Valenciano Reservoir
Water Distribution System Hydraulic Model

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Table of Contents

LIST OF TABLES

LIST OF FIGURES

Valenciano Reservoir
Water Distribution System Hydraulic Model

1 Introduction

In August 2000, Black & Veatch completed the report "East Central Regional Aqueduct Project Water Distribution System Master Plan" for the Puerto Rico Infrastructure Financing Authority (PRIFA). The report identified additional facilities needed in the East Central Region, defined as the aqueduct systems within the municipalities of Gurabo, Juncos and San Lorenzo. The definition of the region excluded the area of Gurabo served by Caguas, and included the San Salvador system in southern Caguas, and the Cubuy system in southern Canóvanas. The Valenciano Water Treatment Plant (WTP) was proposed to alleviate the demand deficit and transfer water to Las Piedras.

In December 2000, Black & Veatch produced the Request for Proposal for a design of the "East Regional Aqueduct System Water Treatment Plant and Transmission System." Various recommendations from the Master Plan were used to develop the conceptual design for the Valenciano WTP and its main transmission system. Due to various problems, including funding, the Valenciano Reservoir and the WTP were postponed and PRIFA decided to design and build the Guaynabo-Caguas-Gurabo-Juncos Transmission Line as a complementary project to alleviate part of the demand need. The pipeline project was to bring surplus water from the North Coast Aqueduct to Gurabo and Juncos, increasing the supply by approximately 13 mgd. This new transmission pipeline is to be supplied from the Metro Area and the availability of water depends on the Metro Area's use and optimization of its system. Particularly, under drought conditions, this transfer is not sustainable since the large treatment plants serving the Metro Area operate at much higher flow than their safe yield. The East Central Region will continue to suffer from a high supply deficit without the transfer of Metro Area water. Thus, this project did not eliminate the need for the Valenciano project, and it was necessary to find a solution for the region that would alleviate this large scale water problem. In the short-term, as previously discussed, the region will be supplemented with the transfer of water from the Metro Area through the Guaynabo-Caguas-Gurabo-Juncos Line. For long-term conditions, the East Region needs a large-scale water solution that reduces to a minimum the water transfers and dependency on the Metro Area; the Valenciano project is the feasible solution.

Over the years, the project had been "postponed" for a variety of reasons, including funding, but decision-makers kept returning to this concept since other alternatives failed to deliver the necessary water. In the 2006 report titled "Planning and Feasibility Studies for Potential Dam Sites in Puerto Rico", Greg Morris Engineering evaluated for PRASA three alternatives for reservoirs in the East Central municipalities of Gurabo, Juncos and San Lorenzo, and the only one recommended as a viable option was the Valenciano Reservoir. That same year, the Puerto Rico Aqueduct and Sewer Authority (PRASA) validated the conceptual design for the Valenciano and authorized CSA Group, as East Region PMC the development of the project. A revision of this hydraulic model presented by Black & Veatch in its "East Central Regional Aqueduct Project Water Distribution System Master Plan" report was completed by CSA Group. The following discussion provides a summary of the results and conclusions; it includes a discussion of demands, supplies, tanks, pump stations, and pipeline needs.

The following tasks were performed for the development of the new hydraulic model of the East Central Region.

- Demands - Recalculated according to the "Update of Puerto Rico Water Demand Forecast, Final Report" submitted to the Water Plan Office of the Puerto Rico Department of Natural and Environmental Resources by CDM Caribbean Engineers P.S.C. and PMCL@CDM in November, 2004
- Pipe Network, Pumps, Tanks, Valves – Previous database was reviewed and re-organized according to data from the GIS inventory prepared by CSA for the PRASA Master Plan ("Plan Maestro") and interviews with operations staff.
- Mass Balance and Storage Analysis – Revised according to new demands and proposed transmission system.
- Model - Performed iteratively in order to match mass balance and to propose improvements so that criteria were met for low pressure, high pressure, and high headloss/velocity.
- Proposed Improvements - Revised previously proposed pipeline routes and diameters, pump upgrades and tank capacities according to results of mass balance analysis, model results, and storage analysis.

1.1 Study Area

The East Central distribution system encompasses the municipalities of Gurabo, Juncos, and San Lorenzo. **Figure 1-1a** shows the study area boundary overlaid on the satellite photograph and how it relates to municipal limits, wards, and the existing distribution system. The study area boundary was redefined in the model revision to include the Gurabo area that is currently supplied from Caguas, and to exclude systems which are supplied from sources outside of the three municipalities. These would be the San Salvador system in southern Caguas and the Cubuy system in southern Canóvanas.

Figure 1-1b shows the Valenciano Reservoir service area overlaid on the existing water treatment plant service areas and the wards. The Valenciano system service area includes the following wards: all of Juncos except for Gurabo Arriba and Caimito (unless Juncos WTP is eliminated); all of San Lorenzo; Collores, Las Piedras Pueblo, Montones, Tejas, Quebrada Arenas and Ceiba in Las Piedras; during the first project phases and for emergency purposes Gurabo Pueblo, Mamey, Jaguar, Rincón and Navarro in Gurabo; Tejas, Mabú, Collores and Mambiche in Humacao; and Tomás de Castro in Caguas.

2 Water Demand Estimation

Water use (demands) by consumers were developed and assigned to the points within the distribution system (model nodes) in the revised model for years 2005 and 2025. Demands were based on the "Update of Puerto Rico Water Demand Forecast, Final Report" submitted to the Water Plan Office (OPA by its Spanish acronym) of the Puerto Rico Department of Natural and Environmental Resources by CDM Caribbean Engineers P.S.C. and PMCL@CDM in November 2004, which performed demand projections for various scenarios by municipality, currently in revision by PRASA. The Alternative Forecast used in the hydraulic model analysis is the most conservative and does not include loss reduction, as requested by the PRASA Planning Department. PRASA is currently developing a loss reduction program, but has no formal estimates of its long-term results yet. These demands were assigned to model nodes within each municipality using the following procedure:

- Assigning populations from the 2000 census to pressure zones (areas of similar ground elevations that are supplied with water at a target hydraulic grade elevation, i.e. water tanks, water treatment plants, wells, and/or pump stations providing similar pressures). The assignment was a procedure performed by superimposing census polygons and pressure zone polygons in geographic information system software.
- Distributing the total municipal demand among the pressure zones contained in each municipality by proportioning according to the populations assigned in the previous step.
- Subdividing the assigned demand of each pressure zone among the model nodes contained within.

Table 2-1a shows the production needs for each pressure zone by service area in the revised model, which includes both accounted for and non-accounted for demands, as defined by the Water Demand Forecast by OPA. **Table 2-1b** shows the production needs for each pressure zone by municipality. Accounted for demands are those that are currently being billed to customers, whereas non-accounted for demands include both commercial and physical losses in the system. The following scenarios are shown in **Table 3-1**: average production need and maximum day production need. Average production needs correspond to the demand assigned in the model as the "average" yearly demand by customers. Demands for the other scenarios are calculated using multipliers, which were based on PRASA design standards, as well as standard practice and the guidelines of the American Water Works Association (AWWA). The peaking factors were typical and reasonable for water systems that have a seasonal variation in water demands.

Peaking factors used were:

- Maximum Day = 1.5 x Accounted-For Average Day + 1 x Non-Accounted-For Average Day ~ 1.25 Total Average Day
- Peak Hour = 2.25 x Accounted-For Average Day + 1 x Non-Accounted-For Average Day ~ 1.625 Total Average Day ~ 1.3 Total Maximum Day
- Reservoir Refill = 0.5 x Accounted-For Average Day + 1 x Non-Accounted-For Average Day ~ 0.75 Total Average Day ~ 0.462 Total Maximum Day

PRASA's Rules and Regulations for the Design Standards call for the peaking factor Maximum Day to Average Day ratio to be 1.5. Without an adequate peaking factor, the distribution system does not function properly, leaving the higher and outer regions of the system without water during peak hours and maximum day events (highest use days of the year). This condition leads to water rationing, where operations staff begins opening and closing valves to divert water to affected areas. This valve operation is detrimental to the system causing surge events by the rapid valve opening and closing. Surge events cause high and low pressure spikes in the pipelines that deteriorate them and may cause them to burst. Low system pressures also leave pump stations without sufficient suction pressure and may cause pumps to burn out. Both of these conditions damage the distribution system, increasing both leakage and maintenance costs.

The scenarios were modeled to determine system performance under various demand conditions, which are typically the most critical to determine the deficiencies of the system and need for improvement. Maximum Day is the highest demand day of the year, which represents conditions that are typical of the highest demand period of the year (e.g. summer months). The initial model analysis is performed under this scenario to determine if water supplies are balanced with demands under this condition. Peak Hour is the highest demand rate occurring for 1-hour duration during the Maximum Day event. Analyzing the Peak Hour reveals, whether or not, the water supply (wells and WTPs), pump stations, and the water stored in tanks, are adequate to meet the peak demands. Reservoir Refill also referred to as Minimum Hour is the lowest demand rate occurring for the day during the Maximum Day event. Analyzing the Reservoir Refill tests the system's capacity to refill tanks during the off-peak demand times (e.g. night), which can be the most critical, especially in systems with high amounts of non-accounted-for water.

3 Existing Facilities

3.1 Supplies and Service Areas

Table 3-1 shows a summary of the existing supplies in the East Central Region and other service areas of the Valenciano project (parts of Las Piedras/Humacao and Caguas) for the year 2005, and for possible scenarios from 2010-2025. Sources of supply for the region are listed by municipality and include WTPs (six existing), wells, transfers from the Metro Area and between municipalities and two superficial systems (to be eliminated by 2010).

Production for the year 2002 (see **Table 3-1**) was ~13 mgd with transfers of ~8 mgd and production for 2005 increased to ~15 mgd with the addition of the San Lorenzo WTP. This value compares with an average demand of ~22 mgd and maximum day demand of ~28 mgd for an availability factor of ~1.1. This is including the transference from Metro Area/Caguas of ~3 mgd through the Gurabo and Navarro pump stations. The availability factor for the region is too small, since 1.1 is only 10% above average, and dependent on a transfer from Metro Area / Caguas with little reliability, particularly during drought conditions. In addition, many of the sources in the region such as the Ceiba Sur WTP and the Juncos wells also pose problems with their operation and reliability. The Valenciano project has the goal of alleviating these water reliability problems, reducing dependence on the Metro Area, as well as providing a significant amount of water for the region's growth and to transfer to Las Piedras.

Production for the year 2010 (see **Table 3-1**) is expected to increase to ~17 mgd and transfers to ~17 mgd, mainly if the increase in the transfer from Metro Area/Caguas goes up to ~13 mgd from the actual ~3 mgd with the new Guaynabo-Caguas-Gurabo-Juncos line. There is also the increase in production at the Gurabo WTP from 2 to 4 mgd, and the increase in the transfer of water from San Lorenzo to Caguas to 2 mgd. The additional transfer from the Metro Area would alleviate the existing shortfalls in Gurabo and Juncos, with an availability factor of 1.4. However, this transfer is unreliable and may be lower than needed since the availability of water in the Metro Area is dependent on the optimization of the system and is not sustainable during drought periods.

With the new Valenciano WTP substituting the existing Ceiba Sur WTP and the transfer from the Metro Area / Caguas to Juncos, production for the years 2015-25 (see **Table 3-1**) will decrease slightly to ~14 mgd, transfers decrease to ~7 mgd and the Valenciano project provides ~15 mgd of in-region additional supply. The Valenciano WTP is expected to produce at its safe yield of ~15 mgd, from which ~6 mgd will be transferred to Las Piedras and ~9 mgd will be available for the East Central Region. Of this ~9 mgd, ~3 mgd will be transferred to San Lorenzo and Jagual areas, leaving ~6 mgd in Juncos to substitute the production of the Ceiba Sur WTP and the transfer from the Metro Area / Caguas. At its maximum production, the Valenciano WTP will have ~23 mgd going into the distribution system (of ~24 mgd total maximum production), allowing it to send water through the Gurabo-Juncos line in reverse into Gurabo and eliminating the transfer from Area Metro / Caguas to Gurabo. A similar but somewhat lower effect would be present with the Valenciano WTP at a production of ~15 mgd and a net loss reduction of 15%, with a transfer to Gurabo of ~3 mgd.

The Juncos WTP (Quebrada Grande) may continue to serve its current service area (up to Amgen commercial area on PR-31) and it is beneficial to maintain its operation to utilize the raw water source and to maintain it as a secondary source for redundancy purposes in the Region. However, if PRASA decides to close the Juncos WTP for operational reasons, there are some additional improvements to be considered for its service area (See Section 3.2.)

Finally, if the Valenciano WTP was not present in 2025 (see **Table 3-1**) and transfers from outside the Region including the Metro Area/ Caguas were eliminated, sources within the East Central Region would produce ~14 mgd, which would fall short of the ~28.5 mgd average demand for a net deficit of ~14.5 mgd in the Valenciano service area. In addition to the impact on the East Central Region, without the Valenciano WTP and its future transfer of ~6 mgd for Las Piedras, the water shortages in this municipality would aggravate as its water source, the Humacao WTP, becomes needed in the Humacao area.

Figure 3-1a shows the existing service areas:

- Caguas,
- Gurabo WTP/Wells,
- Gurabo WTP/Cubuy WTP,
- Juncos WTP/Ceiba Sur WTP,
- San Lorenzo WTP,
- Quebrada Arenas Superficial System,
- Quebrada Honda Superficial System,
- Jagual WTP,
- Espino WTP.

Figure 3-1b shows the proposed service areas, where the proposed service areas are similar to the existing ones, the main difference being that most areas are supplemented by the Valenciano WTP. These areas are:

- Caguas,
- Gurabo WTP/Wells,
- Gurabo WTP/Valenciano WTP,
- Juncos WTP/Valenciano WTP,
- San Lorenzo WTP/Valenciano WTP,
- Jagual WTP/Valenciano WTP,
- Espino WTP/Valenciano WTP.

Figure 3-2a shows the existing supplies for 2005. In Gurabo, sources include transfers from Metro Area/Caguas, the Gurabo WTP, and wells. In Juncos, sources include the Ceiba

Sur and Juncos WTPs and wells. In San Lorenzo, sources include the San Lorenzo, Jagual, and Espino WTPs, and the Quebrada Arenas and Quebrada Honda superficial systems. **Figure 3-2b** shows the proposed supplies for 2025. In Gurabo, sources include transfers from Metro Area/Caguas, the Gurabo WTP, and wells. In Juncos, sources include the Valenciano WTP and Juncos WTP. In San Lorenzo, sources include the San Lorenzo, Jagual, and Espino WTPs.

Figure 3-3 shows the existing transmission and distribution systems overlaid with the Valenciano Reservoir project. This figure shows how the isolated service areas will be linked by the proposed Valenciano project.

3.2 Transmission System

A transmission system has been proposed to operate with the Valenciano WTP, which will replace the existing Ceiba Sur WTP. **Figure 3-4** shows the proposed improvements for the Valenciano Project. **Table 3-2a and 3-2b** give details on the proposed pump stations and tanks, respectively. The figure shows the elements in the final proposed project: reservoir, treatment plant, transmission lines, pumps and tanks; and compares these elements with the original proposed project conceptualized in 2000 by Black & Veatch. The project attempts to use gravity whenever possible as a criterion for improvements. The most important transmission line changes were:

- elimination of the Juncos-Gurabo reach since this pipeline was built as part of the Guaynabo-Caguas-Gurabo-Juncos project,
- elimination of the segment from Valenciano 2 to Valenciano Arriba,
- addition of pipeline to Juncos 1.5 MG Tank and Juncos pueblo,
- addition of pipeline to Las Piedras Collores 2 MG Tank, and
- addition of pipelines to San Lorenzo and Jagual WTPs.

The Valenciano WTP Distribution Tank bottom elevation should be at least 166 m, in order to fill the Juncos New Tank with 157 m top elevation, and to reach the Las Piedras Tank with ~140 m top elevation. This relationship is shown in a conceptual hydraulic profile of **Figure 3-5**. In addition, the transmission lines will connect to the existing lines of the Juncos WTP system and need to meet its operating hydraulic grade line (HGLs) of ~170 m. The minimum elevation needed for the WTP distribution tank was based on that the tank filled at half can fill the Juncos Tank to the top and have an extra 10 psi or 7 m of head to overcome headloss from valves at the inlet to the tank. With the bottom of the tank at 170 m, the HGL reaching the Las Piedras / Ceiba Norte Tank is borderline and the diameter of the pipeline may need to be increased if found too close during the design stage.

Location alternatives for the Valenciano WTP Distribution Tank will be considered during the design process because of the difficulty of selecting a site. The alternatives considered include:

- an elevated tank at the Valenciano WTP
- a ground tank in the nearby area

Water from the Valenciano WTP will be pumped to this tank, where it will flow towards the north. The northern pipeline will supply Juncos and Gurabo, and a pipeline to the east to

Las Piedras and Ceiba Norte. Also, water from this tank will be conveyed to the existing Ceiba Sur 1 MG Tank to supply the pipeline to the southern San Lorenzo and Jagual systems, as well as the Lirios Florida system. All pipelines leaving the Valenciano WTP are transmission lines to other tanks and pump stations, where they connect to other transmission lines or the distribution system. Below is a description of recommendations in each direction.

1) Juncos / Gurabo Reach (Line 7, 9, and 8)

Figure 3-4a shows the Juncos / Gurabo Reach. The transmission pipelines are fed by gravity from the Valenciano WTP with the hydraulic grade line (HGL) falling from ~170 m to ~157 m at the Juncos 1.5 MG Tank. Wards supplied through the Juncos system include Juncos, Mamey, Gurabo Abajo, and Ceiba Norte; through the Gurabo system include Gurabo, Mamey, Jaguar, Rincón and Navarro; and through the Las Piedras system include Collores, Las Piedras, Tejas and Montones.

A transmission pipeline with 36" diameter is proposed from the Valenciano WTP to the center of Juncos (Line 7) through PR-9934 and PR-928. Currently, a 16"pipeline is used to convey water from the Ceiba Sur WTP to Juncos, but this line has an insufficient diameter to carry future flows, which are expected to range between 10 mgd (Average Day, AD) and 13 mgd (Reservoir Refill, RR). These flows would increase to between 15 mgd (AD) and 20 mgd (RR) if Gurabo is supplied, which would be feasible only during the first project phase when lines to the southern areas are not being supplied and periods of emergency.

Line 7 connects into a 30" diameter transmission line to the Juncos 1.5 MG Tank (Line 9) through PR-198 and to a 30" diameter transmission pipeline to Las Piedras and the Juncos WTP system (Line 5) through PR-30. Line 9 is needed since there is no inflow line to the Juncos Tank from the Ceiba Sur / Valenciano WTP site given that the tank is currently supplied from Gurabo through the Juncos PS with Metro Area water. Line 5 is discussed in the following sections. The original proposed project did not include the Juncos Tank, and it was modified to connect to the 30" diameter inflow pipeline to this tank, to substitute a segment of 16" inflow pipeline in the access road to the tank with 30" pipeline, and to add an additional 16" diameter outflow pipeline to the existing 16" line so that water can be sent from the tank into the Gurabo system as well as the Juncos system. This will allow the tank to "break" pressure towards Gurabo and to serve the areas connected in this direction such as the Ciudad Jardín and adjacent industries, if desired, with flows ranging from 4.7 mgd (AD) to 6.9 mgd (RR).

From the Juncos Tank, a 16" distribution line will flow to the town of Juncos and the suction of the proposed relocated El Ensanche Pump Station (Line 8), along the same route as Line 9. Line 8 is needed to provide additional conveyance into Juncos town because the existing 8" lines are insufficient to convey the flow needed, which will range between 3.4 mgd (AD) and 6.4 mgd (RR).

The original proposed project included pipelines with 24" and 30" diameter between Juncos and Gurabo, but this segment was eliminated since the pipeline was built with the Guaynabo-Caguas-Gurabo-Juncos project. This pipeline is connected with the Juncos 1.5 MG and can be used to send water in reverse from Juncos to Gurabo using the additional 16" line proposed outflow line from the Juncos Tank. The connection to the Gurabo Tank must be verified to work in reverse with incoming flow from Juncos. Although sending water to Gurabo will be feasible, particularly if the San Lorenzo reach construction is done at a later date, when the project is fully operational at its safe yield of 15 mgd and without loss reduction, the amount of water produced at Valenciano WTP will not be sufficient to supply Gurabo and the transfer from the Metro Area/Caguas will need to continue. With either an increase in production or a loss reduction effect, the transfer of Valenciano water to Gurabo is then feasible.

2) Ceiba Norte / Las Piedras Reach (Lines 5 and 6)

Figure 3-4b shows the Ceiba Norte / Las Piedras Reach. Wards supplied include Ceiba Norte in Juncos and Collores, Las Piedras, Montones and Tejas in Las Piedras.

Transmission pipelines with 30" and 24" diameters are proposed from the main transmission line to Juncos/Gurabo (Line 7) to Ceiba Norte and Las Piedras. The transmission pipeline (Line 5) is fed by gravity from the main transmission pipeline from the Valenciano WTP Distribution Tank to the Ceiba Norte/ Las Piedras New Tank (T5-2) at ~140 m through PR-30. The 30" pipeline (Line 5A) will feed both the 24" pipeline (Line 5B) as well as provide a reliability connection to the Juncos WTP system existing 8" lines on PR-31. Line 5 is needed since there is no pipeline currently installed on PR-30 and no transference of water from Juncos to Las Piedras; flows are expected to be 6-7 mgd

From the Ceiba Norte/ Las Piedras New Tank , two pump stations PS6-1A and PS6-1B located at the same site will convey water through Line 6 to the Ceiba Norte Tank (~180 m) and the Las Piedras Collores 2 MG Tank (~191.5 m). These lines will carry ~1 mgd and ~6 mgd, respectively, although the pump stations can also operate at half of their design flow. The segment to the Ceiba Norte tank is needed since the flow pumped is increased from 0.3 mgd. The segment to Collores Tank is needed since there is no transference from Juncos to Las Piedras in the present.

The original proposed project proposed the transfer of water to the Las Piedras Urban Tanks, and the pipeline was extended to reach the Collores 2 MG Tank. The original project also included the Ceiba Norte Tank with a capacity of 1 MG, which was eliminated since there is an existing 0.44 MG tank with significant capacity to serve the area and it was difficult to find a site at the same elevation to expand the storage capacity.

The connection to the 8" lines from the Juncos WTP system can be accomplished since the lines operate at an HGL of 170 m. This connection permits the redundancy of the system since Juncos WTP has adequate capacity to feed its service area up to this connection, although with the growth of the Amgen industrial area it may be necessary to supplement from the Valenciano system.

3) Valenciano Reach (Lines 12, 4 and 3)

Figure 3-4c shows the Valenciano Reach. Wards supplied in Juncos include Ceiba Sur, Valenciano Abajo, Valenciano Arriba, Lirios, Quebrada, and Florida; and all of San Lorenzo.

Transmission pipelines with 20" and 16" diameters are proposed from the Valenciano WTP to the Valenciano 2 Tank. The 20" pipelines (Lines 12 and Line 4A) will convey water from pump station PS4-1, which will pump from the existing Ceiba Sur 1 MG tank at ~130 m top elevation to the 16" pipeline (Line 4B) and a connection to the Lirios Florida Reach (Line 10) on PR-919. The 16" pipeline will send water through PR-919 to the existing Valenciano 1 Tank system through a sustaining/reducing valve at ~149 m and the proposed Valenciano 2 Tank and the San Lorenzo/ Jagual reach at ~216 m top elevation. Lines 12, 4 and 3 will be installed along a route where there are only very small pipelines 4-6"in diameter, since there is currently no transfer of water from Juncos to San Lorenzo. Flows are expected to range between 4.5 mgd (AD) and 5.7 mgd (RR).

The original proposed project had lower flows and smaller diameters of pipeline between the Valenciano WTP and the Valenciano 2 Tank. Proposed flow for the Valenciano 1 PS (PS 4-1) is 2960 gpm and this may be increased to 3500 gpm if it is desired to eliminate the Jagual WTP. The original proposed project also had a segment to supply the Valenciano Arriba Tank from the Valenciano 2 Tank, which was eliminated since this is a smaller distribution system project and the Valenciano Arriba area is currently supplied through another route. There are three distribution system connections in the Valenciano reach, all with sustaining / reducing valves to protect the transmission system: from Line 4 to the inflow line to the existing Valenciano 1 Tank, to an existing 4" pipeline on intersection with PR-183, and from the Valenciano 2 New Tank to the inflow line to the existing Valenciano 2 Tank.

4) Lirios Florida Reach (Line 10)

Figure 3-4d shows the Lirios Florida Reach. Wards supplied include Lirios, Quebrada and Florida in Juncos.

Transmission pipelines with 16" and 12"diameters are proposed to supply the Lirios Florida area. The 16" line will receive water from the PS10-1, which will connect to the transmission line from the Valenciano WTP (Line 4). The 16" line will convey water to a new tank T10-1 located at the existing Mariceci Tank site at ~246 m. From this tank water will be pumped through a new pump station PS10-2 and a new 12" line to a new tank T10-2 at the existing Lirios Tank site at ~268 m. Line 10 is needed in order to convey water to the Lirios Florida and Peyo Pomales 2 pressure zones, which are currently supplied at the end of the Lirios and Ensanche PS systems and suffer water shortages. Flow needed ranges between 0.9 mgd (AD) and 1.1 mgd (RR).

There will be three distribution system connections from the 12" line. The original proposed project had lower flows for the pump stations and larger volumes for the tanks. The current project proposes a flow of 740 gpm for the pump stations, and capacities of 0.25 MG and 0.40 MG for the tanks. There are other PRASA projects in areas close to Lirios Florida: the Quebrada project serves a lower elevation area to the south, and the Ensanche PS project will serve the Lirios Cala development and the Peyo Pomales 1 area and up to the Mariceci tank.

5) San Lorenzo Reach (Line 2)

Figure 3-4e shows the San Lorenzo Reach, which will supplement all wards in San Lorenzo.

A transmission pipeline (Line 2) is proposed with 16" diameter from Valenciano 2 to the San Lorenzo WTP through PR-183. This pipeline will be fed from the transmission lines to the Valenciano 2 Tank (Line 4) and will convey water into a new 2 MG tank at the San Lorenzo WTP at ~129 m top elevation. This pipeline is needed since there is currently no transfer of water from Juncos to the San Lorenzo and Jagual systems. Flows are expected to be ~3 mgd.

The original proposed project had lower flows and smaller diameter pipeline for this reach, which is currently proposed for a ~2400 gpm flow, which can be increased to ~2900 gpm if it is desired to eliminate the Jagual WTP. The San Lorenzo WTP Tank would receive water from both the Valenciano transmission system and the existing San Lorenzo WTP by gravity. Water from the tank would be conveyed through the existing 20" line into the San Lorenzo service area and to the Cerro Gordo PS at the WTP.

6) Jagual Reach (Line 1)

Figure 3-4f shows the Jagual Reach, which will supply the Jagual, Quebrada Honda, Espino and Cayaguas wards in San Lorenzo. A transmission pipeline with 12" diameter (Line 1) is proposed from the transmission line to San Lorenzo (Line 4) to the Jagual WTP. The 12" line will be fed from the transmission line at an HGL close to ~216 m and will convey water to the new San Lorenzo Jagual Tank (T1-2) and PS 1-1 at ~120 m. The pump station will send water through a 12" pipeline to a new Jagual Tank (T1-1) at ~180 m, which will supply the new Jagual PS (PS1-2) at the Jagual WTP. This pump station can receive water from both Valenciano and the Jagual WTP, which currently produces ~300 gpm, and will replace the existing pump station at the WTP. Line 1 is needed since there is currently no transfer of water between the San Lorenzo and Jagual systems. Flows are expected to be ~1.4 mgd.

The original proposed project had lower flows for the pump station capacities, which are currently ~1000 gpm for and may be increased to ~1540 gpm if desired to eliminate the Jagual WTP. The possibility of eliminating the San Lorenzo / Jagual Tank and PS exists since the HGL from the Valenciano 2 Tank ~216 m may be sufficient to reach the Jagual New Tank at ~180 m, but because it is very close due to losses during the ~7 km route, this should be evaluated during the design.

7) Juncos WTP (Quebrada Grande) Closing

Figure 3-4 shows the 16" lines and pump station needed if PRASA decides to cease operation at the Juncos WTP (Quebrada Grande). This plant currently serves the area around PR-31 including the Caimito, Gurabo Arriba and Gurabo Abajo wards in Juncos and has a small transfer of water to Las Piedras. This plant may continue to be operated along with the Valenciano WTP by limiting its service area up to the Amgen commercial area in PR-31. It is beneficial to maintain its operation to utilize the raw water source and to maintain a secondary source for redundancy purposes in the region.

However, if the plant needs to be eliminated for operational reasons, a transmission pipeline with 16" diameter would be needed from the line to Ceiba Norte / Las Piedras (Line 5) to the existing 16" line that is served from the Juncos WTP. The 16" line will be fed from the transmission line at an HGL close to ~170 m. Higher elevation areas around the plant will probably need a pump station, since otherwise low pressures would result. Flows are expected to be ~2 mgd. It is also recommended to utilize the raw water from the Juncos WTP at the Valenciano Reservoir by building a 16" pipeline between the two.

3.3 Pump Stations and Tanks

Data on the distribution system was reviewed, including GIS files from the inventory for the PRASA Master Plan and interviews with PRASA operations staff during 2006: Pedro J. Soto, and Juan Calderón for Caguas/Gurabo/San Lorenzo, and José Nieves for Juncos/Las Piedras. The data compiled was entered into the hydraulic model files and is summarized on **Table 3-3a** for pump stations **Table 3-3b** for Tanks, and is shown along with proposed improvements on **Figure 3-6.**

Data on pump stations includes existing capacity and total dynamic head, as well as upgrade capacity and upgrade dynamic head. Data on tanks includes elevation, existing capacity, and upgrade capacity. Upgrades were the result of the hydraulic model analysis and mass balance analysis, which is a simplified way to look at the hydraulic model, which is discussed in the following section.

The purpose of storage tanks is twofold: to supplement the water conveyed by pipelines and pump stations during peak hour conditions and to provide water for emergency and fire fighting purposes. The storage required for each pressure zone roughly corresponds to a volume of water equal to one day of average demand, since the difference between peak hour and maximum day demands is about 0.75 x average demands. This criterion is consistent with PRASA's Rules and Regulations for the Design Standards in urban systems, which require a storage tank volume equal to the average daily consumption (400 gallons per family). An alternative to in-zone storage is to size pump stations and pipelines between pressure zones to provide for peak hour water transfers.

3.4 Pressure Zones and Mass Balance

The topography of the East Central Area varies widely, with elevations ranging from sea level along the coast to about 350 m in the highest points in Gurabo and Juncos and 400 m in the highest areas of San Lorenzo. Water system pressures depend on water tanks placed at the correct height above the area served; typically 20 meters to 70 meters (30 psi to 100 psi) is required. Pressure zones are areas of similar ground elevations that are supplied with water at a target hydraulic grade elevation, i.e. water tanks, water treatment plants, wells, and/or pump stations providing similar pressures. The pressure zone boundaries generally follow the ground contour such that all points could be supplied with a minimum pressure of 30 psi. For example, the upper boundary of the 120 meter zone would be the ground contour 100 meters. Usually pressure zones are named according to the reservoir overflow elevations that serve the area.

Existing pressure zones were modified in the previous and revised models based on elevations of existing and proposed tanks and the ground surface they are serving and their interaction with other facilities (pumps, valves and pipelines). Unless zones have pump stations or can be gravity-fed from adjoining areas, pipes crossing boundaries are assumed to be closed.

Table 3-4 shows the mass balance for the pressure zones in the system. The mass balance analysis consists of listing pressure zones according to their supply chain and their demands for the year 2025, which is our design condition. These demands are then added cumulatively for each of the scenarios considered, maximum day, average day, reservoir refill, and peak hour. These cumulative demands are then compared to existing pump flows to see if these are adequate, pipeline sizes are analyzed to determine if they are sufficiently large, and existing storage can also be changed to improve balance in the scenarios were tanks are active. The mass balance analysis gives a preliminary result that is verified through runs in the hydraulic model. The model gives further information, such as pressures in every node and pipeline losses, which can be looked at to ensure that the system is under acceptable operating conditions.

3.5 Computer Hydraulic Model

A hydraulic model was developed using H2OMap Version 4.5. This program integrates ArcView GIS and EPANET. H2OMap provides the capacity to analyze the pipeline system along with a GIS platform that permits to visualize the system and to import and export layers of information to ArcView and ArcGIS. The program uses a database and provides the capacity to easily input data and extract results, including copying to Microsoft Excel. The program uses as a computational engine the program EPANET, which was developed by the U.S. Environmental Protection Agency. This program determines a distribution of flows in a pipeline system (including flows at tanks) and calculates the pressures at the nodes (including points of intersection and water demand); and determines losses in pipelines with the Hazen-Williams or Darcy-Weisbach equations. The flows of the pump stations and their head are also provided by the computations of the hydraulic model.

Minimum pipeline sizes to be included in the hydraulic model depend on the size of the municipality. In the East Central Model all pipelines above 2" were included, according to the inventory of the PRASA Master Plan, and were also verified with operations staff from PRASA during the hydraulic modeling activities through interviews conducted in 2006.

To determine pipeline losses in the hydraulic model the Hazen-Williams equation was used and generally C=100, since most pipeline ages and materials are unknown.

The diameters for proposed pipelines were judged to be sufficient by observing the node pressures and pipeline velocities and headlosses. The following values were used to determine when a hydraulic problem may be occurring.

Criteria	Value
Minimum Pressure, psi	30
Maximum Velocity, ft/s	5
Maximum Headloss, m/1,000 m	4

These values were used as a guide and are not absolute. Pipelines with smaller diameters and shorter pipelines can tolerate larger velocities and higher losses than larger transmission lines. These values are consistent with PRASA design standards, which require a minimum pressure of 30 psi (section 2.07.01) and maximum velocities of 4 and 8 ft/s, respectively, for pipelines flowing by gravity and pressure (section 2.07.02). Even though PRASA doesn't have standards for maximum pressure, pressures which are too high can cause breaks and leaks, so that maximum pressures are normally limited to 100-125 psi.

3.6 Conclusions / Recommendations

The East Central Region has a high need for water which is reflected in the lack of reliability in the current system and the large deficit that would be present if transfers from the Metro Area are eliminated. In the short-term the Guaynabo-Caguas-Gurabo-Juncos pipeline will supplement the region by further increasing the transfers from the Metro Area, but these transfers are not reliable since they depend on the optimization of the Metro Area system and are not sustainable during drought periods. The Valenciano project will enable the East Central Region to meet its water needs by minimizing the transfers from the Metro Area and giving the system the reliability that it has lacked for many years.

The transmission system will link the systems of Juncos, Gurabo, San Lorenzo, Las Piedras, Humacao and Caguas and provide adequate storage and pumping capacities to transmit water between Valenciano and these municipalities. This transmission system was originally proposed by Black & Veatch in 2000 and was validated through a hydraulic model analysis in 2006. The facilities inventory was revised with PRASA staff and changes in the system since 2000 were incorporated to update the transmission system according to conditions currently in place and expected. Demands were updated according to most recent estimates and the capacities of pipelines, pump stations and tanks were recalculated and verified using the hydraulic model. This model is a tool that has been developed in the East Central Region to validate the concept of the Valenciano project and that will serve to support upcoming phases of the project, as it is designed, built and placed into operation.