with 83,000 cfs (2,351 m^3/s)with a drainage area of 89.8 sqmi (232.58 km^2), which results in a yield of 922 cfs/sqmi (10.11 m^3/km^2). This shows that the peaks measured at Hato Rey are reasonable and we can trust the data to formulate a frequency series. Engineers would probably design for water works to control about 20,000 cfs (566.4 m^3/s) at Hato Rey.

(Nov. 9, 2012). Cuando el "head" hidráulico del río es mayor que el de la bahía (en mareas bajas) el agua del río, siendo dulce y menos densa, se desplaza hacia el centro de la bahía en un "plume" casi directamente hacia el norte noroeste, hasta que se mezcla totalmente en la bahía. Cuando el "head" en la bahía es mayor que el del río (mareas altas), el agua se acumula en el río y ocurre "backwater" hacia las zonas que se inundan, que es el caso más común. En estas condiciones el flujo de agua salina puede ser de la bahía hacia la Laguna San José por el Caño. Por eso cuando una inundación ocurre al principio del ciclo de mareas bajas, la inundación en Puerto Nuevo dura varios días. Sin tener el beneficio del modelo del COE, creo que la posibilidad de que agua per se del río fluya hacia el Caño es cero. El "head" del río aún en una creciente máxima se disipa rápidamente al entrar a la bahía, donde las velocidades del agua son esencialmente cero, excepto por corrientes de densidad debido a los sedimentos suspendidos en el agua dulce (el "plume"). Recuerda también que la Laguna San José también recibe una cantidad sustancial de escorrentía y su nivel es controlado por las mareas en Boca de Cangrejos, lo que a su vez controla la dirección del flujo de agua a través del Caño. En mareas bajas, el agua puede fluir desde la Bahía hacia la Laguna San José porque la Bahía es dominante en el "head" por su gran volumen.

(Nov. 14, 2012). La palabra "hydrodynamics" se refiere a cambios en elevaciones. Primeramente se calibró el modelo de cambios en elevaciones del estuario para luego añadirle los componentes de calidad de agua. Esto es lo estándar en todos los modelos hidrológicos que utilizan cambios en energía para predecir valores y luego se acoplan a modelos de calidad de agua, donde se añaden módulos de dispersión y de reacciones químicas. El régimen de fluctuaciones no fue extremo, pero como verás abajo, el issue es que en la bahía y lagunas esos extremos no se reflejan vis à vis. El régimen de mareas en la Bahía de San Juan no es de mucha elevación, y por eso es una bahía considerada segura para que desde tiempos de España los barcos encuentren protección de las altas mareas mar afuera. Los arrecifes que causaron el encallamiento del famoso barco que derramó todo el petróleo hace décadas son causa principal de la mitigación del oleaje.

Los máximos históricos de mareas observadas en la Bahía de San Juan son los siguientes (de la página de NOAA Tides and Currents):

Highest and Lowest Values:

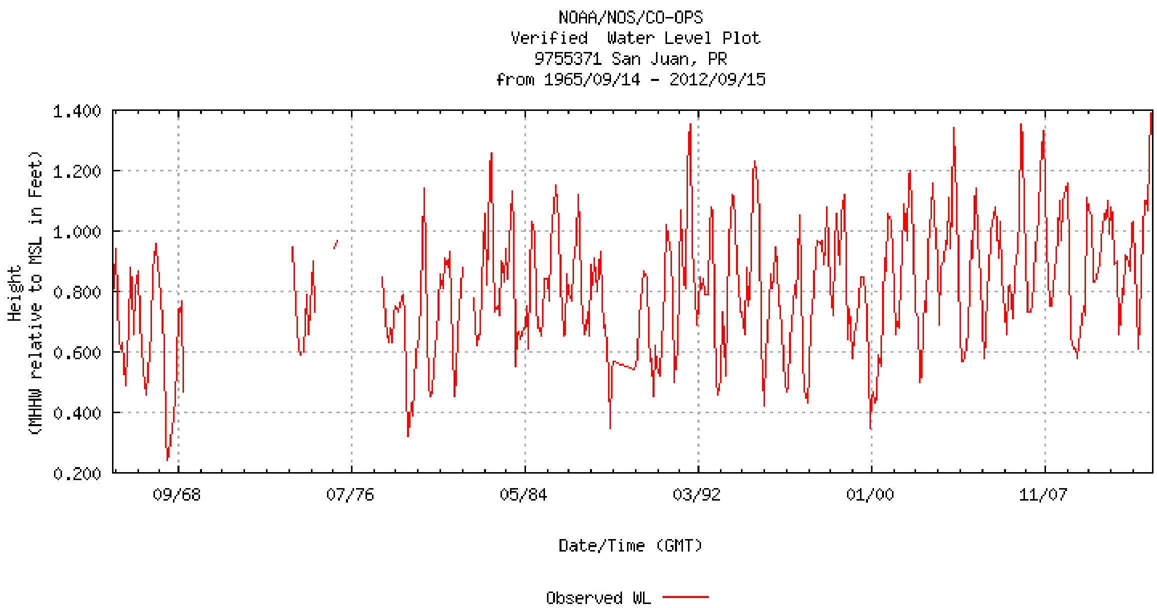
Station: 9755371	Begin Date: 19650518
Name: San Juan, PR	End Date: 20121114

Product: High/Low
Datum: StnDatum

Units: Feet (multiply by 30.48 to obtain cm)
Quality: Verified

Rank	Highest	Highest	Date	Zone	Lowest	Lowest	Date	Zone
1	7.73	19890918	14:54	LST	2.30	19681220	06:24	LST
2	7.73	19890918	10:54	LST	2.46	19991222	05:24	GMT
3	6.17	19980921	23:42	GMT	2.47	19900107	22:48	LST
4	6.05	20061106	14:06	GMT	2.48	19700107	00:00	LST
5	6.04	20031028	15:42	GMT	2.49	19900622	13:48	LST
6	6.02	20031027	14:48	GMT	2.50	19871221	02:30	LST
7	6.00	19911027	16:42	GMT	2.50	19991224	07:06	GMT
8	5.98	19911028	17:36	GMT	2.51	19991223	06:18	GMT
9	5.95	20061011	17:00	GMT	2.53	19871222	03:30	LST
10	5.94	20061105	13:12	GMT	2.54	19900427	16:00	LST

La próxima figura es la tendencia en las mareas en la Bahía de San Juan.



Finalmente, existen fotos de la marejada del 28 de marzo de 2008 en Piñones y Mar Chiquita, que enterró con más de un metro de arena todas las *Thallasias* trasplantadas a la Laguna del Condado, pero en la Bahía de San Juan el efecto fue normal. ¿Cómo se explica que esta marejada de 20+ pies no se reflejó en la Bahía de San Juan?

Expert 3

(Nov.13, 2012). I was looking at the Corps Model and some items in the hydrodynamic model (data) called my attention. The first one is that they use climate data for 1990's and for a short period May-Sep (we can see it as little wet season) but not considering the real rainy season in San Juan and extreme weather events (+30 percent).

In a Climate Change context we can expect more stream flow with extreme events, more urbanized area with "development" or impervious areas (more percent runoff), less green areas (less percent interception - less percent infiltration), etc. We have no other option than to trust in the sewer (drainage) system that was built using old climate data and old land use patterns.

In my opinion, we also should take under consideration phenomena whose effects can be catastrophic in Puerto Rico even if they don't pass through the island. Last week, Hurricane Sandy (only category 1-2) passed a thousand miles away, but caused coastal floods all over the island, lucky we didn't receive rain at the same time. It wasn't storm surge but waves and "prevailing wind" for a few days from WSW-SSW. Usually when the wind is blowing from the SW the afternoon rainfall over SJ metro area, never happens.

We have evidence that rain patterns are changing in SJ since 1950 and specifically the last decade. And there is evidence; too, from UPR-Mayagüez that sea level is raising a few mm/years as well as temperature. I'm worried about the hydrodynamics results in SJ Bay Estuary, not only in water quality but also in hydrological response (floods), since the Estuary system is very complex.

Expert 4

(Nov. 13, 2012). A critical factor controlling storm surge impacts is whether the surge coincides with the peak rainfall. Typically this is not the case, which is why runoff models (e.g., 100-year flood) are not normally run against the 100-year storm surge, since this is a decidedly rarer occurrence and would no longer represent a 100-year level of risk. Having said that, if they do coincide, which is also quite possible, and then you have a much more severe event.

Sea level rise is an important issue. It has been gradually rising (against local land surface) in the San Juan area since we have accurate records. Some years ago we did sea level monitoring near the pump station in Cataño, and if I am recalling correctly the actual mean sea level is today at about 30 cm higher than the "mean" sea level as it appears on maps, etc. I do not know to what extent the current sea level has been incorporated into FEMA and other storm surge models. Sea level rise as a result of climate change will not "cause" sea level rise, but only ensure it continues into the future or accelerates. There may also be long-term local ground subsidence in some of the lowest-lying areas.

As to the hydraulic restriction posed by the entrance to San Juan Bay, I would not characterize the entrance to the bay as being "small", and the combination of high storm surge and a wind field from north to south pushing water into the bay, and also against the river outlet, could produce serious impacts. However, the amount of water entering through Boca de Cangrejos would indeed be very much limited by that construction.

As for mitigating flooding impacts by detention in the watershed, there are some things to consider. First, a lot of the green area is on slopes where there is very little possibility to detain runoff, the soils do not have a high level of permeability, you must expect significant antecedent rainfall and saturated soils when the "big" event arrives, and your really severe flood would occur on a day delivering 10 inches (254 mm) or more of rainfall. This will generate a huge volume of runoff, and I don't know of any low-impact development technology that could be implemented in this heavily and densely developed watershed that would be highly effective. The widespread use of green roofs, for example, would be an interesting detention technology to look at, but again given the very deep rainfall depths that we get, these systems could be overwhelmed. They are great for controlling smaller events, but to control really large events like our design flood events here, they have to be designed so that they would leave most of their storage empty during smaller events, waiting for that 1-in-100 year event to come along.

In the end, no obvious "alternative" solutions that I can see in this densely developed area with all its concrete. I don't like channelization in general, and the proposed channel works can themselves be overwhelmed by large events, particularly to the extent that climate change impacts (changes in sea level and storm intensity) have not been considered in the design. And in the end, you always end up designing for a particular level of protection, and that level of protection will eventually be exceeded by nature.

Structures like modern dams are designed for really extreme events (Probable Maximum Flood, for example) because of the catastrophic consequences of failure, and because to increase spillway capacity to accommodate a more severe event does not represent a disproportionate cost. Flood control projects based on dikes may have higher levels of protection than projects based on channelization because the consequences of dike overtopping are worse (catastrophic) as compared to overbank flooding that occurs when channel capacity is exceeded. To increase the level of protection at a large flood control project represents a very high cost, and in the end it's a balancing act of getting a reasonable result from the funds available.

I've looked at this from a couple of angles previously and no brilliant and feasible alternative solution has been forthcoming to date. However, I believe it is indeed appropriate to be concerned about the storm surge and long-term climate change issues, and even within the "protected" areas there are certainly many areas that will continue to flood, simply due to local deficiencies in the storm drainage system (Hato Rey, for example).

The modeling that the Corps did for the San Juan Bay Estuary has nothing to do with extreme storm events. As described in the final report, it is a long-term simulation to examine water quality impacts. There is nothing there about extreme events.

Caño Martín Peña is already connected to Río Piedras, but it has become filled in with sediment and rubbish over the years so it now has relatively little hydraulic capacity. The Suárez Canal also has limited hydraulic capacity. By increasing the hydraulic conveyance along both of these, the ability of storm surge to penetrate inland into Laguna San José will be significantly increased. On the other hand, it would also permit faster drainage of stormwater that enters Laguna San José. However, from my recollection the stormwater drainage issue is potentially not as important as the ocean surge elevation. I have not seen any study that analyzes the effect on flood levels, but there may be something out there. However, it is not presented in the "Hydrodynamic and Water Quality Model of San Juan Bay Estuary", as in that study the hydrodynamic model was used to drive the circulation pattern for the water quality model.

Because the Río Puerto Nuevo/Río Piedras Flood Control Project has already enlarged the connection of that drainage to San Juan Bay, especially in the vicinity of the Ave. Kennedy Bridge, I don't think that the Martín Peña Project will have a significant additional impact on the Puerto Nuevo/Río Piedras flooding situation. However, Laguna San José could be a different matter. This connection also makes it possible for water from Río Puerto Nuevo to discharge, not only into the bay, but also to flow to the east and enter Laguna San José. Again, I haven't seen any evidence that this has been analyzed.

Expert 5

(Nov. 14, 2012). Lo que yo sugiero para algún futuro es adoptar para el estuario de la Bahía de San Juan algún modelo más sofisticado y que el expertise para correrlo resida aquí en la isla. Por ejemplo, ver

http://tidesandcurrents.noaa.gov/ofs/creofs/creofs.html.

Ya hemos logrado hacer algo equivalente en cuanto al pronóstico de vientos y oleaje alrededor de la isla ya que hay dos ex-estudiantes míos haciendo eso en el NWS en San Juan corriendo los modelos allí mismo (ver http://www.caricoos.org/drupal/). Y uno de ellos está también corriendo el mismo modelo que se usa en el primer enlace que aparece arriba, pero en este caso para el pronóstico de mareas ciclónicas y oleaje de huracanes.

En cuanto a si se puede confiar en los modelos del CoE (*Corps of Engineers*), creo que no es conveniente. Mira las experiencias de Katrina y las constantes inundaciones del Mississippi en el Mid-west. En Aguadilla construyeron una marina gigantesca que rápido se les llenó de arena. El siguiente enlace te detalla las experiencias de un reconocido geólogo con el CoE:

(http://www.amazon.com/The-Corps-Shore-Orrin-Pilkey/dp/1559634391).

Hay que tomarlo caso a caso.

(Nov. 17, 2012). Aunque solamente el modelaje puede iluminar más precisamente, es un hecho de que huracanes que pasan por trayectorias críticas para la Bahía pueden bombear agua hacia dentro de la misma. Solo hay que mirar los datos del mareógrafo en La Puntilla y se puede ver la marea ciclónica. Y si esto dura un par de horas es posible que afecte el sur de la Bahía. Y va a depender también de la lluvia. Me acuerdo que cuando Hugo el oleaje hizo daños en los muelles abajo, daño que vi con mis propios ojos ya que me llevaron a los puertos para verlo (la Bahía es calmada bajo condiciones normales y Hugo solo fue Categoría 2 en la Isla Grande). Y ese oleaje rompiendo en la costa sureste de la Bahía, junto con el viento, ciertamente podrían subir el mar allí y ataponar el agua en la desembocadura del Caño. Esto se observa en las desembocaduras de ríos que descargan al mar abierto.

En resumen, veo posible el ataponamiento de la desembocadura del Caño, y hasta que el agua penetre upstream. Y será más fácil si lo dragan. Y no te olvides que según pasan los años las inundaciones ocurrirán con más facilidad. Justo en estos últimos dos meses el nivel promedio del mar ha estado cerca de 0.2 metros por encima del msl (mira lo que está pasando en Vega Baja; y en un lugar de Mayagüez). Y ese msl está subiendo a razón de 2.7 mm/año en la Bahia desde por lo menos 1993 (un mm más que hace décadas), cuando los satélites empezaron a medir, por ahora. Eso es lo que muestra el mareógrafo en La Puntilla. The best is yet to come.

Espero que en un año más o menos podamos jugar con escenarios como estos. Aunque la parte de incluir el efecto de la lluvia y su descarga a la Bahía, o al mar, por los ríos podría tomar un poco más de tiempo. Hemos estado en contacto con la gente que está en el proyecto CI-FLOW (http://www.nssl.noaa.gov/projects/ciflow/) para en su momento incluir el efecto de la lluvia.

SEA-LEVEL CHANGE CONSIDERATIONS FOR CIVIL WORKS PROGRAMS

On October 1, 2011, the Corps of Engineers published Circular 1165-2-212 (U.S. Army Corps of Engineers 2011), which contained guidance for incorporating the direct and indirect effects of projected future sea-level change across the Project life cycle in managing, planning, engineering, designing, constructing, operating, and maintaining Corps projects and systems of projects. The circular applies to all Corps elements having civil works responsibilities and is applicable to all Corps civil works activities. The Corps advises that global mean sea level be distinguished from local or relative mean sea level. Potential sea-level change must be considered in every Corps coastal activity as far inland as the extent of the estimated tidal influence. Fluvial or flood control studies that include backwater profiling should also include potential sea-level change in the starting water surface elevation for such profiles. The vertical datum of projects must be current or updated to NAVD88. The directive is based on extensive scientific information generated by other government institutions and universities including international organizations. The Circular calls for ending the identification of a best alternative for a Corps project and instead comparing all alternatives against all scenarios.

The Corps Circular contains available data for sea level rise in various locations including Puerto Rico. The global mean sea level rose at an average rate of 1.7 $\pm$ 0.5 mm/yr during the 20th century. The Corps advocates that sea level rise data sets contain at least 40 years of measurements before they are used with some confidence as the trend standard error decreases as the length of the data set increases. For Puerto Rico the sea-level rise was 1.65 and 1.35 mm/yr for San Juan and Magueyes Island, respectively.

A procedure for incorporating sea-level increase into the analysis of projects at a minimum should include an extrapolation of historical rates at the project's locality. A maximum of 2.0 m raise in global sea level is projected for the 21st century.

ANALYSIS

The flooding issue in the Río Piedras Watershed and the San Juan Metropolitan area is obviously complicated and even expert opinion is divided as reflected in the comments above. However, it is possible to reach some conclusions from the opinions given above by the experts and from the documentation reviewed up to date in this manuscript. For example:

- The Corps documents reflect the best that could be done under the scope of approach and assumptions that they established in their documents.
- When the Flood Control Project was conceived in the 1980s, the Corps followed conventional approaches for developing and modeling hydrologic models and these conventions did not include sea level rise and climate change. It now appears that the Corps has been mandated to take these phenomena into consideration in the design of projects near the coastline like the Río Piedras Flood Control Project. For example, see http://www.georgetownclimate.org/resources/sea-level-change-considerations-in-civil-works-programs-usace-ec-1165-2-212, which expired on September 30, 2013; and Engineering and Construction Bulletin number 201410, issued by CECW-CE on May 2, 2014 and set to expire in May 2, 2016. This Bulletin provides guidance for incorporating climate change impacts to inland hydrology in civil works studies, designs, and projects.
- The Water Resources Reform and Development Act of 2014 lays out guidelines for de-authorization of inactive and backlogged Corps projects no longer viable for construction. According to Title VI Section 6001, water resources projects or elements of projects that are eligible for de-authorization include those that were authorized for construction before November 8, 2007 for which construction was not initiated before the date of enactment of the Act, or for which construction was initiated but for which no funds (federal or otherwise), were obligated for construction of the project or element during the current fiscal year or any of the six preceding fiscal years. Aside from the dredging of the Caño Martín Peña, the rest of the remaining Río Piedras Flood Control Project elements would fall into this potential de-authorization category.
- Experts agree that the Río Piedras watershed does not have sufficient water storage capacity to reduce the peak discharges that flood the lowlands. Such capacity has been reduced by wetland filling and covering surfaces with impermeable concrete.

- Non-structural solutions do not appear to provide answers to large-magnitude flooding events of the Río Piedras.
- Solutions of the flooding problem in San Juan will require a new approach that combines conventional with non-conventional solutions (including social ones) functioning at multiple spatial scales, and as much knowledge about the watershed and its environment as is available to modern science and technology.

Regarding the objectives of this analysis, we have established that many of the assumptions used by the Corps when they designed the Flood Control Project for the Río Piedras, as well as their decision to not consider the storm runoff infrastructure of the watershed, have been either incorrect or not passed the test of time. Current and future conditions in the Río Piedras Watershed are not anywhere near those assumed by those who designed the Flood Control Project, a situation that makes the current Project design incompatible with the goals of the original Project, and not adaptive to the future conditions of the watershed. Moreover, costs of the Flood Control Project have escalated over tenfold to levels not anticipated in the recent past. We conclude that the whole Flood Control Project, as well as the approach to resolving the flooding problems of the Río Piedras Watershed, requires reassessment.

ACKNOWLEDGMENTS

This work was done in cooperation with the University of Puerto Rico. The Fideicomiso de Conservación shared documents with us as did the San Juan Office of the US Army Corps of Engineers. Mildred Alayón edited the manuscript and we are thankful to the following colleagues for their review of earlier drafts of the document: Ferdinand Quiñones, Frank Wadsworth, and Soledad Gaztambide Arandes.

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Appendix 1. Letter from the governor of Puerto Rico to the US Army Corpos of Engineers, requesting assistance regarding the flooding in the Río Piedras Watershed.

COMMONWEALTH OF PUERTO RICO
OFFICE OF THE GOVERNOR
LA FORTALEZA, SAN JUAN

January 4, 1978

Colonel Donald A. Wisdom
District Engineer
Corps of Engineers
Jacksonville District
Department of the Army
PO Box 4970
Jacksonville, Florida 32201

Dear Colonel Wisdom:

During your recent visit this past November, various Commonwealth officials had some good discussions on the Corps of Engineers program in Puerto Rico. As a result of the meeting, we have determined the need to readjust the present water resources planning study effort.

During fiscal year 1978, we would like the Corps of Engineers to complete the two on-going major regional studies: Ponce Regional Water Resources Management Study and Islandwide Water Supply Study. Our priorities for the new studies to begin in fiscal year 1978 (listed in order of preference) are the following Level C studies:

(1) Río Puerto Nuevo Flood Control.

(2) Initiate the Río Grande de Loíza.

(3) A Broad Study of Water Resources Development of the El Yunque Area.

(a) Begin the Virgin Islands Pipeline Study authorized by the May 1977 House Committee on Public Works and Transportation Resolution. As part of your preliminary work, close attention should be given to the flood control aspects of a multi-purpose reservoir on the Río Fajardo.

Colonel Donald A. Wisdom
Page 2
January 4, 1978

(b) Examine the opportunities for multiple purpose projects leading to the development of water supply for the San Juan Metropolitan Area and Eastern Puerto Rico. As the results of the Islandwide Water Supply Study emerge, identify the projects with sufficient potential in the El Yunque area that offer the possibility of Federal funding. I would appreciate early notification of your recommendation of any possible Level C studies which you may identify.

The above study on the Río Puerto Nuevo has been selected to replace the Río La Plata Study which you had originally scheduled for the present fiscal year.

Relative to the Section 205 projects we assign the following priorities:

(1) Move ahead on detailed Project Report for Río Coamo Flood Protection.

(2) Río Nigua of Arroyo.

(3) Río Guayanés of Peñuelas.

(4) Río Guanajibo at Sabana Grande.

(5) Río Maricao of Maricao.

We look forward to continued close discussions with you relative to the Corps of Engineers study program for the next few years. As you know, Resident Commissioner Baltasar Corrada del Río submitted a Resolution to the Congress to review the report of the Chief of Engineers on San Juan Harbor to determine advisability of modifying the existing project at the present time and to consider references concerned with urban water resources problems including transportation, associated land implications, recreation, urban flood reduction, improvement of water quality and environmental enhancement in the area of San Juan extending from San Juan Bay to Piñones Lagoon along the Martín Peña Canal.

It is our hope that the Congress will authorize the study and that the Corps of Engineers will be able to initiate

Page 3
January 4, 1976

the works necessary to promptly resolve the problems associated with the Canal. We are looking forward to your support during testimony before the Congress to look into the Martín Peña Canal.

Cordially yours,

Carlos Romero Barceló

Carlos Romero Barceló

Appendix 2. Letter from the Executive President of the Puerto Rico Aqueduct and Sewer Authority, the Secretary of the Department of Natural and Environmental Resources, and the Executive Director of the Conservation Trust to the US Army Corps of Engineers.

Autoridad de Acueductos y Alcantarillados

DRNA

para la Naturaleza

September 18, 2013

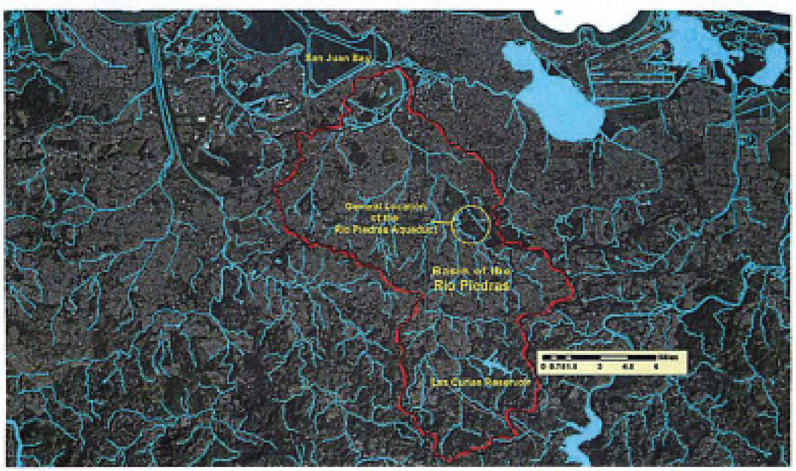
Eng. Sindulfo Castillo, PE
Chief, Regulatory Section
US Army Corps of Engineers
400 Fernández Juncos Avenue
San Juan, PR 00901

Re: Restoration of the Rio Piedras Aqueduct

Dear Mr. Castillo:

The Puerto Rico Aqueduct and Sewer Authority (PRASA) is assisting the "Conservation Trust of Puerto Rico" (the Trust) and its "Para La Naturaleza" unit in obtaining the required local and federal permits for the restoration of the Rio Piedras Aqueduct (referred from here on as the ARP). The ARP, located adjacent to the Rio Piedras Experimental Station and the UPR Botanical Garden was inaugurated in 1899 and at the time was the most advanced water purification facility in Puerto Rico. As it was planned and built before 1898 it is the only Spanish period's aqueduct retaining most of its integrity on US territory.

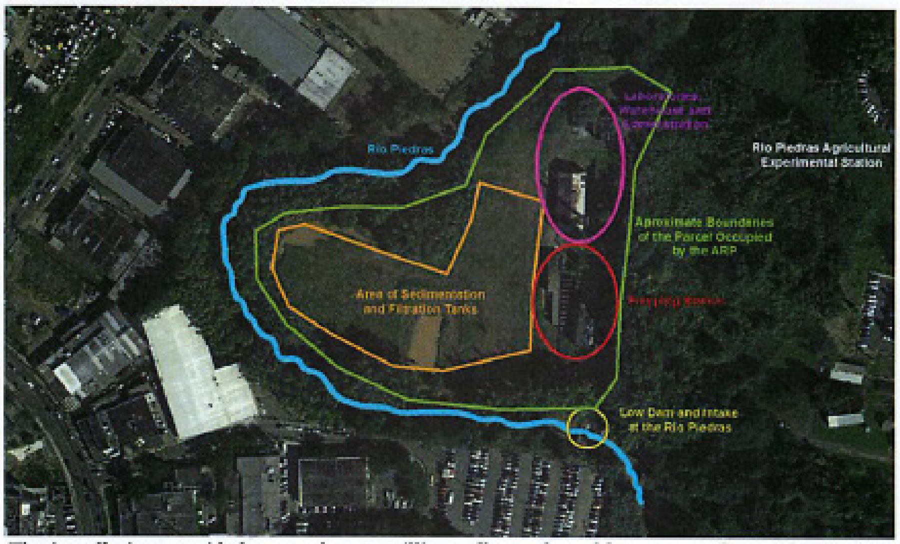
Figure 1. General location of the Rio Piedras Aqueduct at the Experimental Station.



Page 1 of 4

The installation included a low-water dam connected to an intake; sedimentation and filtration tanks operated by gravity; a pump house initially operated with steam, later with coal, and finally with electric power; a small laboratory; and maintenance, storage and administrative buildings. The specific location of the ARP and a close-up view of the faculties are shown in Figure 2.

Figure 2. Aerial photograph of the Rio Piedras Aqueduct and its facilities



The installation provided as much as 2 million gallons of potable water to the residents of Rio Piedras and sectors of San Juan. The facility closed in the early 80's upon the consolidation at the Sergio Cuevas filtration plant in Trujillo Alto of the potable water supplies for the San Juan Metropolitan Area. In 2005 the Trust began conserving and managing the grounds and structures of the ARP as part of a long term use agreement. The ARP was included in 2007 in the Department of Interior, National Park Service Register of Historic Places.

The facilities at the ARP have decayed with time and lack of maintenance, particularly the low-water dam, as shown in Figure 3. Silts now fill the sedimentation and filtration tanks and the buildings are in general disrepair. The Trust plans to restore the facilities at the ARP as close as possible to its original condition, although no actual operation or water production will occur. The restoration effort is directed to the preservation of the infrastructure at the site and enhancement of certain elements of the site with cultural and educational purposes. The restoration will include the rehabilitation of the low water dam to as near as possible its original construction style and structure. The sedimentation and filtration tanks will be restored by removal of the accumulated sediments and reuse of the dredged materials at the site or disposal at uplands of any excess materials. The buildings will be restored to resemble its original architecture and colors.

Figure 3. Low water dam at the Rio Piedras Aqueduct

The pertinent permits for the indicated restoration activities will be obtained from the local and federal regulatory agencies. A Federal-Commonwealth Joint Permit Application will be filed with the DNER and your office to apply for a Section 404 Individual Permit for the restoration activities, particularly, the rehabilitation of the low-water dam. The Trust and PRASA representatives will attend the USACE Interagency Committee meeting of October 2013 to present detailed information about the project to you, your staff, and other representatives from local and federal agencies members of the committee.

An important issue related to the coordination with the USACE surfaced during the initial planning activities of the project. The issue relates to the route of the planned channelization project of the Rio Piedras that the USACE has proposed since the early 1980's. As shown in Figure 4, the planned route of the flood control channel traverses through the grounds of the Aqueduct, potentially impacting severely this unique historical site.

In 2012, the Executive Director of the Trust, Esquire Fernando Lloveras, met with representatives of the USACE at the Jacksonville to discuss alternatives to the flood control channel that would not impact the ARP. The Trust had previously commissioned a conceptual study of alternatives to the routing of the flood control channel as proposed more than 30 years ago. These alternatives were presented to the senior staff at Jacksonville, including District Commander Col. Alan Dodd and Jerry Scarborough, Chief of the Project Management Division within the Water Resource Branch. During this meeting, USACE staff recognized that the significant development in the watershed since original design will likely require redesign and preparation of a General Reevaluation Report or Limited Reevaluation Report. In regards to the restoration of the low-water dam, Esquire Lloveras was advised to apply for a permit under the normal permit process.

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