CHAPTER 6 – WATER SYSTEM HYDRAULIC MODELING

6.1 Introduction – Hydraulic Network Analysis

Hydraulic network analysis is the process of using a water distribution system computer model to analyze performance capabilities and to define the requirements necessary to meet system design standards for pressure and flow. Applications of hydraulic network analysis generally fall into three categories: planning, design, and operations.

6.1.1 Planning

A primary planning application of network-analysis is the development of long-range capital-improvement plans (CIP), which include scheduling, staging, sizing, and the preliminary routing and locating of future facilities. Other applications include the development of a main-rehabilitation plan and system-improvement plan. Rehabilitation plans call for cleaning and/or cement-mortar lining of mains. System improvement plans call for installing new mains to keep up with growth or to upgrade the distribution system to utility standards.

6.1.2 Design

Network-analysis design applications include the sizing of various types of facilities. Pipelines, pump stations, pressure-regulating valves, tanks, and reservoirs can be sized using pressure and flow calculations resulting from hydraulic modeling. In addition, system-performance capabilities can be analyzed to determine fire-flow capabilities and the improvements necessary to meet fire-demand requirements.

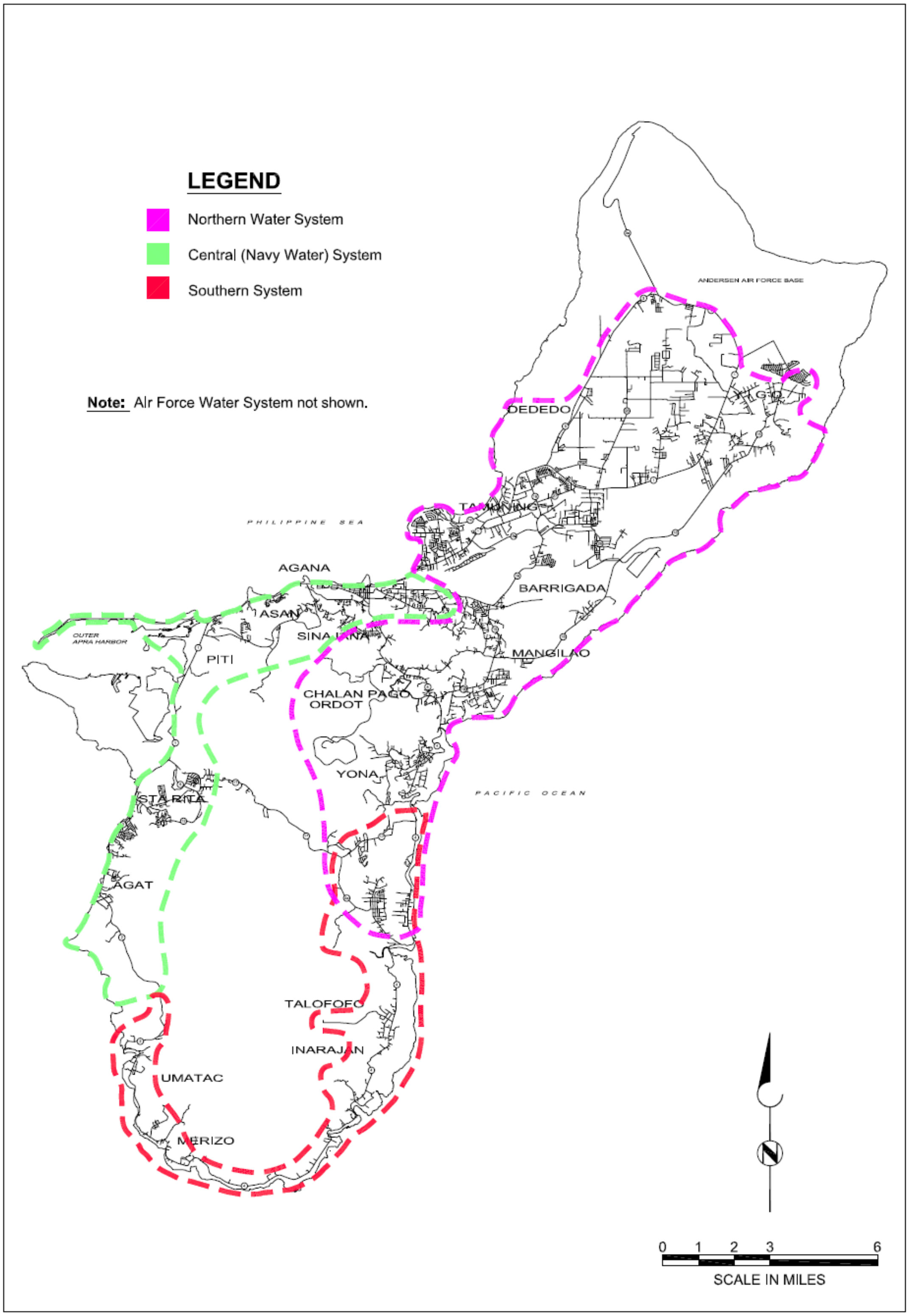
6.1.3 Operations

The development of operating strategies, operator training and system troubleshooting are applications supported by modeling system operations. Operating strategies may be based on emergency conditions, energy-management restrictions, water availability, or other conditions of particular concern. For example, contingency plans for an outage of a key facility, such as a pump station, can be developed. Hydraulic modeling can also be used to develop operational strategies based on energy management guidelines and restrictions for more efficient system operations. Modeling and network analysis are also good ways of training personnel involved in the operation of distribution systems. Distribution-system operators can experiment with the model to determine how the system will perform under specified operating conditions. System troubleshooting, based on modeling and network analysis, can be used to determine the cause of various problems, such as low pressure and unexplained events.

6.2 Water Model Development Background

GWA provides potable water to over 90% of Guam's population except for the Navy and Air Force military facilities. Based on the GEPA's definitions, the GWA water distribution network consists of three systems: the South System, the North System, and the Central System as reflected in Figure 6-1. The water reservoirs and water booster pump stations that make up the water system are shown in Figures 6-2a and 6-2b respectively. In order to provide customers with reasonable water pressure, multiple pressure zones are needed within each of these systems.

Figure 6-1 – GWA Water Systems



Note: Air Force Water System not shown.

"This is a draft report and is not intended to be a final representation of the work done or recommendations made by Brown and Caldwell. It should not relied upon; consult the final report."

Figure 6-2a – GWA Water Reservoirs

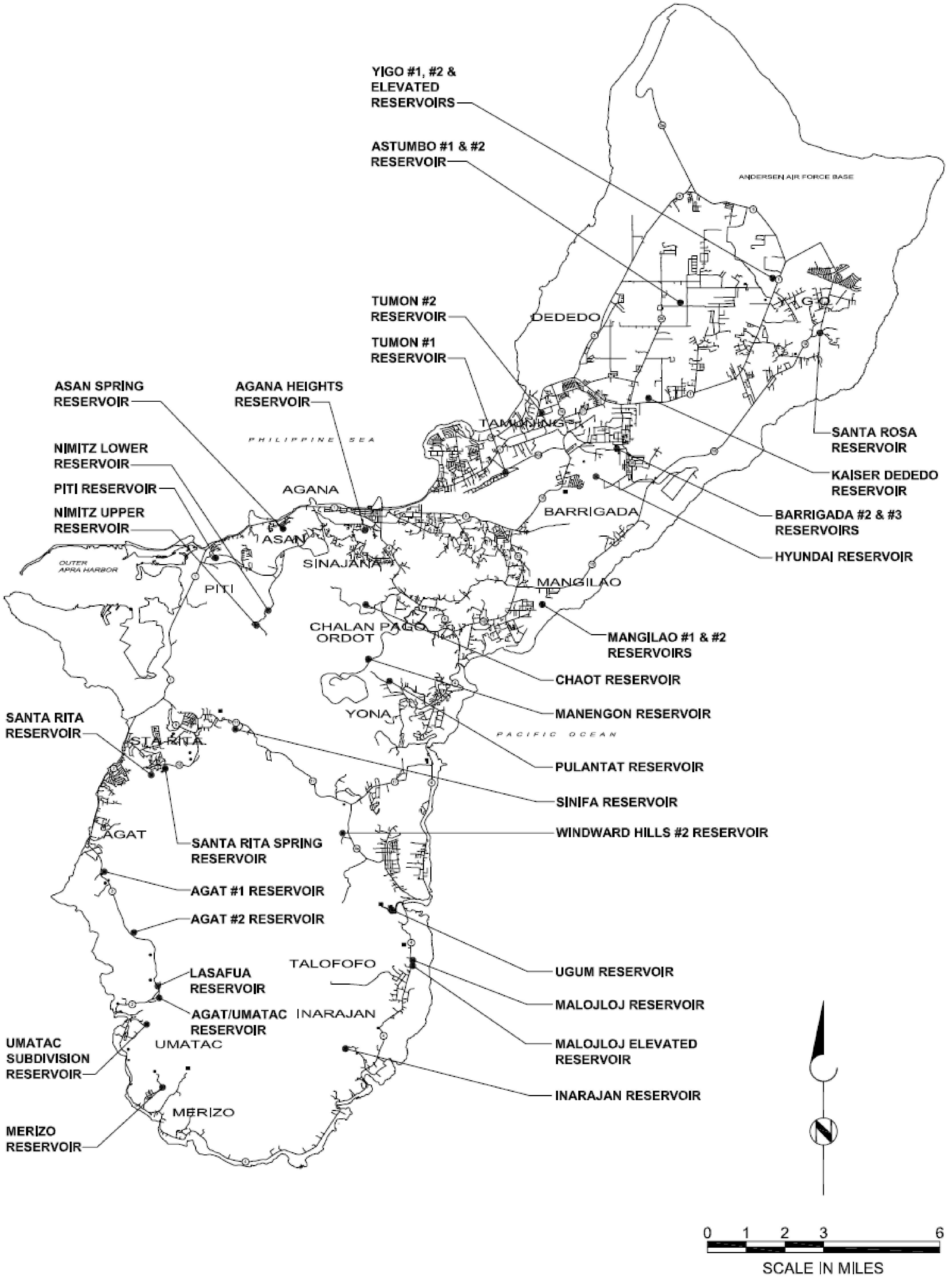
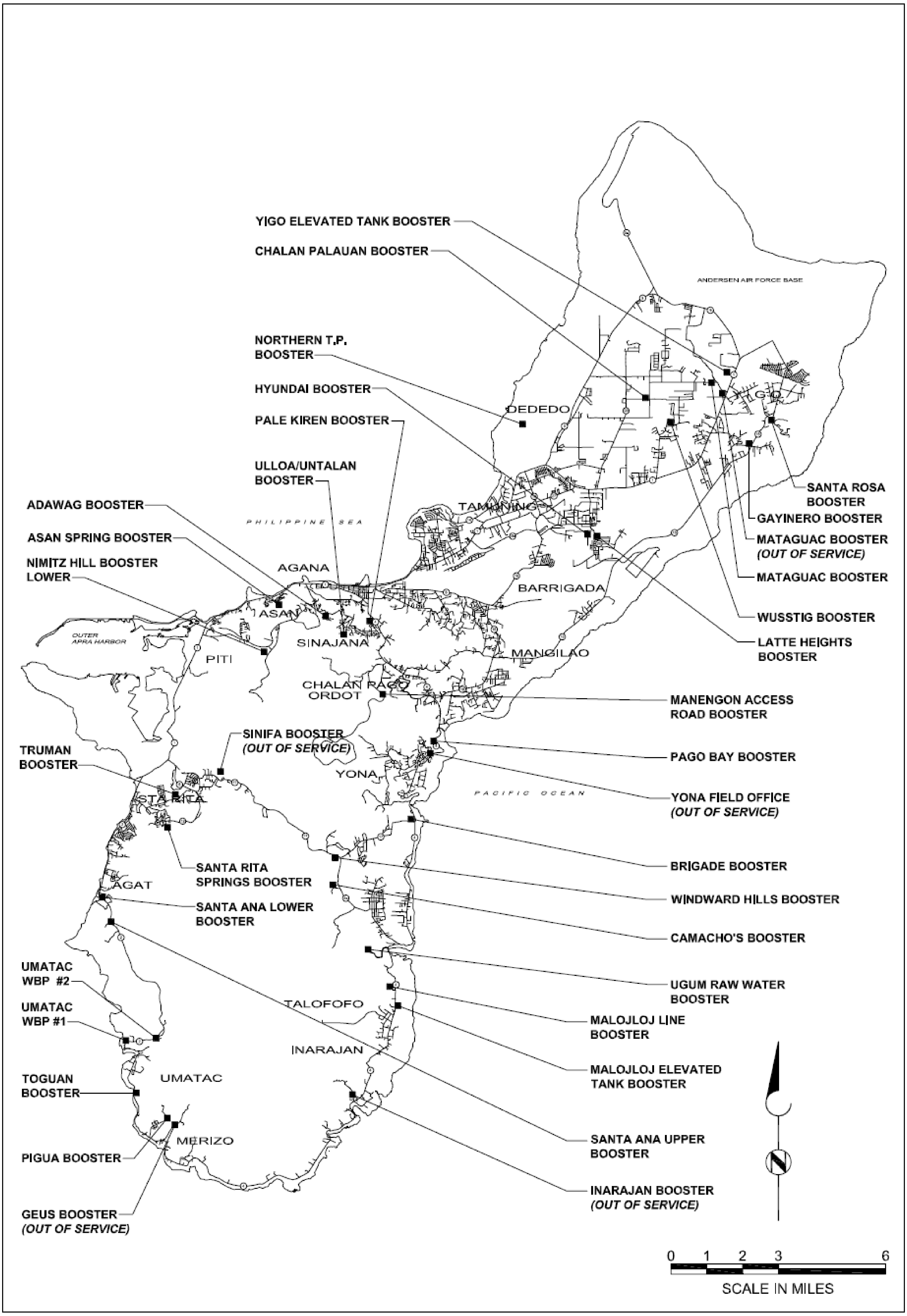


Figure 6-2b – GWA Water Booster Pumps



The hydraulic modeling program used for this project is H_2OMAP Water Version 6.0, a product of MWH Soft, Inc. H_2OMAP was developed specifically to determine the hydraulic capabilities of pressure pipe systems. Selection of the software was based on review of hydraulic model features for several software packages and discussions with GWA staff.

This hydraulic model includes all distribution system facilities and pipelines (6 inches in diameter and greater, as well as smaller pipelines where necessary to connect facilities). The model was designed to simulate the conditions and operation of the water distribution system over a 24-hour period. The hydraulic model provides GWA with a flexible tool for conducting network analysis tasks for the overall water distribution system. Multiple scenarios were created within H_2OMAP for running simulations of the distribution system as a whole, or for running simulations of only selected portions of the distribution system.

Three versions of the Hydraulic Model were prepared for GWA:

- **2005 Existing Condition Model** – This was the model created based on all the available information as of the year 2005. It can be used for detail calibration purposes when additional field data becomes available in the future.
- **Phase 1 CIP Planning Model** – This is a modified version of the Existing Condition Model. It was used to investigate different Phase 1 CIP alternatives to resolve the various system deficiencies identified by the Existing Condition Model simulations under the 2005 Maximum Day Demand Scenarios. In the future, it will be used by GWA staff as a planning tool for evaluating existing and proposed water distribution facilities. Control sets have been developed for running the model under typical maximum day operational controls. Three water demand sets are included in this model: Maximum Day, Average Day, and Minimum Day.
- **Phase 2 CIP Planning Model** – This is also a modified version of the Existing Condition Model. It was used to investigate different Phase 2 CIP alternatives to resolve the various system deficiencies identified by the Existing Condition Model simulations under the 2025 Maximum Day Demand Scenarios. In the future, it will be used by GWA staff as a planning tool for evaluation of existing and proposed water distribution facilities. Control sets have been developed for running the model under typical maximum day operational controls. Three water demand sets are included in this model; Maximum Day, Average Day, and Minimum Day.

During the course of the modeling task, a number of methodologies related to general model development were established and documented. These include:

- Division of distribution system into submodels
- Creation of model components: pipes, nodes, tanks, pumps and valves
- Assignment of elevations to model components
- Identification of large users
- Allocation of demands and diurnal curves
- Submodel merging
- Modification of the model.

In creating the 2005 Existing Condition Model, the GWA water system was divided into 3 submodels. The purpose of creating submodel divisions was threefold:

- To expedite the model creation process by allowing simultaneous progress on all 3 submodels.
- To facilitate validation and future calibration of the model by focusing on manageable portions of the system rather than the system as a whole.
- To provide flexibility in using the model by creating submodel areas that can be run individually via pre-defined scenario functions.

In dividing the distribution system into 3 submodels and multiple pressure zones, efforts were made to select hydraulically isolated areas as the definition of a pressure zone. However, some of the pressure zone areas could not be completely isolated. In addition, flow information was not available for all facilities located at the submodel boundaries.

The North and South systems are connected on the east side of the island by a 12 inch transmission main. A valve on this pipeline is normally closed, which causes the two systems to operate independently. The normally closed valve is located just south of the Route 4 and Route 17 junction. The North and Central systems boundary are not as clearly defined as the North and South Systems. For the purpose of the hydraulic model, the separation point between the North and Central systems is defined as the Brigade Booster Pump Station. All facilities downstream of the Brigade Booster are considered the Central system. The Central and South systems are not connected on the west side of the island between Agat and Umatac. The Central and North Systems are not connected on the west side of the island between Piti and Santa Rita. A more complete and detailed description of the GWA water distribution system can be found in Chapter 1, Volume 2 of this report.

The three submodels were individually created and validated, and then merged to form the full model. The merged model was examined to ensure that hydraulic balance status was maintained. The merged model formed the first complete version of the model, titled the 2005 Existing Condition Model. Following completion of this first version, pipe and facility modification were added to create a second and third version of the model titled Phase 1 CIP Planning Model and Phase 2 CIP Planning Model respectively.

6.3 Model Network Development

The GWA hydraulic model consists of a network, water supply, and water demands. The model network includes pipes, nodes, pressure reducing and pressure sustaining valves (PRVs and PSVs), check valves, closed valves, tanks, reservoirs, and booster pump stations (BPSs). The water supply sources available to GWA include springs, wells, the Ugum surface water treatment plant, and Navy and Air Force military supplies. Water demands are based on population projections from the 2000 census data and water production data. A mass balance of water supply and demand was performed to calculate the water demand per capita.

Data from a number of different sources were necessary to develop the distribution system hydraulic model. Primary data needs for the model development are the following:

- Water system infrastructure geometry
- Water demand quantity and pattern

- Ground elevation
- System operating procedures and controls.

The water model requires geo-referenced data for all pipelines in the system as well as ancillary facilities including booster pump stations, pressure reducing and pressure sustaining valves, and reservoirs. The development of these data is described below.

6.3.1 Pipes

The model network was built from scratch as GWA did not have a GIS based inventory of its water system pipe network. A geodatabase, using the ESRI ArcInfo software, was constructed by digitizing available water system construction as-built drawings. A detail description of the GWA geodatabase is provided in Volume 1, Chapter 9 – GIS Program of this report. The GWA/EPA map and the 1968 USGS water system maps (maps on which the water system was kept current by hand entries through about 1998) were also used as a resource to supplement the geodatabase created from the as-built drawings.

Pipes 6-inch in diameter and greater were drawn electronically, as well as smaller pipes that are part of water service facilities and those that are essential to the hydraulic circulation of the larger pipes. The electronic file contains pipes that were drawn along the correct street, but do not necessarily follow the actual alignment of the pipe on the street, since the alignment details are beyond the scope of this GWA Hydraulic Model.

In the north/central area about 28 percent of the existing pipe was not included in the draft GIS coverage during the initial phase of the model creation and since a complete network is needed in order for the model to function properly, the missing pipes were digitized from the USGS or GWA/EPA map. In the south area about 6 percent of the pipe was not in the draft GIS coverage and was digitized from the USGS or GWA/EPA map. Discrepancies were resolved to the extent possible based on available information and most of the missing information was obtained through interviews with GWA staff and field investigations. However, it should be noted that ongoing QA/QC of the geodatabase is a dynamic activity that requires GWA's staff focus to maintain the integrity of the database and model.

The model contains two databases relating to pipes: Pipe Information and Pipe Modeling Data. The fields of information used to model each pipe are listed below for each of the two databases.

6.3.1.1 Pipe Information

- ID - This is a character field that holds the unique identification number for each pipe in the model.
- DESCRIPT - This is a character field that contains the names of all pipes associated with a water service facility, trunk line, major connections, or the default value of "New Pipe" for all other pipes.
- YR_INST - This is a date field that identifies, when available, the year in which the pipe was installed.

- ZONE - This is a character field that lists the pressure zone the pipe is part of (generally, the maximum hydraulic grade).
- MATERIAL - This is a character field that identifies the pipe material.
- LINING, YR_RETIRE, COST_ID, PHASE - These are fields that are standard in the H_2OMAP software but are not currently used for this model.

6.3.1.2 Pipe Modeling Data

- ID - This is a character field that holds the unique identification number for each pipe in the model.
- LENGTH - This is a number field that is automatically calculated by the model when it was created or last modified, and represents the length of the pipe element used in the model, in feet. The length can be modified in the model, if desired.
- DIAMETER - This is a number field that identifies the inside diameter of the pipe, in inches.
- ROUGHNESS - This is a number field representing the Hazen-Williams roughness coefficient, C-factor, of the pipe. C-factors were entered for each pipe based on the planning criteria, as listed in Volume 2, Chapter 8 – Water Distribution Systems, Table 8-2.
- MINORLOSS - This is a number field containing the minor loss coefficient, K value for calculating minor headloss for pipes. All pipes have been assigned the default value of "0."
- TOTALIZER - A Boolean field and optional function in H_2OMAP that can be used to calculate the total flow through a pipe. This function is not used on the pipes in the model, hence all pipes have a value of "N" for this field.
- CHK_VALVE - A Boolean field where a "Y" indicates the presence of a check valve on the pipe and a "N" indicates the absence of a check valve. Where a check valve is present, flow is restricted to one direction only.

The initial status of a pipe refers to the status of a pipe element at the beginning of an extended period simulation, or model run. By default, most pipes have the initial status of "none," which allows water to travel freely through the pipe. Some pipes may have the initial status of "closed" with no additional controls if the pipes have been modeled as closed pipe throughout the duration of a model run. Some pipe may have the initial status of "closed" but additional controls have been entered for the pipe such that the pipe opens during a model run.

6.3.2 Junctions

Junctions are required at the ends of model pipes to accept supply and to provide for demands. To create Junctions once the pipe networks were assembled and in the model, the coordinates of the upstream and downstream ends of the pipes were calculated and Junctions were created in H_2OMAP. Junctions were also added to connect and/or break up segments of a pipeline at the following locations where:

- Two or more pipelines intersect
- Pipeline material changes
- Pipeline diameter changes
- Change in date of installation
- Pipe connects with a water service facility
- Pipe ends

The model contains two databases relating to junctions: Junction Information and Junction Demand Data. The fields of information used to model each junction are listed below for each of the two databases.

6.3.2.1 Junction Information Database

- ID - This is a character field that holds the unique identification number for each junction in the model.
- DESCRIPT - This is a character field that lists the facility name for all junctions associated with a water service facility and lists the default value of “New Junction” for all pipeline junctions.
- ZONE -This is a character field that lists the pressure zone in which the junction resides.
- PHASE - This is a number field that holds the unique Phase identifier for each junction in the model.
- ELEVATION - This is a number field that holds the elevation in feet, assigned to that junction.
- YR_INST, YR_RETIRE -These are three number fields that are standard in the H_2OMAP software but are not currently used for this model.

6.3.2.2 Junction Demand Data

- ID - This is a character field that holds the unique identification number for each junction in the model.
- DEMAND1 - This is a number field that contains the demand value assigned to the demand node. Units are gpm. (Demand4 through Demand10 fields are standard in the H_2OMAP software but were not used for this model).
- PATTERN1 - This is a character field that identifies the name of the diurnal curve used to modify the demand for the junction to simulate hourly changes in demand over a 24-hour period. (Pattern4 through Pattern10 fields are standard in the H_2OMAP software but were not used for this model).

- DEMAND2 - This is a number field that contains the population value (information only) assigned to the demand node based on the Development Polygon. Units are number of people.
- PATTERN2 - Zero demand pattern used to prevent the population value affecting the junction demand.
- DEMAND3 - This is a number field that contains the demand value assigned to the Large Water Users. Units are gpm.
- PATTERN3 - This is a character field that identifies the name of the diurnal curve used to modify the demand for the junction to simulate hourly changes in demand over a 24-hour period.

6.3.3 Valves

Valves are created in H_2OMAP to simulate pressure regulating valves, flow control valves, and pressure sustaining valves. The model contains two databases relating to valves; Valve Information and Valve Modeling Data. The fields of information used to model each valve are listed below for each of the two databases.

6.3.3.1 Valve Information

- ID - This is a character field that contains the unique identification number for each valve element in the model.
- DESCRIPT - This is a character field that identifies the facility name.
- YR_INST - This is a date field that lists the year in which the valve was installed at the facility, if the data was readily available.
- ZONE - This is a character field that lists the upstream/downstream pressure zones for the valve element.
- PHASE - This is a number field that holds the unique Phase identifier for each element in the model.
- YR_RETIRE, PID, UCL, LCL, COST_ID - These are fields that are standard in the H_2OMAP software but are not currently used for this model.

6.3.3.2 Valve Modeling Data

- ID - This is a character field that contains the unique identification number for each valve element in the model.
- TYPE - This is a character field, internally generated by H_2OMAP, which identifies the type of valve assigned to the valve element. Type consists of 0=Pressure Reducing Valve, 1=Pressure Sustaining Valve, 2=Pressure Breaker Valve (not used in this model), 3=Flow Control Valve, 4=Throttle Control Valve (not used in this model), 5=User Defined Valve (not used in this model), 6=Float Valve (not used in this model).
- DIAMETER - This is a number field that contains the valve diameter, in inches.

- SETTING - This is a number field whose value and units depend on the type of valve modeled. For type 0 pressure reducing valves and type 1 pressure sustaining valves, this field contains the pressure setting in psi. For type 3 flow control valves, this field contains the flow setting of the valve in gpm. For type 4 throttle control valves without assigned percent-open versus K value curves, this field contains the minor loss coefficient K value of the valve. For type 4 throttle control valves with assigned percent-open versus K value curves, this field contains the percent open of the valve. This field does not apply to type 5 user defined valves.
- MINORLOSS - This is a number field containing the K value for hydraulic calculation of minor headloss associated with the valve.
- CURVE - This is a character field that contains the curve ID number for type 4 throttle control valves and type 5 user defined valves.
- PID, UCL, LCL - These are fields that are standard in the H_2OMAP software but are not currently used for this model.

The initial status of a valve refers to the status of a valve element at the beginning of an extended period simulation, or model run. Valves that are intended to be open during the model run have an initial status of “none” and valves that are intended to be closed during the model run have an initial status of “closed” without any additional controls. Valves that are set to an initial status of “open” without any additional controls are fully open, with the valve responding merely as a pipe with a minor loss coefficient.

6.3.4 Pumps

Pumps were created in H_2OMAP to simulate pumps within pumping stations and well pumps. The model contains two databases relating to pumps; Pump Information and Pump Modeling Data. The fields of information used to model each pump are listed below for each of the two databases.

6.3.4.1 Pump Information

- ID - This is a character field that holds the unique identification number for each pump element in the model.
- DESCRIPT - This is a character field that identifies the pumping station or well name and pump number for the pump element.
- YR_INST - This is a date field that lists the year in which the pump was installed at the facility, if the data was readily available.
- ZONE - This is a character field that lists the suction/discharge pressure zones for the pump element.
- PHASE - This is a number field that holds the unique Phase identifier for each element in the model.
- YR_RETIRED, RATED_PWR, COST_ID - These are fields that are standard in the H_2OMAP software but are not currently used for this model.

6.3.4.2 Pump Modeling Data

- ID - This is a character field that holds the unique identification number for each pump element in the model.
- TYPE - This is a character field, internally generated by H_2OMAP, to identify the type of pump curve assigned to the pump element. Type consist of 0=Constant Power Input, 1=Design Point Curve, 2=Exponential Three Point Curve, 3=Extended Curve and 4=Multiple Point Curve. Pumps in this model are assigned type 0 for all well pumps for which no data is available, type 4 for all pumps for which pump curves are available, and type 1 for all pumps for which only the design point is available.
- DIAMETER - This is a number field containing the diameter of the pump's discharge pipe in inches.
- HP - This is a number field that holds the value of horsepower of the pump for type 0 pumps.
- DSGN_HEAD - This is a number field that holds the value of design head for type 1 pumps in this model. Units are in feet.
- DSGN_FLOW - This is a number field that holds the value of the design flow for type 1 pumps in this model. Units are gpm.
- CURVE: This is a character field that contains the ID number of the pump's head/flow curve assigned to type 4 pumps in this model.
- SHUT_HEAD, HIGH_HEAD, HIGH_FLOW, MAX_FLOW, NPSH_CURVE - These are fields that are standard in the H_2OMAP software but are not currently used for this model.

Pump controls are entered in the model to change the operational status of a pump (e.g. turn pumps on or off). H_2OMAP is capable of performing two types of controls:

- Operational control rules (standard controls in H_2OMAP)
- Programmable logic controls (PLCs).

Operational control rules are the standard controls in H_2OMAP and provide a basic mechanism for controlling links, but do not implement decision logic. Operational controls allow pumps to turn on/off at specific times (time switch), at specific pressures (pressure switch), at specific link flow rates (flow switch), or at specific tank water levels (grade switch). Programmable logic controls permit the use of decision logic. They can be combined using standard "If," "Elseif," and "Else" logic statements. This provides a more powerful method to simulate complex controls in the distribution systems but is not currently used for this model.

Controls typically have the most significant impact on the length of time to run simulations. This is directly related to the increase in trials needed to monitor and react once a control switch is reached. Therefore, in the effort to implement controls, the goal was to create simple and accurate control statements. Operational control rules (standard H_2OMAP controls) were used to control the modeled pumps.

The initial status of a pump refers to the status of a pump element at the beginning of a model run. All pumps have initial status of "open" or "closed" depending on the actual status of the pumps on calibration day. Initial status of none is the same as the initial status of open for pumps. For pumps with pump controls, the entered controls will subsequently alter the status of the pumps during a model run.

PRVs and Booster Pump Station (BPS) locations were identified through the digitizing effort, field investigation and GWA staff input. Some PRV information, such as pressure settings, upstream and downstream pressure, and GPS locations in the south, was collected by GWA staff. Initial BPS information including number of duty and standby pumps, flow, horsepower, total dynamic head, and rpm were collected from the asset inventory results. Operations mode information was provided by GWA staff.

6.3.5 Tanks

Tanks were created in H_2OMAP to simulate tanks, reservoirs, groundwater sources and Navy sources in the distribution system. The GIS geodatabase file provided an initial source of information for locating reservoirs throughout the island. The EPA/GWA map and the 68 USGS Maps were reviewed to supplement and confirm the geodatabase information. Additional reservoirs identified from these maps were added to the model. Data for the reservoirs (diameter, floor elevation, and overflow elevation) were provided by GWA.

The model contains two databases relating to tanks: Tank Information and Tank Modeling Data. The fields of information used to model each tank are listed below for each of the two databases.

6.3.5.1 Tank Information

- ID - This is a character field that holds the unique identification number for each tank in the model.
- DESCRIPT - This is a character field that lists the name of the tank.
- YR_INST - This is a date field that lists the year in which the tank was constructed, if the data was readily available.
- ZONE - This is a character field that lists the pressure zone of the tank.
- PHASE - This is a number field that holds the unique Phase identifier for each element in the model.
- YR_RETIRE, COST_ID - These are fields that are standard in the H_2OMAP software but are not currently used for this model.

6.3.5.2 Tank Modeling Data

- ID - This is a character field that holds the unique identification number for each tank in the model.
- TYPE - This is a character field, internally generated by H_2OMAP, to identify the four types of tanks that can be assigned to simulate the facility. Types consist of 0=Fixed Head Reservoir, 1=Variable Head Reservoir, 2=Cylindrical Tank, and 3=Variable Area Tank.
- ELEVATION - This is a number field that holds the elevation in feet assigned to that tank. For type 0 Fixed Head Reservoirs, the elevation is the fixed elevation of the water surface. For type 1 Variable Head Reservoirs, the elevation can be either the bottom elevation or the first hour elevation of the reservoir. This field is not needed for a variable head reservoir under an extended-period simulation; it is only for steady-state analyses. For type 2 Cylindrical Tank and type 3 Variable Area Tank, the elevation is the bottom elevation of the tank or reservoir.
- MIN_LEVEL - This is a number field that holds the minimum water level at which the tank can operate. The unit is in feet, and the value is measured from the datum entered in the "ELEVATION" field. This field applies only to type 2 Cylindrical Tanks and type 3 Variable Area Tanks. The value is usually zero, but in cases where the bottom elevation of the tank is put in as the elevation, it is the outlet elevation above the bottom of the tank.
- MAX_LEVEL - This is a number field that holds the maximum water level at which the tank node can operate. The unit is in feet, and the value is measured from the datum entered in the "ELEVATION" field. This field applies only to type 2 Cylindrical Tanks and type 3 Variable Area Tanks.
- INIT_LEVEL - This is a number field that contains the water level at hour 0:00 for model runs. The unit is in feet, and the value is measured from the datum entered in the "ELEVATION" field. This field applies only to type 2 Cylindrical Tanks and type 3 Variable Area Tanks.
- DIAMETER - This is a number field that lists the diameter in feet for type 2 Cylindrical Tanks. All other types contain "0" values since this field is not applicable.
- PATTERN - This character field applies only to type 1 Variable Head Reservoirs. It contains the number of the pattern assigned to the reservoir. The pattern contains 24 hours of hydraulic grade (i.e. water surface elevations) fluctuations for the reservoir.
- CURVE - This is a character field that contains the ID number of the depth-volume curve assigned to a type 3 Variable Area Tank. The abscissa (x-axis) of the curve contains the water volume in cubic feet and the ordinate (y-axis) of the curve contains the corresponding

water level in feet as measured from the datum entered in the field "ELEVATION."

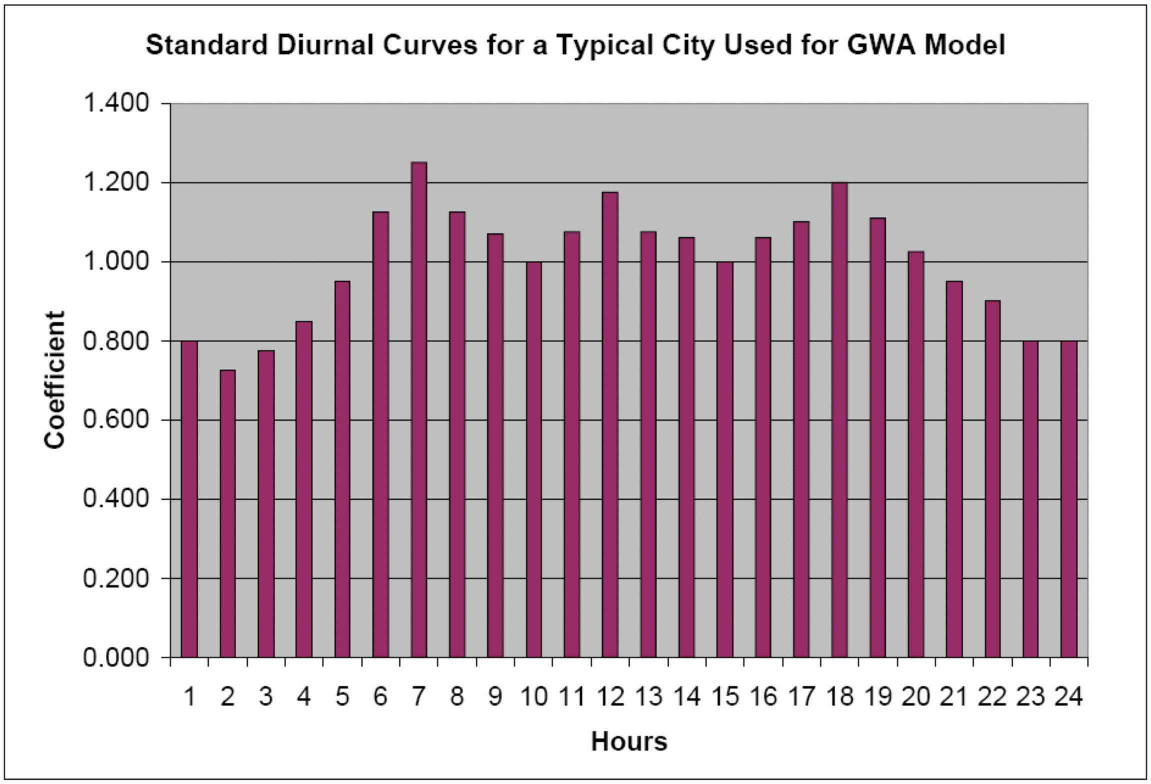
6.4 Model Development

As the model was developed, simplifications were made to decrease the complexity of the model and create a more stable and accurate simulation environment. These simplifications are appropriate for a hydraulic model intended to be used for general planning purposes. Some of these simplifications allow the computer model to run more efficiently by excluding unnecessary details for this level of model. Other simplifications were implemented because gathering of additional details would necessitate extensive field testing and/or investigations outside the scope of the project. The general system simplifications used in the model are described in the following paragraphs.

- Pipes, 6 inches and larger in diameter, were included in the model. Smaller diameter distribution pipes were included if they were required for circulation and/or to connect facilities to the system.
- Dead end pipes that were less than 6 inches in diameter or shorter than 30 feet long were removed from the model.
- Deep Wells in the Model are simulated by one virtual tank for each well and one pump for each well pump. This allows each well to be activated independently in the hydraulic model. However, groundwater drawdown information and pump curve for the well pumps are not available for most of the wells. Hence, a general system simplification has been made by manually setting the well pump flow rate to the EPA permit flow rate. (A virtual tank is one that does not exist in reality, but is added to the model in order to simulate an actual system element.)
- Pressure regulator stations in the Model contain only the largest valve in the regulator stations. This simplification allows the model to calibrate and run more efficiently.
- Relief stations are generally not modeled unless the valves relieve water back into the distribution system, such as the "overflow relief valve" located between the Manengon and Pulantat Reservoir.
- Pumps and regulator stations with downstream check valves are modeled without a separate check valve because the software valve and pump entities have built-in check valve functions.
- Small pump stations are not included in the model. For a planning model, these small pump station have minimal impacts to the hydraulics of the entire system.
- Twin tanks that float together in the distribution system are modeled as two cylindrical tanks. The two tanks should operate properly in the model if both tanks are given the same initial hydraulic grade.
- Hydropneumatic tanks are not included in the model. They are not modeled hydraulically because sufficient detail is not available. Furthermore, they have minimal impacts to the hydraulics of the entire system.

- Altitude valves are not included in the model. Specific information was not available concerning the float settings for the tanks. Since detailed information was not available, the altitude valve was not modeled.
- Navy piping and facilities. In general, the Navy water system is not modeled. However, portions of navy facilities leading to connections with the GWA system may be included in the model. The connections are modeled as either a negative demand node or a virtual tank/pump system similar to the Deep Wells. Virtual tanks with fixed grades set at the pressure of the Navy pipelines are modeled as sources for the Navy Meters.
- Some of the GWA customers receive their drinking water supply exclusively from Navy facilities, such as in the Nimitz Hill Area and the Northern Treatment Plant. Since these are isolated systems with only Navy supplies, they are not activated during the GWA Model simulations.
- In the past, Navy turn over some of its pipeline ownership in the Santa Rita area to GWA, unfortunately a complete record of the transition was not readily available. As a result, pipe networks in the Santa Rita area may be incomplete, thus further investigation of the area is highly recommended.
- Diurnal curves. Since water demand changes over the course of a day, it is necessary to define this diurnal demand pattern in the model. If detail water supply and demand data were available, different diurnal curves should be developed for the different pressure zones to reflect the various usage patterns. However, such information is unavailable, a standard diurnal curve for a typical city was created to simulate water usage patterns throughout the GWA system as shown in Figure 6-3.
- The "Trace Network" tool in H_2OMAP was used to identify and resolve connectivity problems. Connectivity is necessary for the model to operate properly.
- In order to calculate the system pressure, accurate elevation data is needed for every model junction. To assign elevations to the junctions, a three dimensional contour shapefile of Guam was imported into H_2OMAP. Elevations were extracted from the shapefile and assigned to the junctions of the hydraulic model in H_2OMAP using the Elevation Interpolation tool. Elevations for the facility junctions were researched individually and manually entered into the hydraulic model to increase model accuracy.

Figure 6-3 – Diurnal Model



6.5 Water Supply

The water supply for the model included deep wells, springs, military supply, and a water treatment plant in the south as mentioned above. The water supply sources are shown in Figure 6-4a (South) and Figure 6-4b (North/Central).

6.5.1 Deep Wells and Earth Tech Wells

There are 119 wells in the North/Central and 2 wells in the South. In August 2005 there were 104 active wells. The wells were modeled as a combination of virtual tank and pump with design flow in gallons per minute (gpm) set to the EPA permit flow rates identified by GWA records from 2005.

6.5.2 Navy (FENA) and Air Force Water Supply

A list of Navy water meters and their locations were provided by GWA. The monthly bill from the Air Force indicates four meter locations and the flow at each of these locations. The meter locations and amount of metered flow were modeled as either source nodes or virtual tank/pump.

6.5.3 Ugum Water Treatment Plant

The Ugum water treatment plant was put into the model as a fixed head reservoir with pumps and a variable head reservoir. This configuration represents a steady flow of 2.2 mgd located in the south on the eastern side of the island. The 2.2 mgd value was identified from GWA production records.

6.5.4 Springs

The only active spring that GWA is receiving water from is the Santa Rita Spring in the South. Santa Rita Spring was modeled as a virtual tank and pump with a design flow of 165 gpm based on information provided in the GWA State of the Water Resources Master Plan by Mink and Yuen, Inc. June 2005.

6.6 Water Demand Projection

Water demand projections for both water systems are for current (2005) and future (2025) conditions. The demand projections are based on population projections within developed areas of the island. Guam contains a large amount of undeveloped land and land occupied by military bases. The military bases (Anderson Air Force Base and Apra Navy Harbor) and military satellites are supplied by separate water systems that are not owned by GWA and are not included in this study. Development polygons were drawn to allocate the existing population of each municipality to developed areas. Actually developed areas were identified in the census tracts used for population projection by review of aerial photos.

The population projections for each municipality were divided into census block groups. The data for the census block group current and future populations were provided as part of the Guam Population and Land Use Projections Report by D.E. Consulting, April 2005. The demand per capita was determined by calculating an overall water mass balance for the island as described below.

6.6.1 Development Polygons

Each municipality has census block groups with current (2005) and future (2020, 2050, etc.) population projections. Polygons were created within each census block group to distribute the population to developed areas. Using an aerial photo, borders were drawn around areas that appeared to have some buildings present. In addition, a shapefile with partial land use information was used to supplement the aerial to draw the polygons. The final pipes and nodes were used to further subdivide the development polygons to distribute the demands within the water system.

Once the polygons were drawn, the census block group population was distributed to each polygon based on area. Development polygons for the South for current and future scenarios are shown in Figures 6-5 and 6-6, respectively. Development polygons for the North/Central for current and future scenarios are shown in Figures 6-7a/b/c and 6-8a/b/c, respectively.

Once the development polygons were completed, they were imported into the model. The Demand Allocator extension tool of H_2OMAP was used to assign population to the nearest demand node. Finally, the population data in each demand node was multiplied by the per capita demand multiplier (0.18 gpm per person) to get the water demand.

Figure 6-4a – South Water Supply Sources

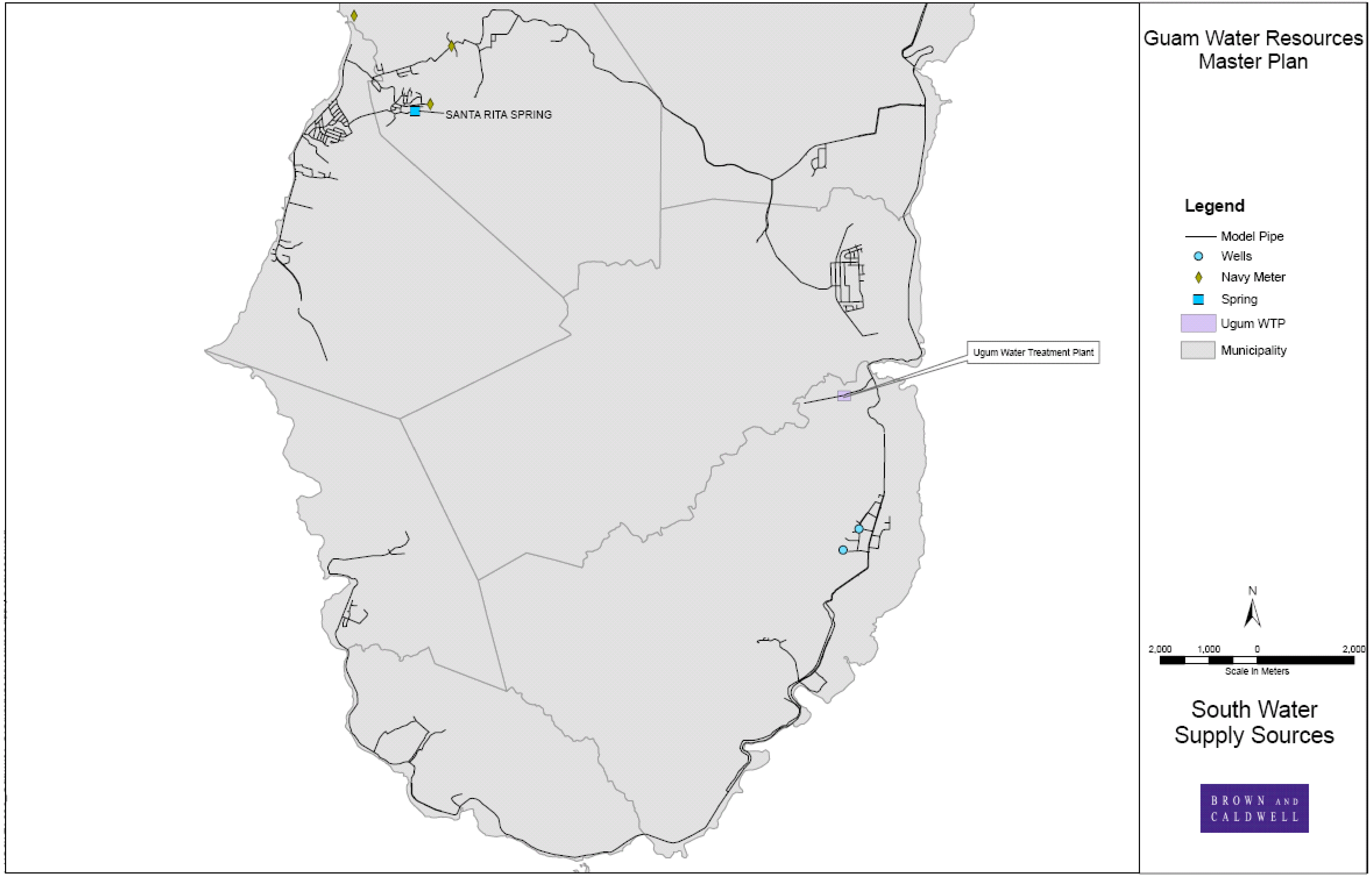


Figure 6-4b – North/Central Water Supply Sources

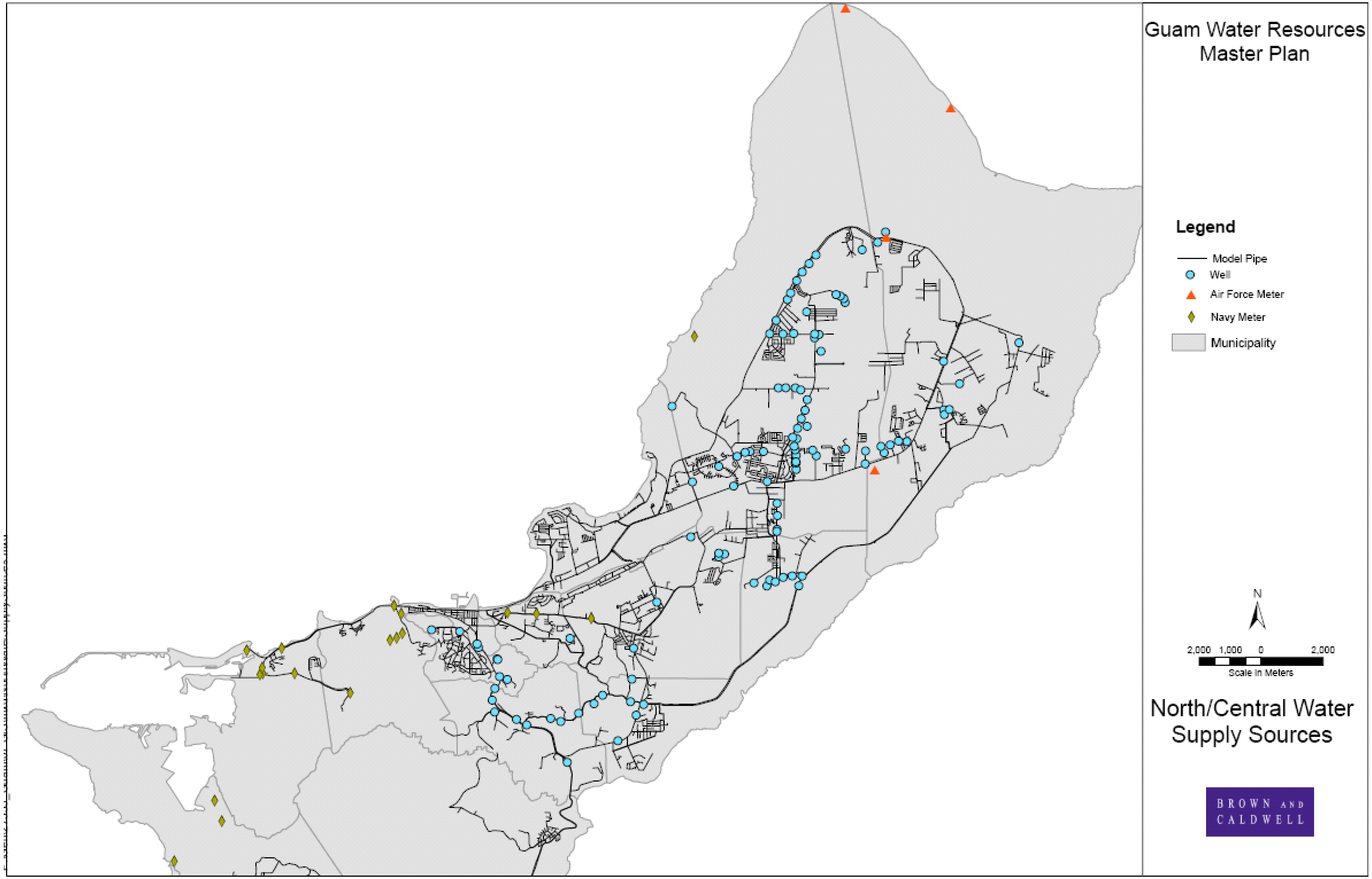


Figure 6-5 – Existing 2005 Demands

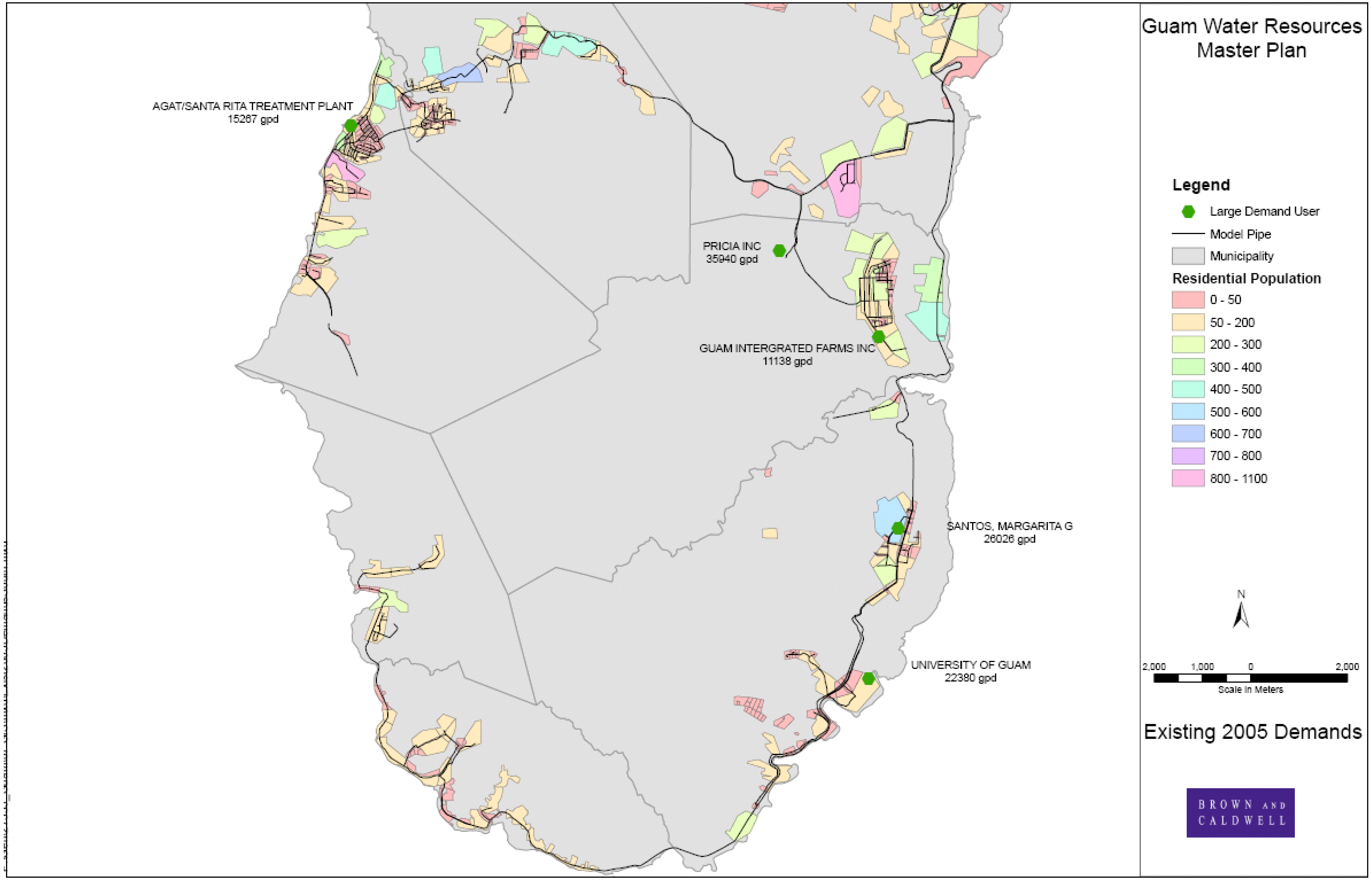


Figure 6-6 – Future 2025 Demands

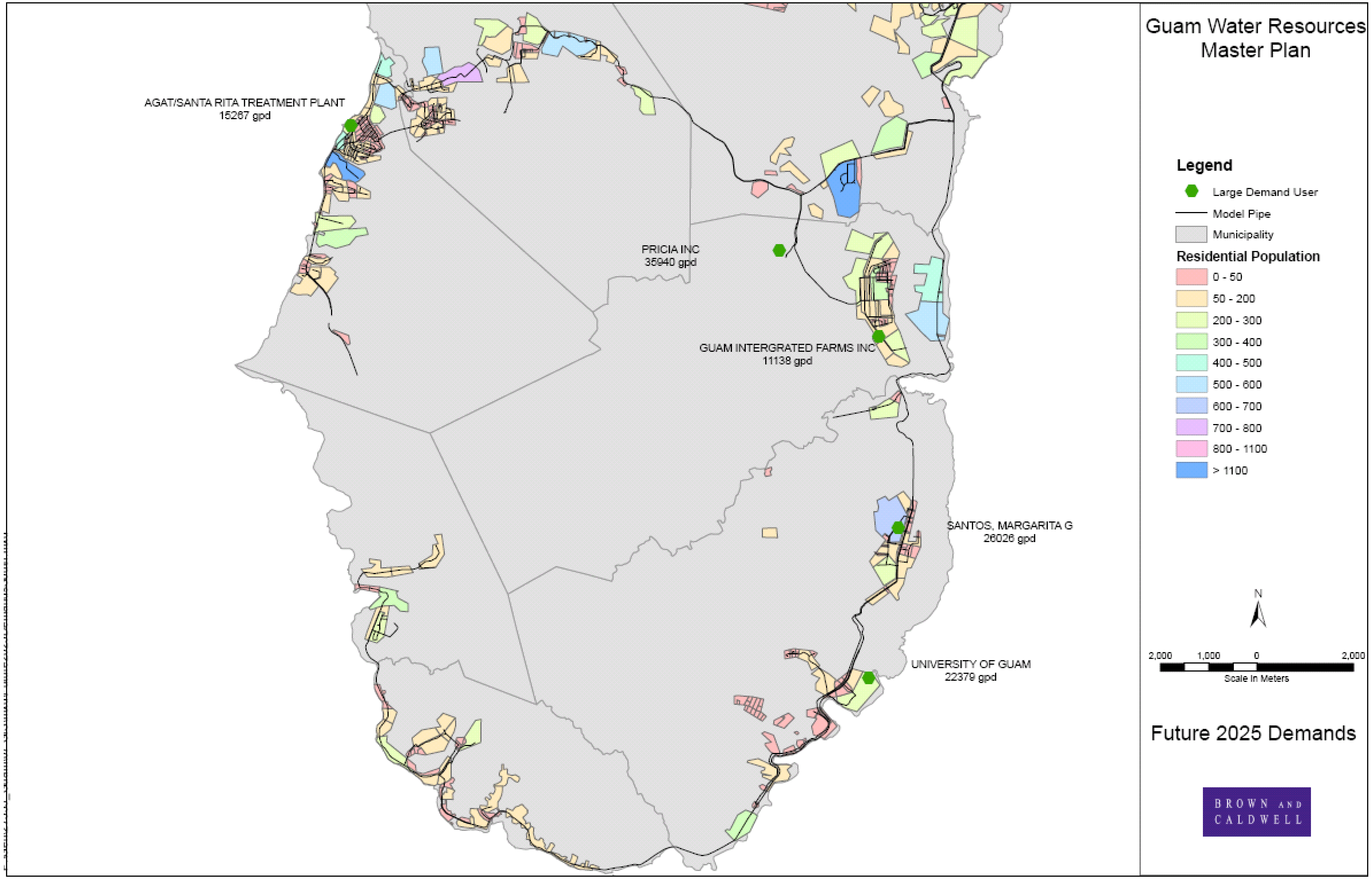
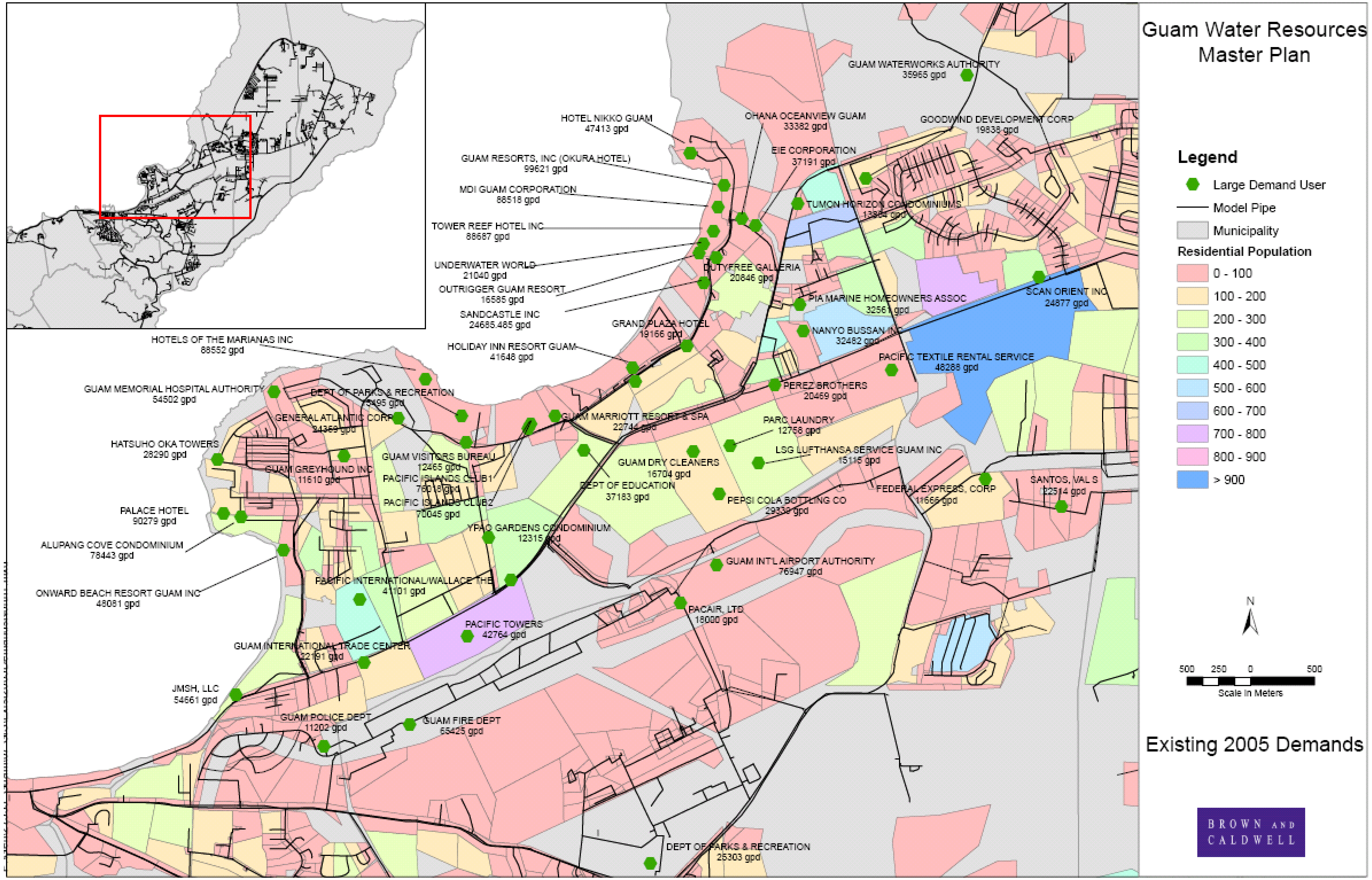


Figure 6-7a – Existing 2005 Demands (North 1)



"This is a draft report and is not intended to be a final representation of the work done or recommendations made by Brown and Caldwell. It should not be relied upon; consult the final report."

Figure 6-7b – Existing 2005 Demands (North 2)

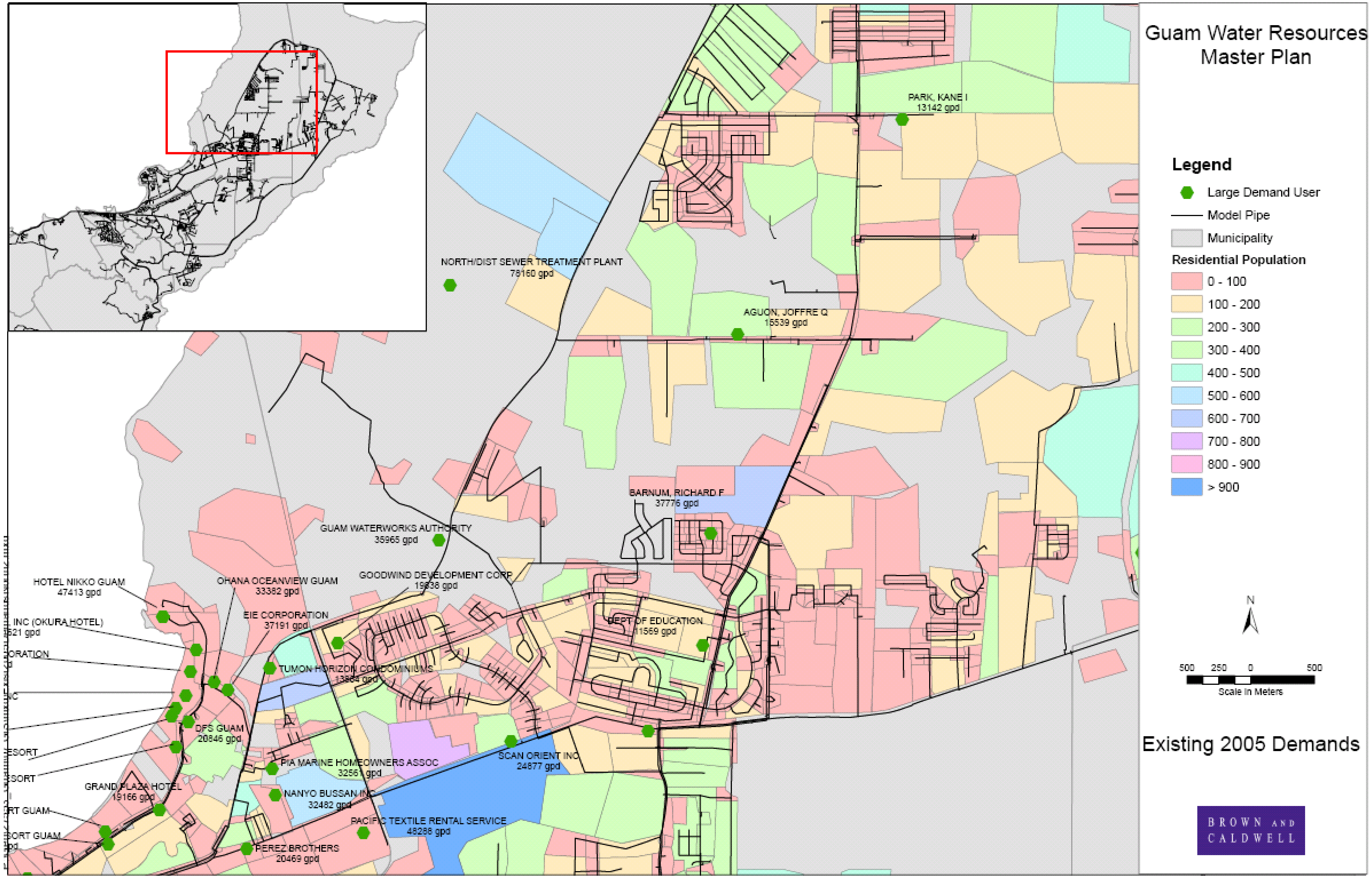


Figure 6-7c – Existing 2005 Demands (North 3)

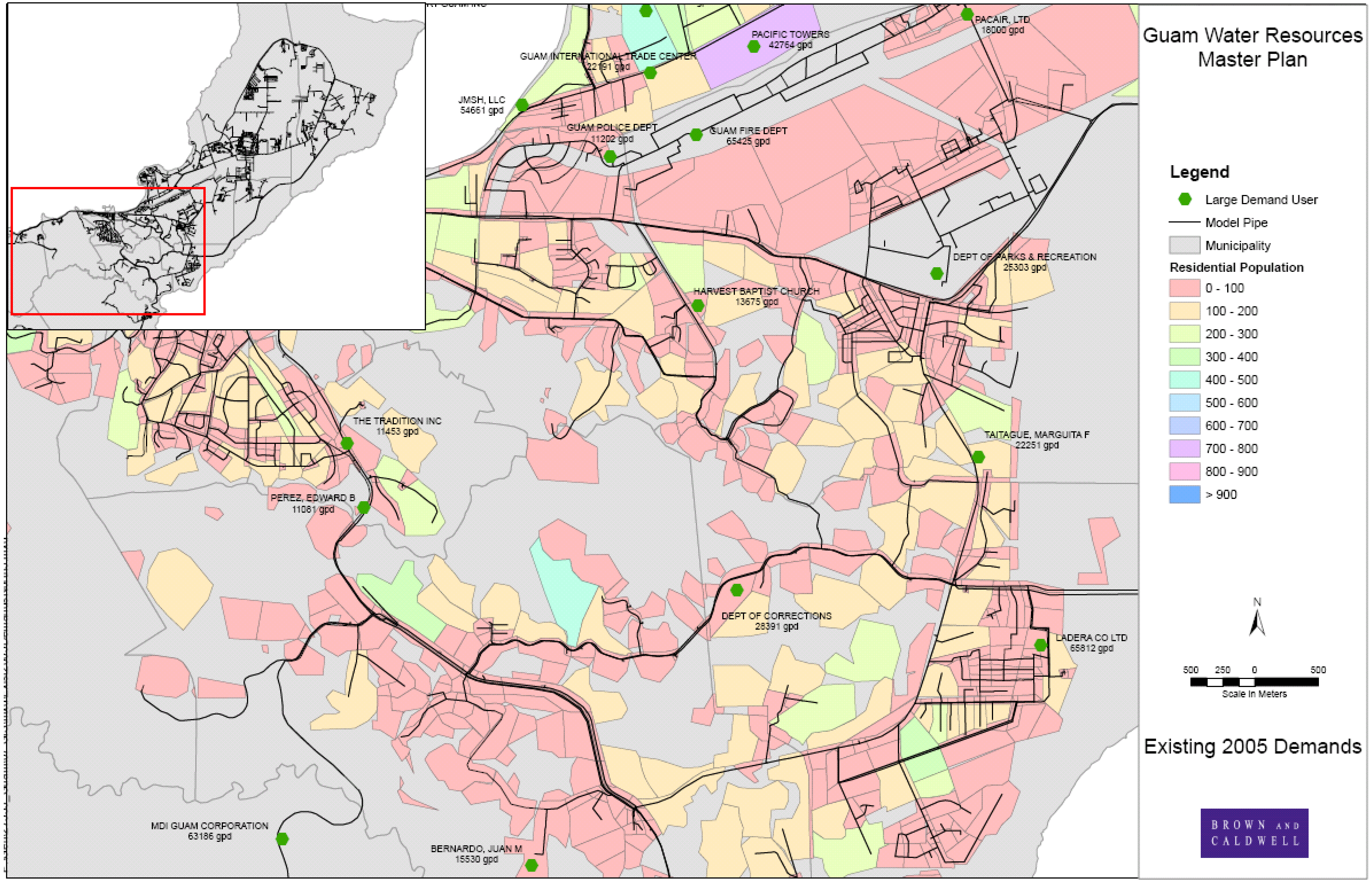


Figure 6-8a – Future 2025 Demands (North 1)

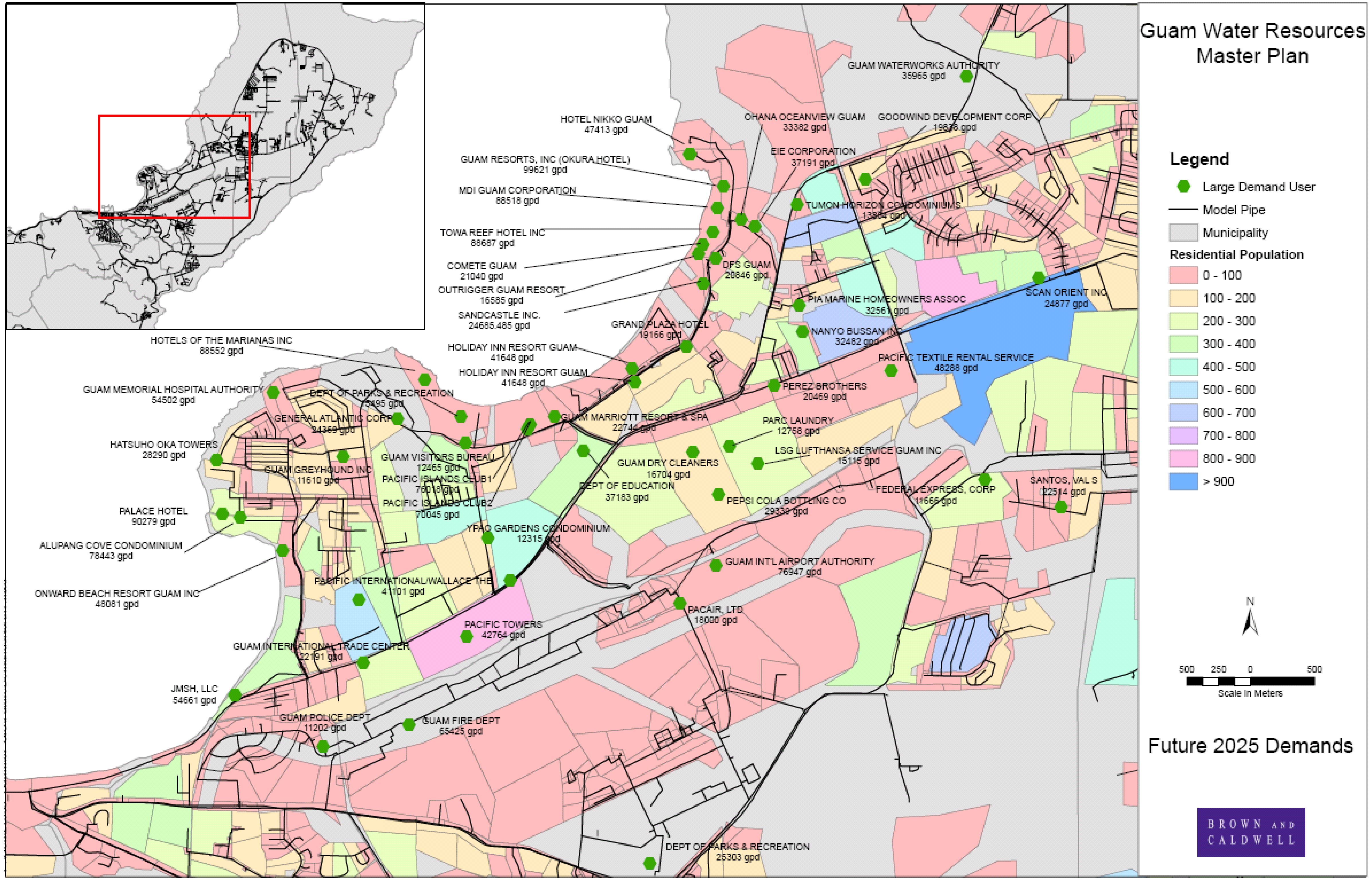


Figure 6-8b – Future 2025 Demands (North 2)

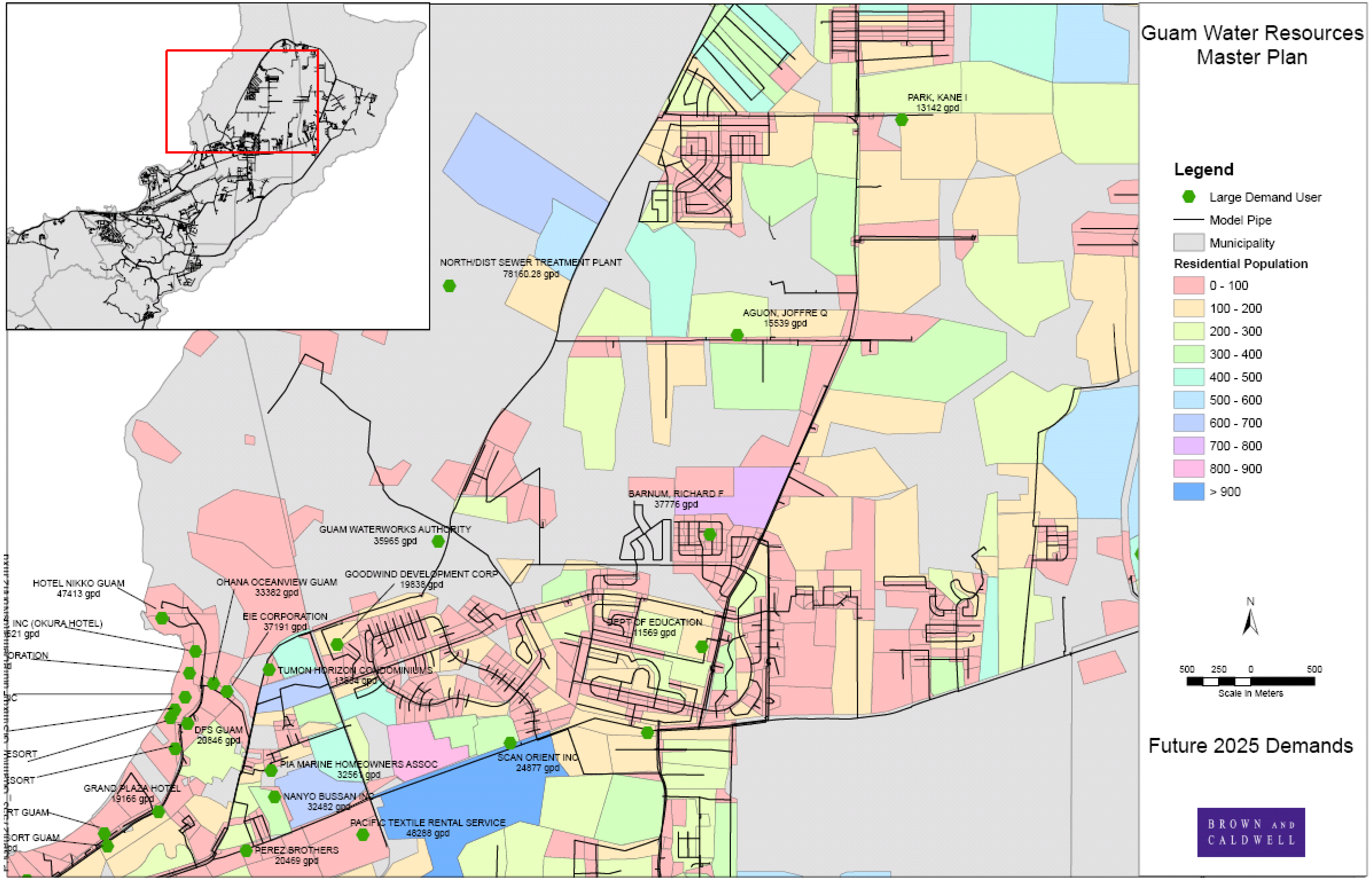
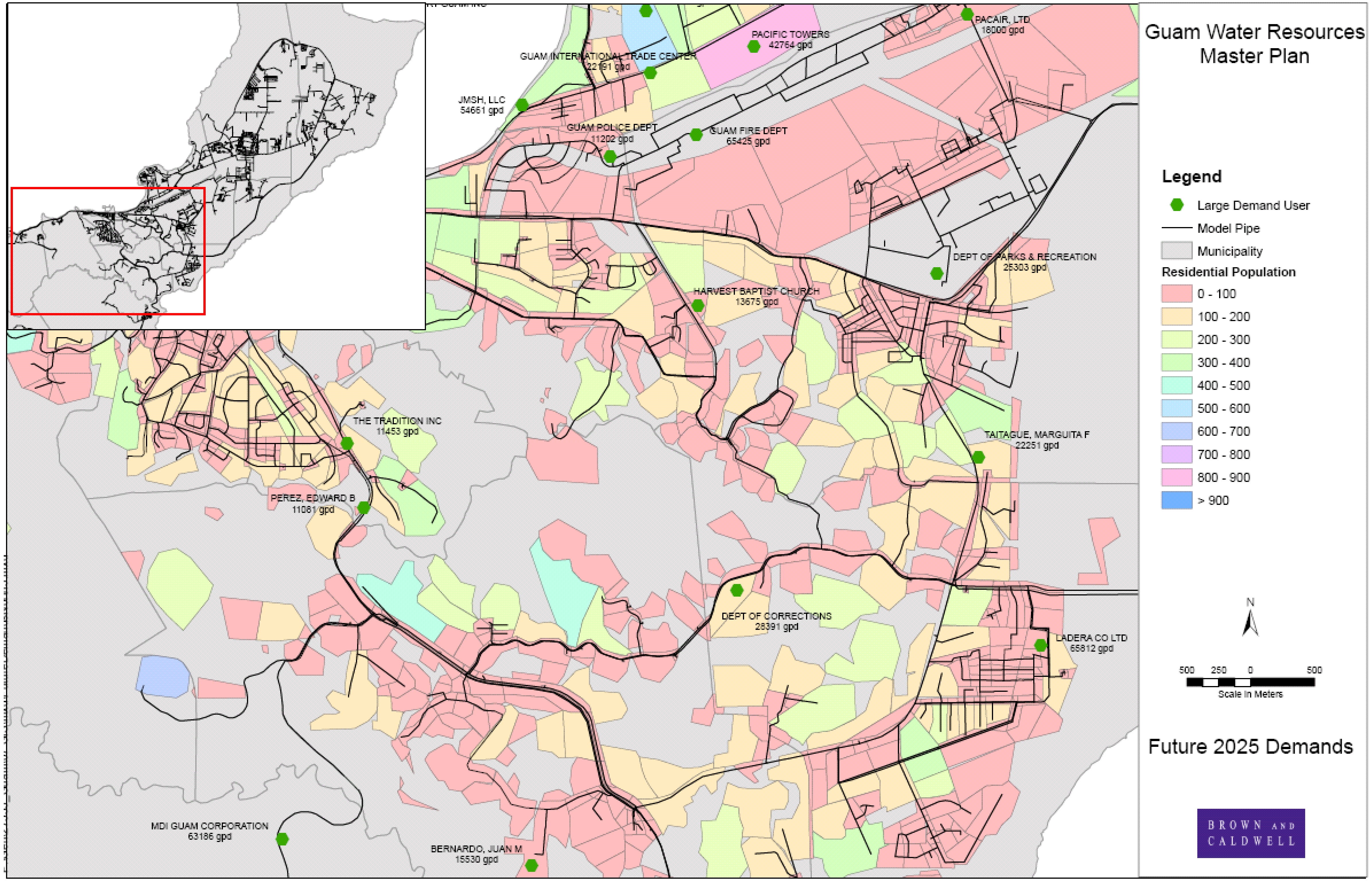


Figure 6-8c – Future 2025 Demands (North 3)



6.6.2 Large Demand Users

Large users were identified as part of the demand allocation process. Large users are customers with a relatively high water demand. Since the concentrated demand influence the hydraulics in the distribution system, large users were input separately in the model. The GWA water accounts data for June 2005 was imported into a Microsoft Access database to identify system demands and large users. Large water users were defined with average flows in excess of 11000 gpd. In total 80 large user were selected and input in the model. The daily demand for these users range from 11,080 gpd to 99,622 gpd. Less than half of these users had addresses in the accounts file. The large demand users without addresses were located by searching internet phone books and hotel maps, or by contacting the businesses directly by phone. These demands are treated as point source demands in the model. The total demand from the large demand users is approximately 2.6 mgd. Table 6-1 lists all large users that have been input in the hydraulic model.

Table 6-1 - Large Users in the GWA Hydraulic Model

ID	Name	Demand (gpm)
1	GUAM RESORTS, INC (OKURA HOTEL)	69.18
2	PALACE HOTEL	62.69
3	TOWA REEF HOTEL INC	61.59
4	HOTELS OF THE MARIANAS INC	61.49
5	MDI GUAM CORPORATION	61.47
6	ALUPANG COVE CONDOMINIUM	54.47
7	GUAM WATERWORKS AUTHORITY	54.28
8	GUAM INT'L AIRPORT AUTHORITY	53.44
9	PACIFIC ISLANDS CLUB	52.79
10	PACIFIC ISLANDS CLUB	48.64
11	LADERA CO LTD	45.70
12	GUAM FIRE DEPT	45.43
13	MDI GUAM CORPORATION	43.88
14	JMSH, LLC	37.96
15	GUAM MEMORIAL HOSPITAL AUTHORITY	37.85
16	PACIFIC TEXTILE RENTAL SERVICE	33.53
17	ONWARD BEACH RESORT GUAM INC	33.39
18	HOTEL NIKKO GUAM	32.93
19	PACIFIC TOWERS	29.70
20	HOLIDAY INN RESORT GUAM	28.92
21	PACIFIC INTERNATIONAL/WALLACE THE	28.54
22	BARNUM, RICHARD F	26.23
23	EIE CORPORATION	25.83
24	DEPT OF EDUCATION	25.82
25	GUAM WATERWORKS AUTHORITY	24.98

Table 6-1 - Large Users in the GWA Hydraulic Model (continued)

ID	Name	Demand (gpm)
26	PRICIA INC	24.96
27	OHANA OCEANVIEW GUAM	23.18
28	PIA MARINE HOMEOWNERS ASSOC	22.61
29	NANYO BUSSAN INC	22.56
30	PEPSI COLA BOTTLING CO	20.37
31	PORT AUTHORITY OF GUAM	19.82
32	DEPT OF CORRECTIONS	19.72
33	HATSUHO OKA TOWERS	19.65
34	SANTOS, MARGARITA G	18.07
35	DEPT OF PARKS & RECREATION	17.57
36	SCAN ORIENT INC	17.28
37	SANDCASTLE INC	17.14
38	ITASI CORPORATION	17.13
39	GENERAL ATLANTIC CORP	16.92
40	STARTS GUAM GOLF RESORT INC	16.75
41	GUAM FIRE DEPT	16.08
42	GUAM MARRIOTT RESORT & SPA	15.79
43	SANTOS, VAL S	15.63
44	TRIPLE J ENTERPRISES, INC	15.56
45	UNIVERSITY OF GUAM	15.54
46	TAITAGUE, MARGUITA F	15.45
47	GUAM INTERNATIONAL TRADE CENTER	15.41
48	COMETE GUAM	14.61
49	DFS GUAM	14.48
50	AQUA WORLD	14.22
51	PEREZ BROTHERS	14.21
52	GOODWIND DEVELOPMENT CORP	13.78
53	ATKINS KROLL GUAM LTD	13.50
54	GRAND PLAZA HOTEL	13.31
55	PACAIR, LTD	12.50
56	DEPT OF EDUCATION	11.97
57	GUAM DRY CLEANERS	11.60
58	OUTRIGGER GUAM RESORT	11.52
59	RE/MAX DIAMOND REALTY	11.27
60	GREGORIO F PEREZ INC	11.06
61	AGUON, JOFFRE Q	10.79
62	BERNARDO, JUAN M	10.78

Table 6-1 - Large Users in the GWA Hydraulic Model (continued)

ID	Name	Demand (gpm)
63	DEPT OF PARKS & RECREATION	10.76
64	GUAM WATERWORKS AUTHORITY	10.60
65	LSG LUFTHANSA SERVICE GUAM INC	10.50
66	TUMON HORIZON CONDOMINIUMS	9.64
67	HARVEST BAPTIST CHURCH	9.50
68	OCEANIC RESOURCES INC	9.21
69	PARK, KANE I	9.13
70	PARC LAUNDRY	8.86
71	GUAM VISITORS BUREAU	8.66
72	YPAO GARDENS CONDOMINIUM	8.55
73	FEDERAL EXPRESS, CORP	8.10
74	GUAM GREYHOUND INC	8.06
75	DEPT OF EDUCATION	8.03
76	THE TRADITION INC	7.95
77	GUAM POLICE DEPT	7.78
78	GUAM INTERGRATED FARMS INC	7.73
79	HOTEL NIKKO GUAM	7.71
80	PEREZ, EDWARD B	7.70

6.6.3 Peaking Factors

The peaking factor requirements are based on the Hawaii Water System Standards. The operating conditions considered for the water distribution system are average day, maximum day (= 1.5 x Avg Day), and peak hour (= 3.0 x Avg Day).

6.6.4 Fire Flows

The fire flow requirements are based on the Hawaii Water System Standards as shown in Table 6-2.

Table 6-2 – Fire Flow Rates

Area Designation	Required Fire Flow (gpm)
Residential	1,500 for 2 hours
Commercial, Light Industrial	2,000 for 2 hours
Hotels, Heavy Industrial	2,500 for 2 hours

6.7 Mass Balance and Demand per Capita

The GWA water supply is attributed to six sources, each of which provides varying quantities of potable water. Table 6-3 breaks down the water production sources.

Table 6-3 – Guam Water Supply Sources

Source	South Quantity (mgd)	North Quantity (mgd)	Total (mgd)
Deep Wells[1]	0.1	32.8	32.9
Navy (FENA)[2]	0.7	3.6	4.3
Ugum Water Treatment Plant [3]	2.2	n/a	2.2
Santa Rita Spring[4]	0.2	n/a	0.2
Air Force[5]	n/a	0.2	0.2
Earth Tech Wells[6]	n/a	3.5	3.5
Total	3.2	40.1	43.3

1. GWA Monthly Deep Wells Production Report 2005
2. FENA Water Supply FY 04-05
3. Based on GWA monthly flow (Pumping minus backwash) for May (72,045,000 gal) and June 2005 (63,360,000 gal)
4. GWA State of the Water Resources Master Plan June 2005
5. August/September 2004 Water Bill provided by GWA
6. 2004-2005 production report by GWA

The main GWA water supply source is the deep wells, which are mostly in the northern/central portion of the island. The deep wells contribute over 75 percent of the water supply. Data for this source was provided by the GWA for all available 2005 months. Data from 2003 provided very similar flow results. It is assumed that all wells that were reported as operating are running 24 hours a day. The Navy water supply data was provided in the form of detailed monthly water purchase data and accounts for about 10 percent of the GWA water supply. The Earth Tech wells provide about 8 percent of the total GWA water supply. The water supply contribution for the Ugum Water Treatment Plant was provided in monthly total flows by GWA for the months of May and June 2005. The Air Force contribution was based on a monthly billing for the August/September 2004 period. The water contribution from the Santa Rita Spring was based on the GWA State of the Water Resources Master Plan June 2005.

Based on customer billing records from April 2005, GWA was able to account for 21.0 mgd. The remaining water, 22.4 mgd, was considered "unaccounted-for" water and was not billable to a customer. "Unaccounted-for" water is water that leaves the system through illegal connections or leaks in the pipeline, or is associated with unreadable meters. This unaccounted-for water rate represents 52 percent of the total system, which is relatively high compared with the prevalent range of 10-15 percent stated by AWWA Manual M32, Distribution Network Analysis for Water Utilities. This amount of unaccounted-for water is similar to that estimated in the 1992 Water Master Plan Update. GWA has recently implemented a Leak Detection Program and has been fixing major leaks as they encounter them to recapture its water resources per the GWA Water Leak Detection Study on All Three Public Water System September 2005.

The demand per capita, 134 gallons per capita per day (gpcd), was calculated by dividing the total water usage (21.0 mgd) by the 2005 population served by the GWA system from the census block group shapefile (156,676 people). An additional demand per capita was added to represent the unaccounted-for water. This additional demand was calculated by subtracting the large demand water usage (2.6 mgd) and the total water usage (21.0 mgd) from the total water production (43.3 mgd) and dividing by the 2005 GWA population. The 126 gpcd of unaccounted-for water demand was added to the demand per capita based on total water usage. The demand multiplier applied in the model, 260 gpcd (0.18 gpcm), includes both the water demand based on water usage and unaccounted-for water. Once the Leak Detection Program has addressed most of the water leakage, a new flow rate from the water sources and a new demand per capita should be calculated.

6.8 Model Simulation

Two basic types of analyses can be conducted using a hydraulic model:

1. Steady-state Simulation (SSS)

A steady-state run simulates the system at an instantaneous point in time. Distribution system boundary conditions (tank elevations, water demands, pump and valve status, etc.) are set in the model to represent initial conditions and then the model predicts pressures and flows at other points in the system under those conditions. A SSS run is most often used for the initial validation of an "unrefined" hydraulic model. Frequently, a calibrated and "refined" SSS model will be used to assess the impact of large demands, for example fire flows, under various conditions.

2. Extended Period Simulation (EPS)

The second type of model analysis is an EPS which simulates the distribution system as it changes over time. Many different factors contribute to the model output, such as water demand and supply fluctuations, booster pumps turning on and off, PRVs becoming activated, and tank elevations changing, etc. EPS runs can be used to assess the adequacy of booster pump stations and storage tanks over the course of a day, a week, or even months under different demand conditions.

6.8.1 Simulations Scenarios

Simulations were performed to analyze the system under the Max-Day demand scenarios. These simulations were done both in steady state mode and in the EPS mode. With these simulations, the pressure and flows under maximum day, were investigated, and deficiencies in the GWA water system were identified. Scenarios were run to observe the pressures and flows under current and future operating conditions. The simulation conditions are summarized as follows:

Simulation assumptions:

- A constant supply of 2.2 mgd from the Ugum WTP was used for the Max-day scenario.
- Tank levels were started at 75%-full condition.
- Pumps were controlled by tank level through telemetry.
- Well pumps are set to run 24-hours a day and flow rates are variable depend on the system hydraulic grade downstream of the well pumps.
- Set points for various valves were adjusted, so that adequate amount of water will be able to cascade down from the higher-pressure zones to the lower zones.

6.8.2 Simulations Results

6.8.2.1 Deficiencies during Max-Day Scenario

Chapters 8 – Water Distribution Systems and 9 – Water System Facilities list deficiencies in the water distribution and treatment system identified through hydraulic modeling.

Areas with low-pressure: During the Max-day simulation, system pressures below 40 psi were observed at various high ground elevation portion. These low-pressure areas are located throughout the Island.

Areas with low available fire flow: During the Max-day stead state fire flow simulation, low available fire flow (less than 1000-2500 gpm) were observed at various locations throughout the Island.

Areas with high velocity: During the Max-day simulation, multiple pipelines in the distribution system had velocity above 6 ft/sec. These high-velocity pipelines are located in throughout the Island.

Figures 6-9 through 6-23 shows the EPS model simulation results of the reservoir water levels and PRVs flow rates respectively.

6.8.2.2 System Improvement Recommendations

A number of system CIP improvement alternatives were evaluated in the model to remedy the aforementioned deficiencies, improve system hydraulics, and increase storage tank capacity.

6.9 Model Maintenance

It is vital that the Hydraulic Model be kept up to date. Without proper model maintenance, the model will quickly become outdated and inaccurate. A model maintenance plan should be developed to establish procedures for maintenance. In general, the plan should required that new pipes and facilities be added to the model annually. It is also recommended that new controls be implemented every 3-5 years. Every 3-5 years, the demands and diurnal curves should be reviewed and adjusted, if needed. All changes should be recorded in a central document, an electronic maintenance log book. This book should keep track of each model change, the model element ID, the date of change, the name of the person who made the change, and the reason or type of change. Types of changes include, among others, new pipes, relining, and abandoned facilities.

Figure 6-9 - North System 1, Max-Day, Min Pressure (<40 psi)

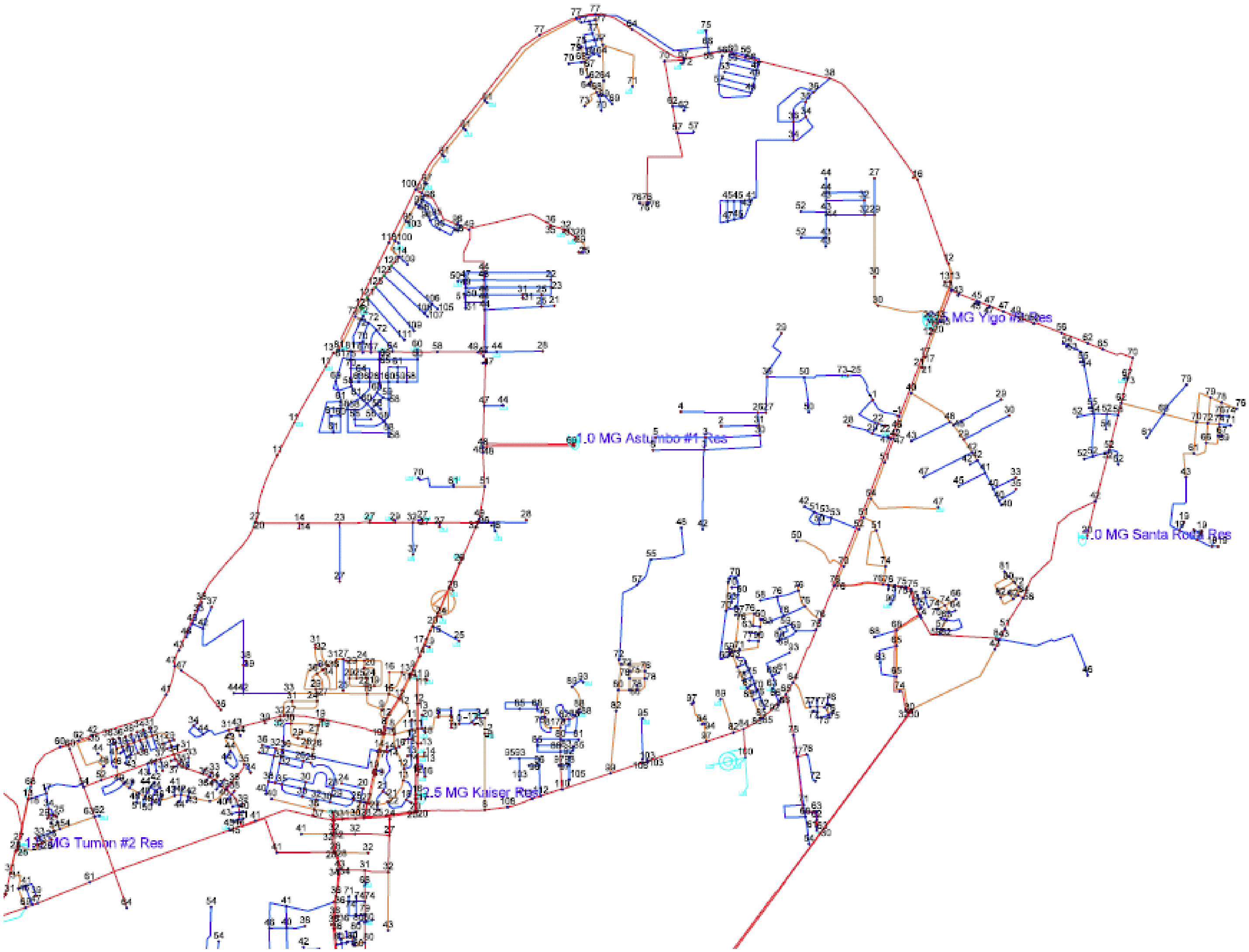


Figure 6-10 - North System 2, Max-Day, Min Pressure (<40 psi)

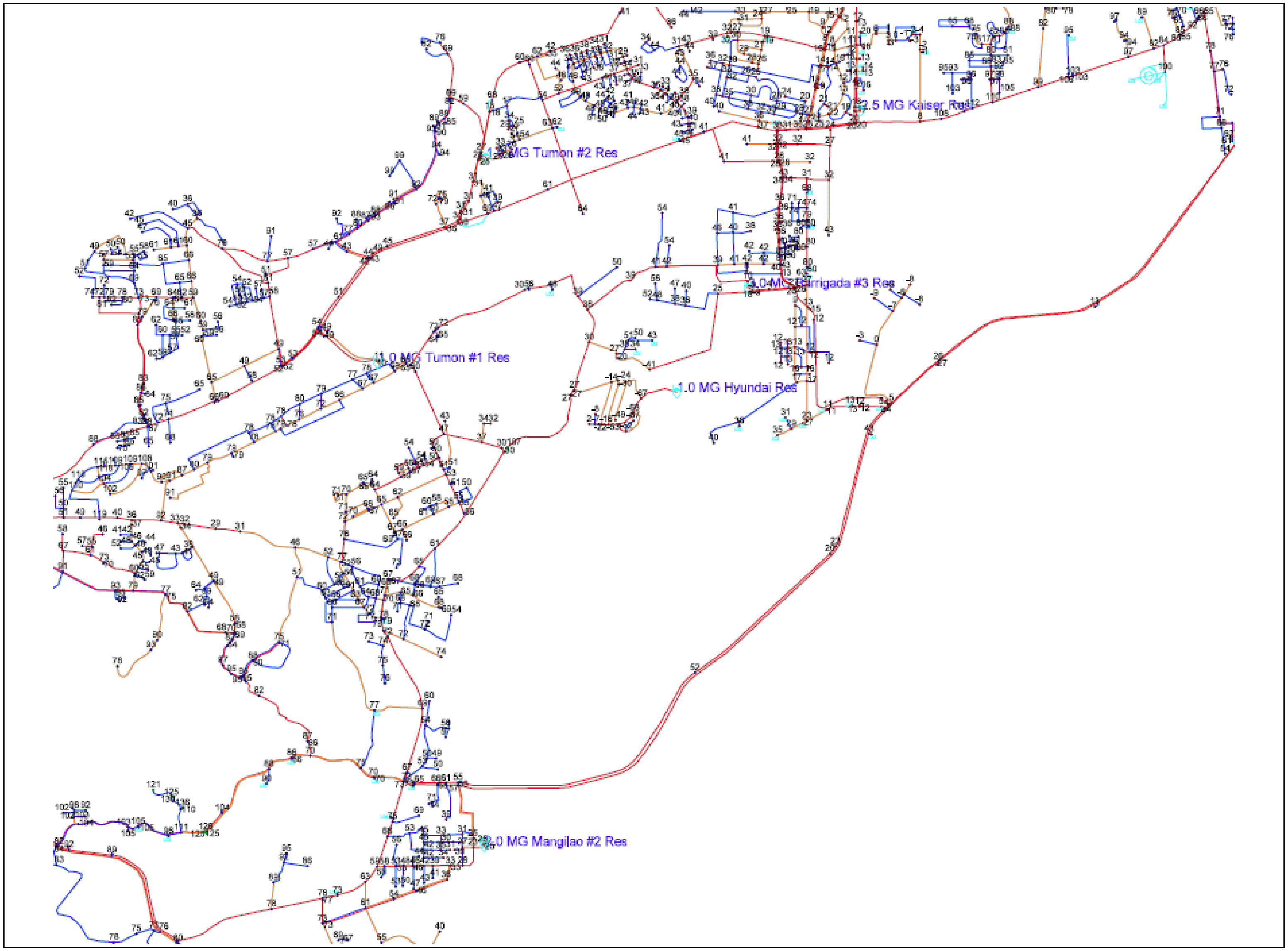


Figure 6-11 - North System 3, Max-Day, Min Pressure (<40 psi)

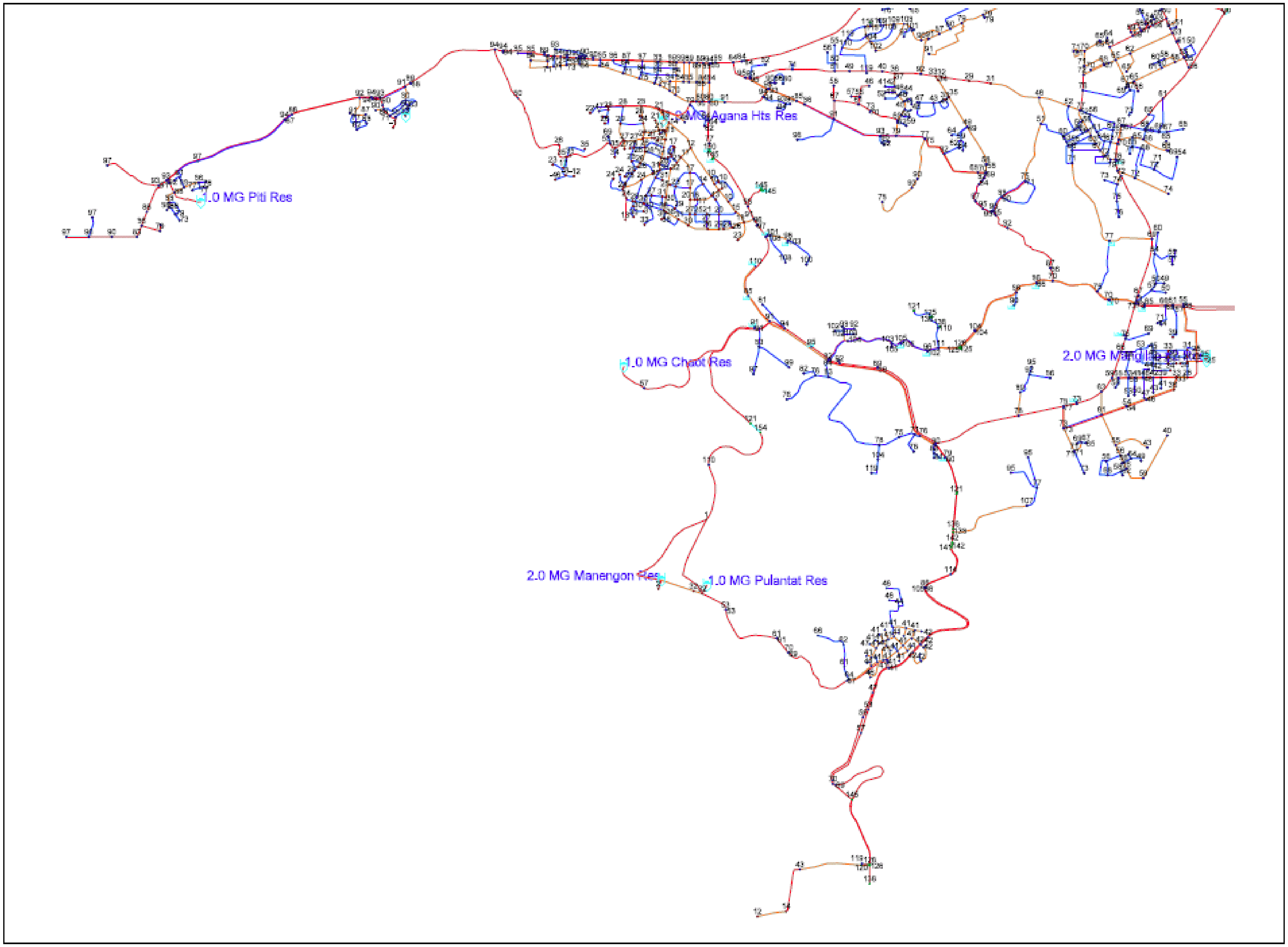


Figure 6-12 - North System 1, Max-Day, Max Velocity (>6 fps)

Figure 6-13 - North System 2, Max-Day, Max Velocity (>6 fps)

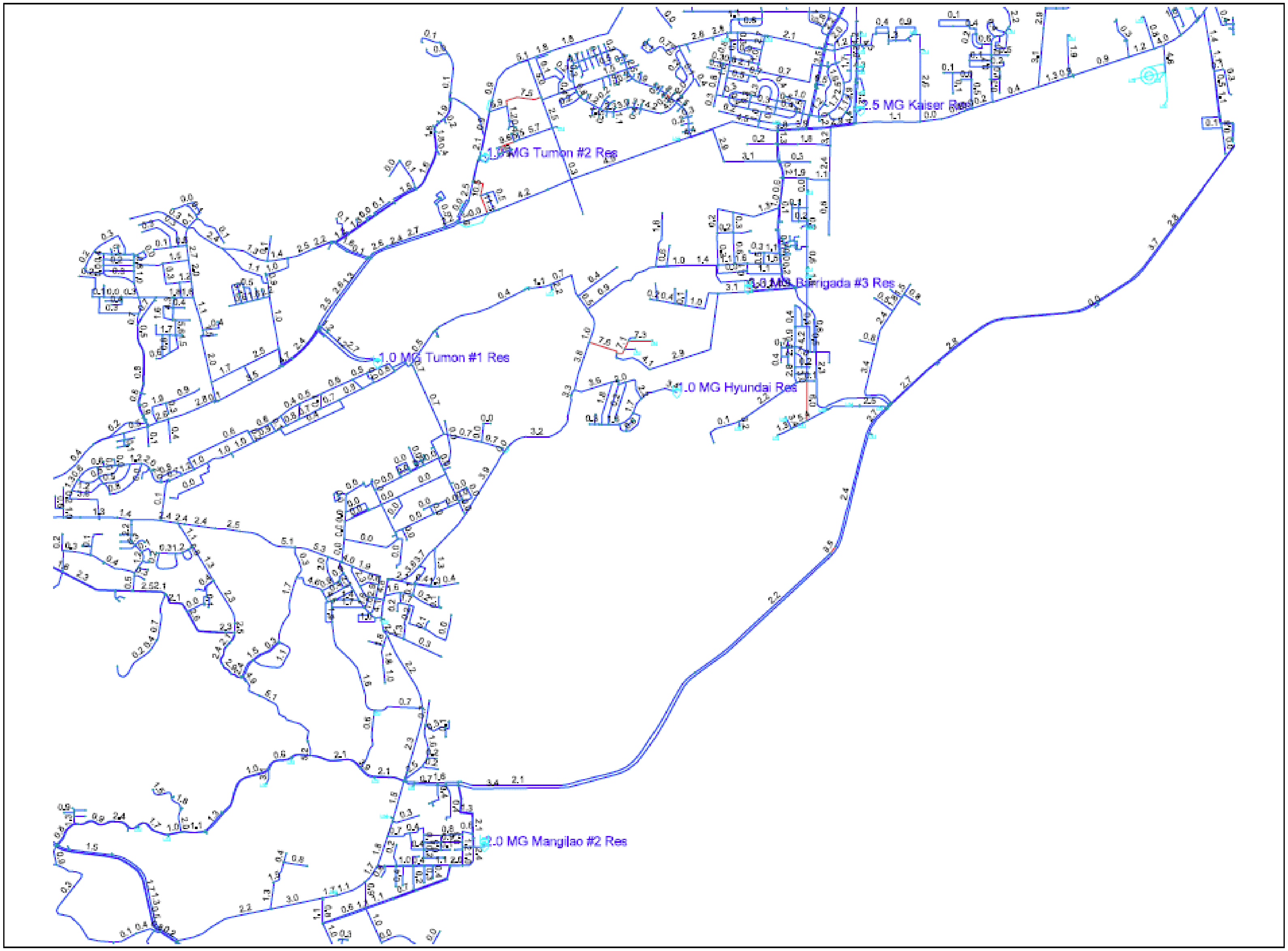


Figure 6-14 - North System 2, Max-Day, Max Velocity (>6 fps)

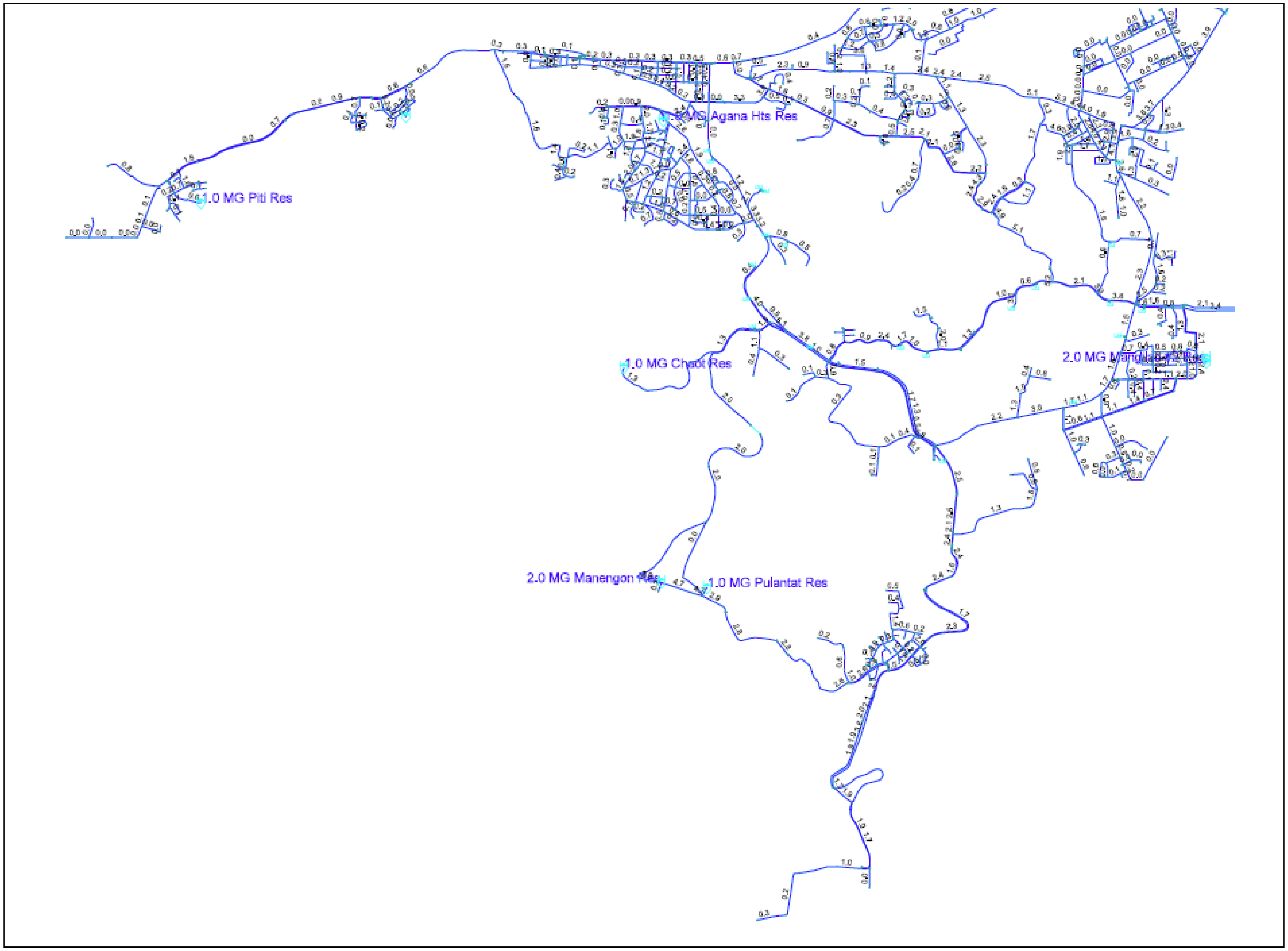


Figure 6-15 - North System 1, Max-Day 9 am, Available Fire Flow

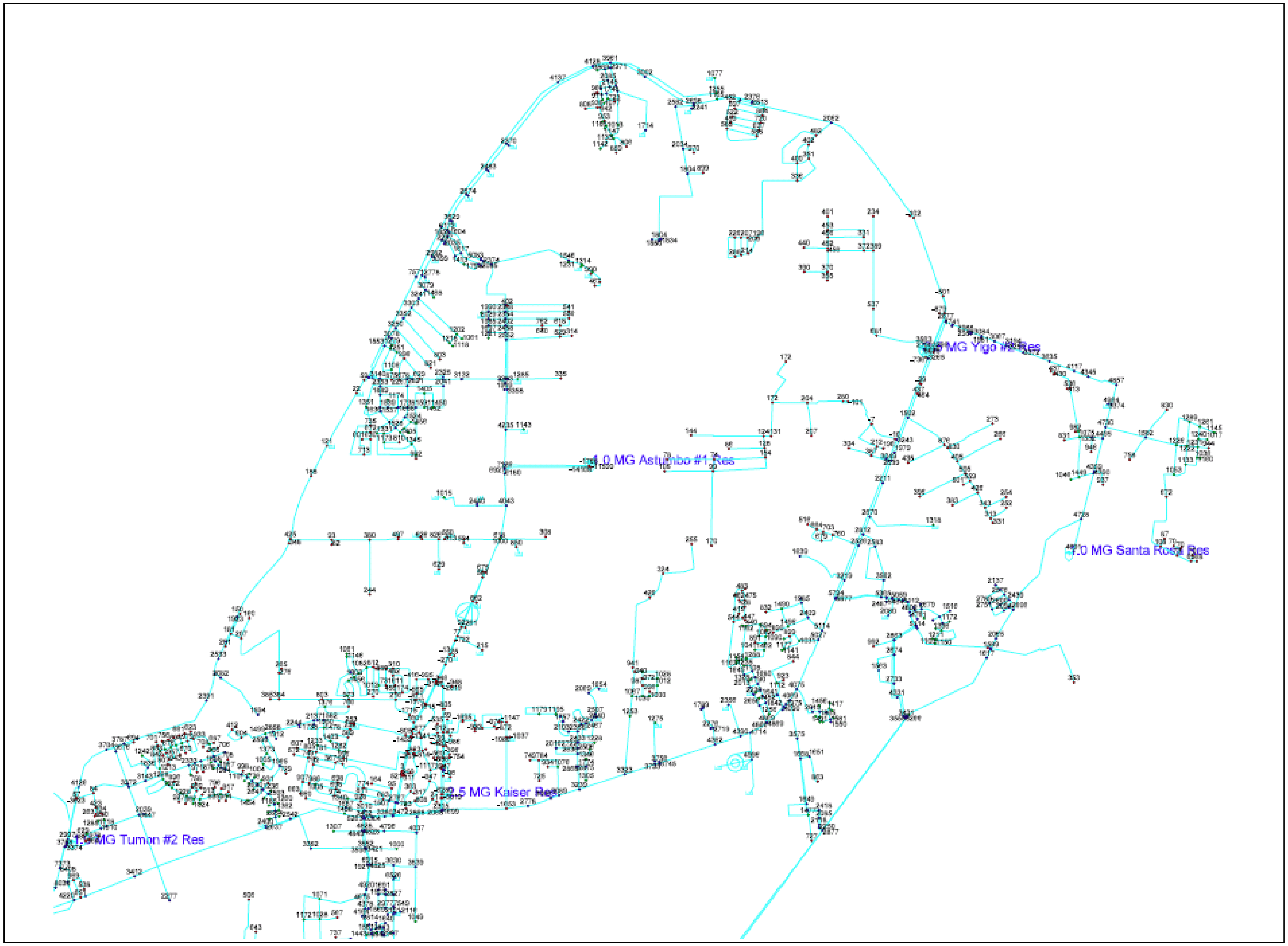


Figure 6-16 - North System 2, Max-Day 9 am, Available Fire Flow

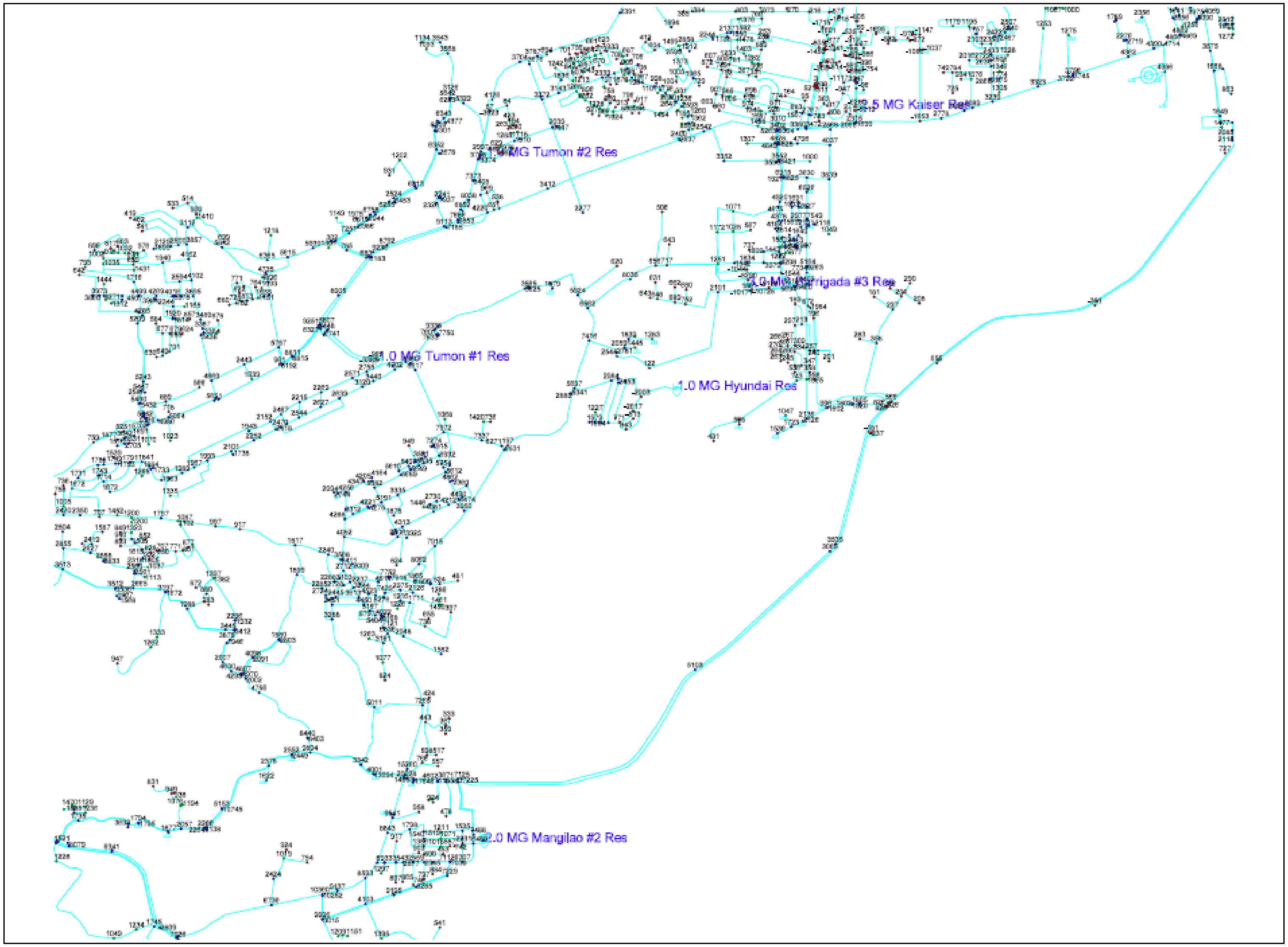


Figure 6-17 - North System 3, Max-Day 9 am, Available Fire Flow

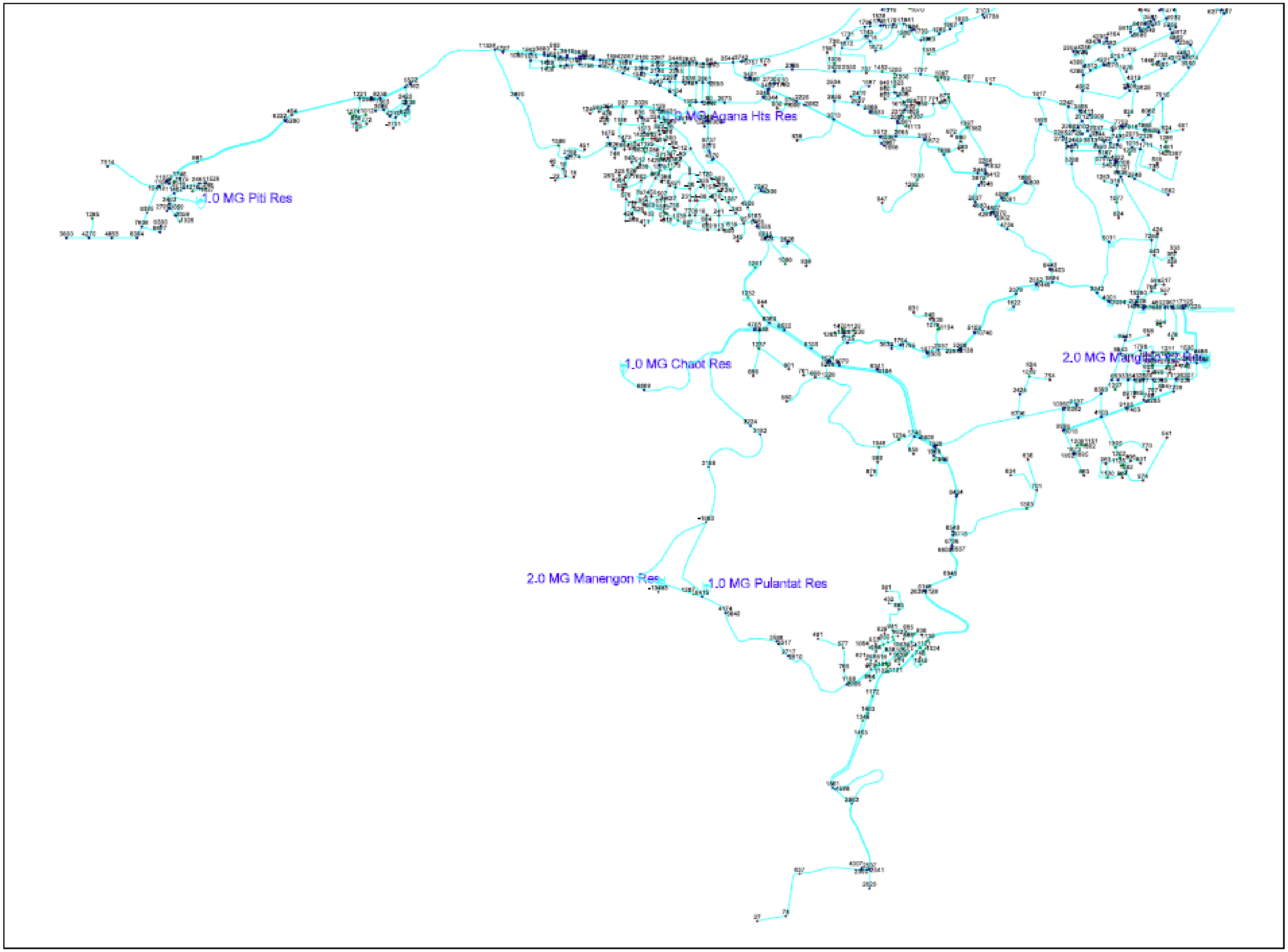


Figure 6-18 – Water System Hydraulic Model Simulation Results – North-Reservoir

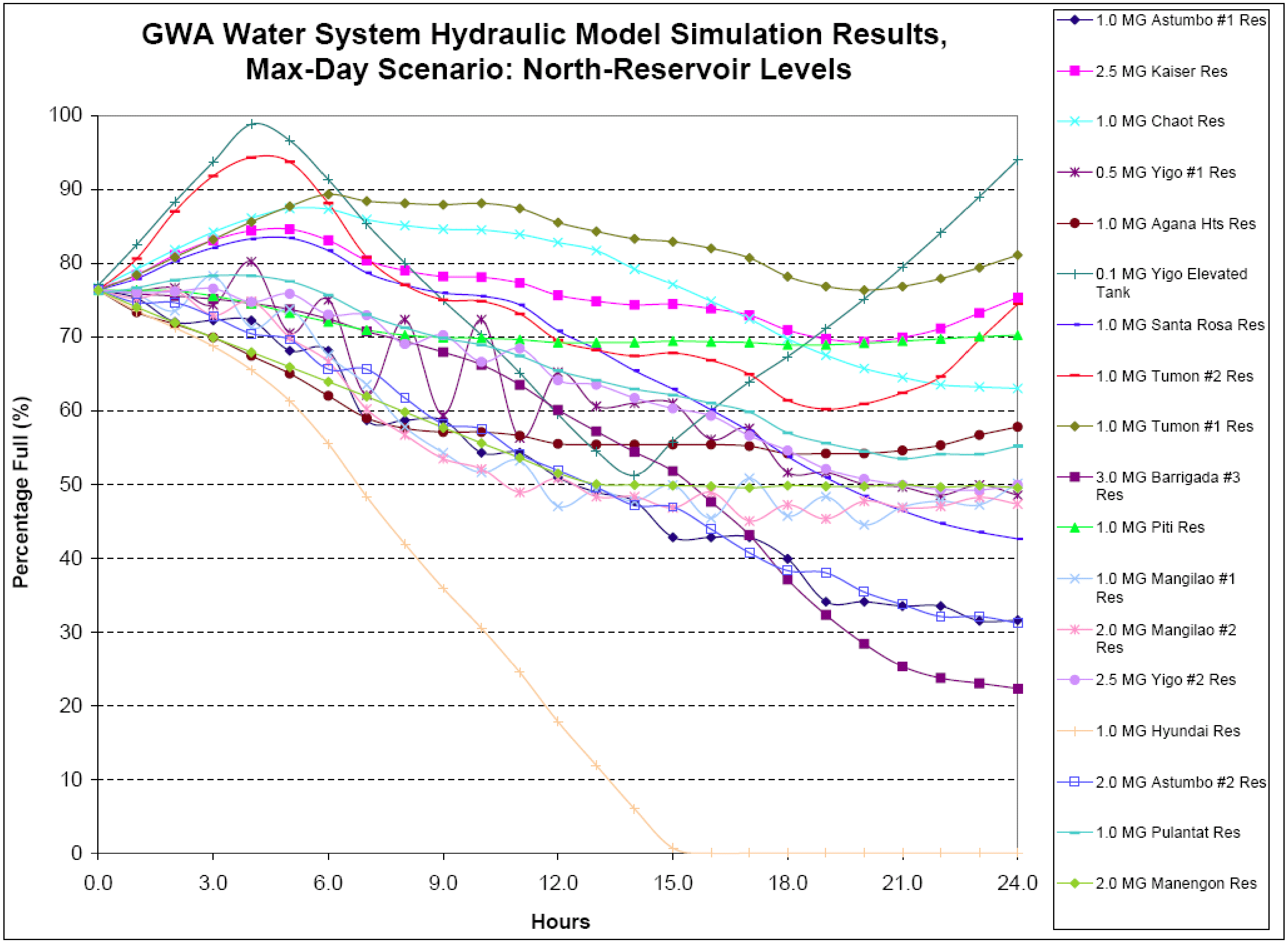


Figure 6-19 – Central System, Max-Day, Min Pressure (<40 psi)

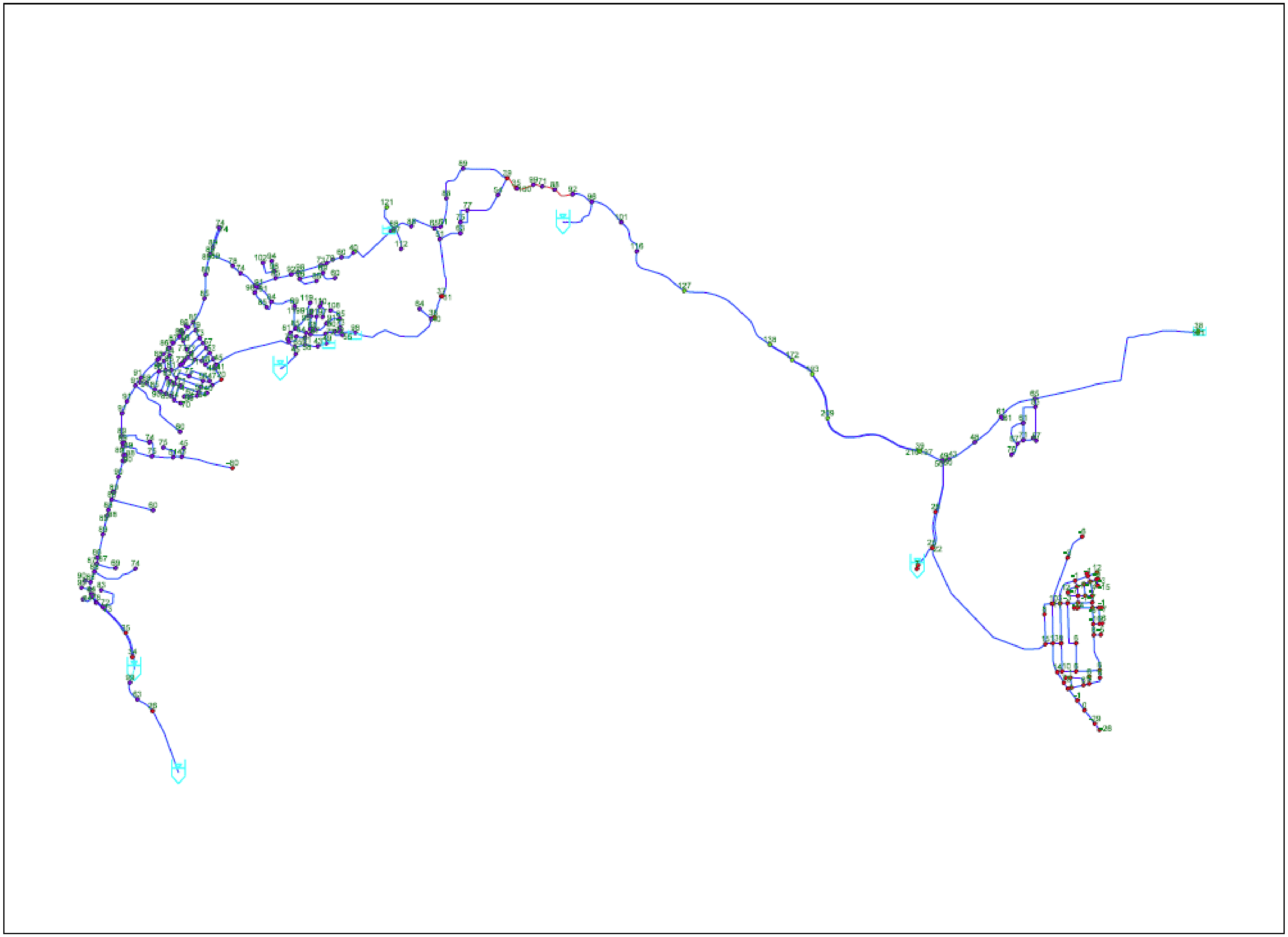


Figure 6-20 – Central System, Max-Day, Max Velocity (>6 fps)

Figure 6-21 – Central System, Max-Day, Available Fire Flow (min 20 psi residual pres)

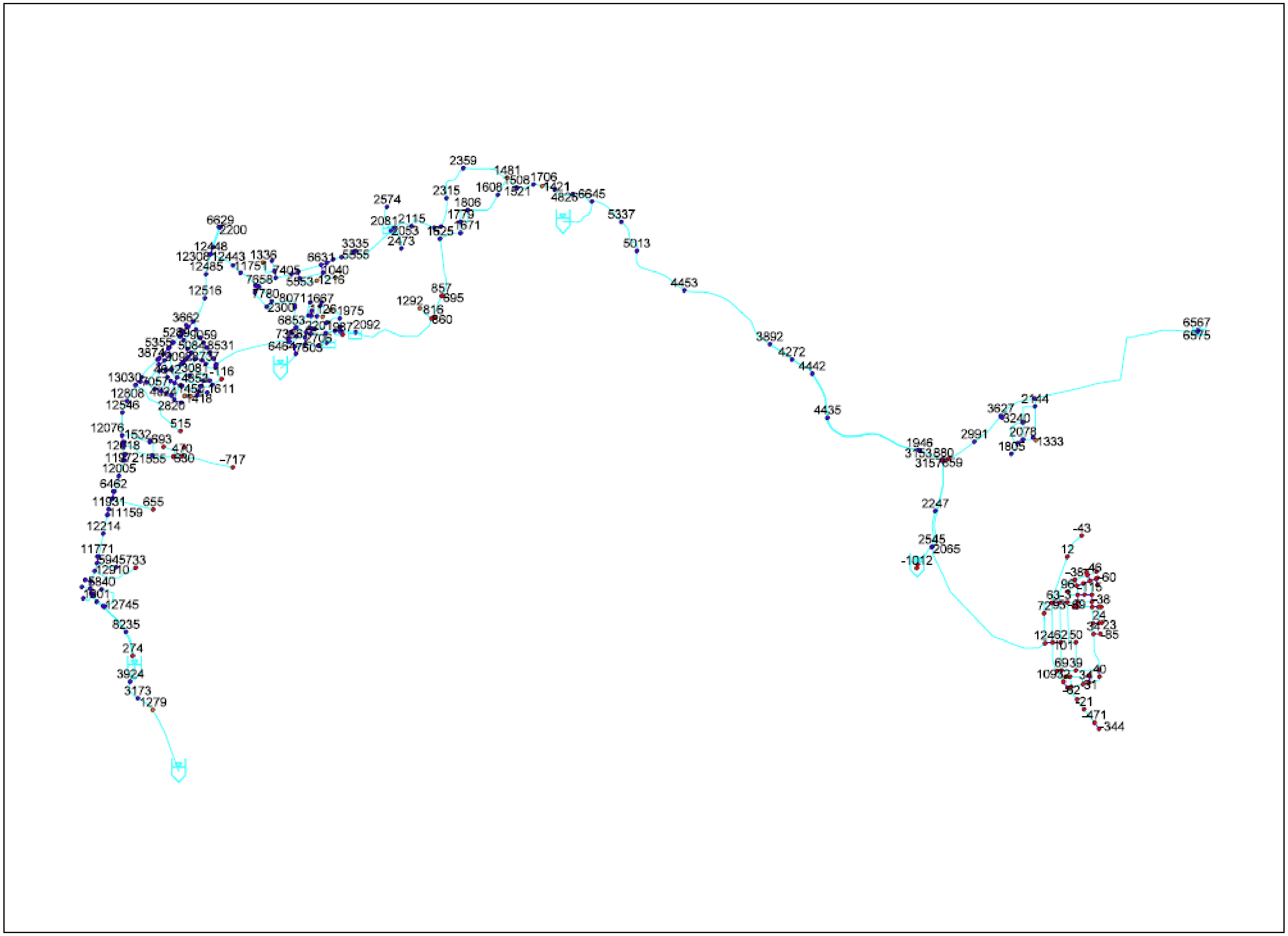


Figure 6-22 – South System, Max-Day, Min Pressure (<40 psi)

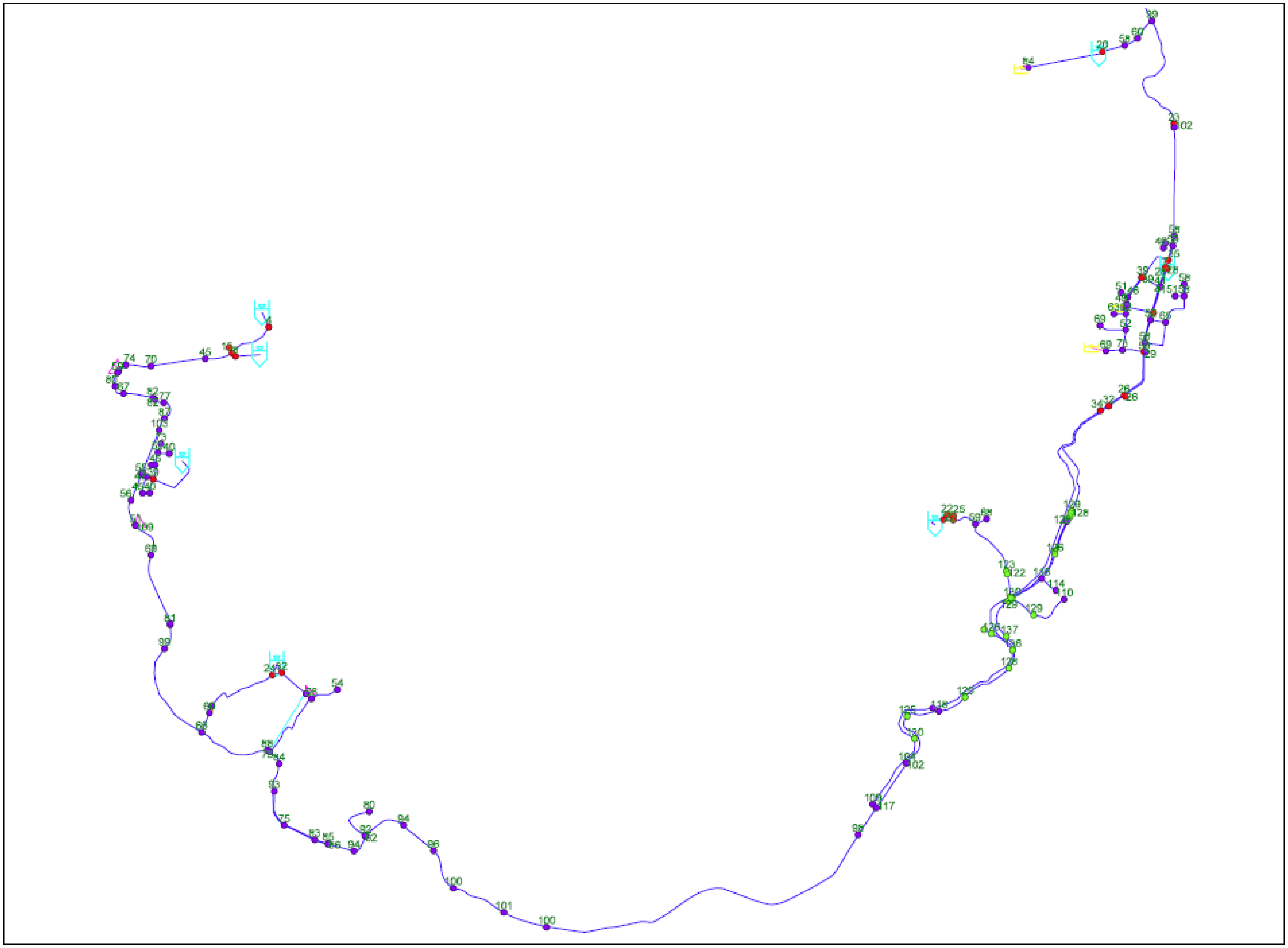
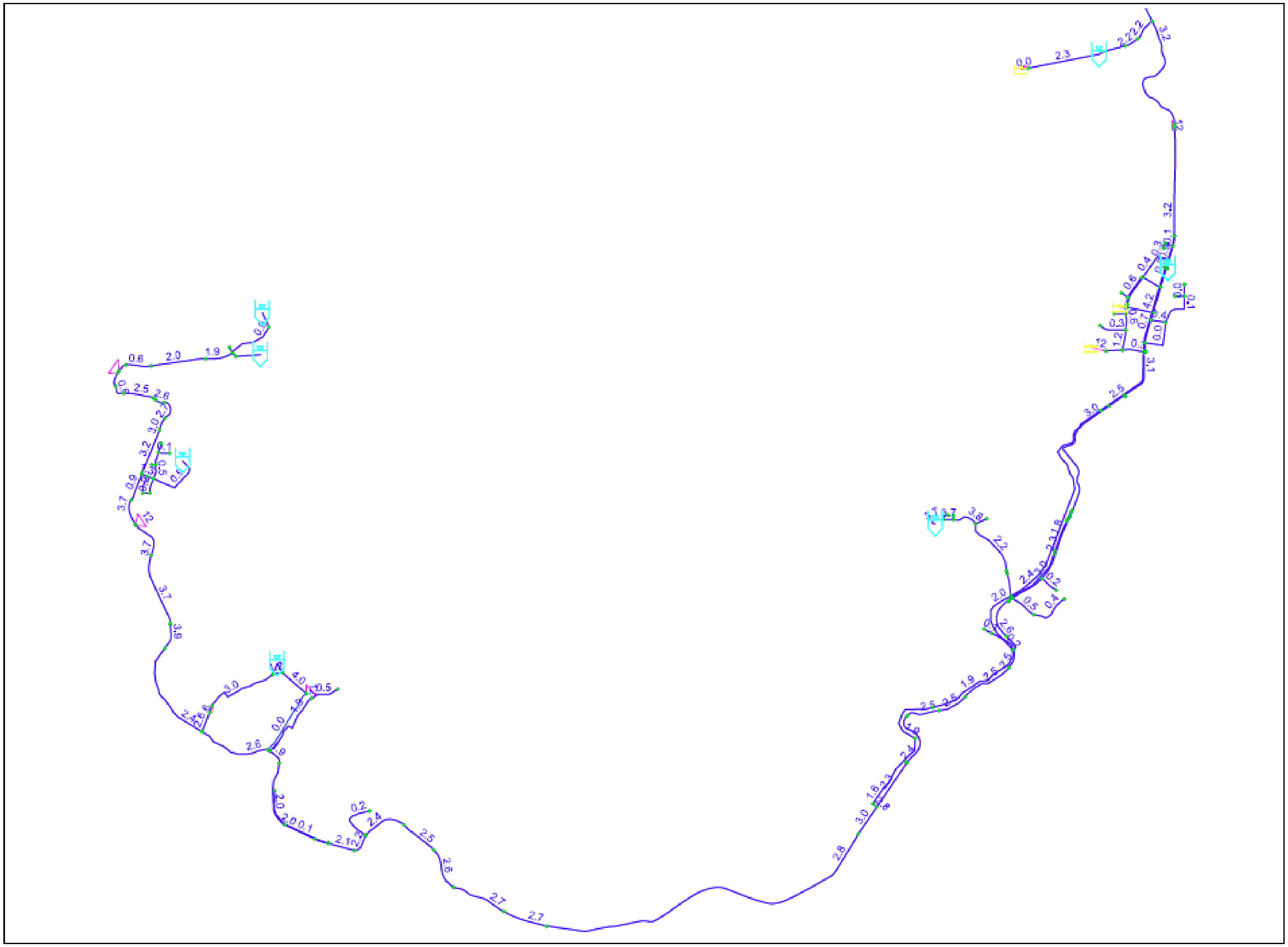


Figure 6-23 – South System, Max-Day, Max Velocity (>6 fps)



"This is a draft report and is not intended to be a final representation of the work done or recommendations made by Brown and Caldwell. It should not be relied upon; consult the final report."

Figure 6-24 – South System, Max-Day 9am, Available Fire Flow (Min 20 psi residual pres)

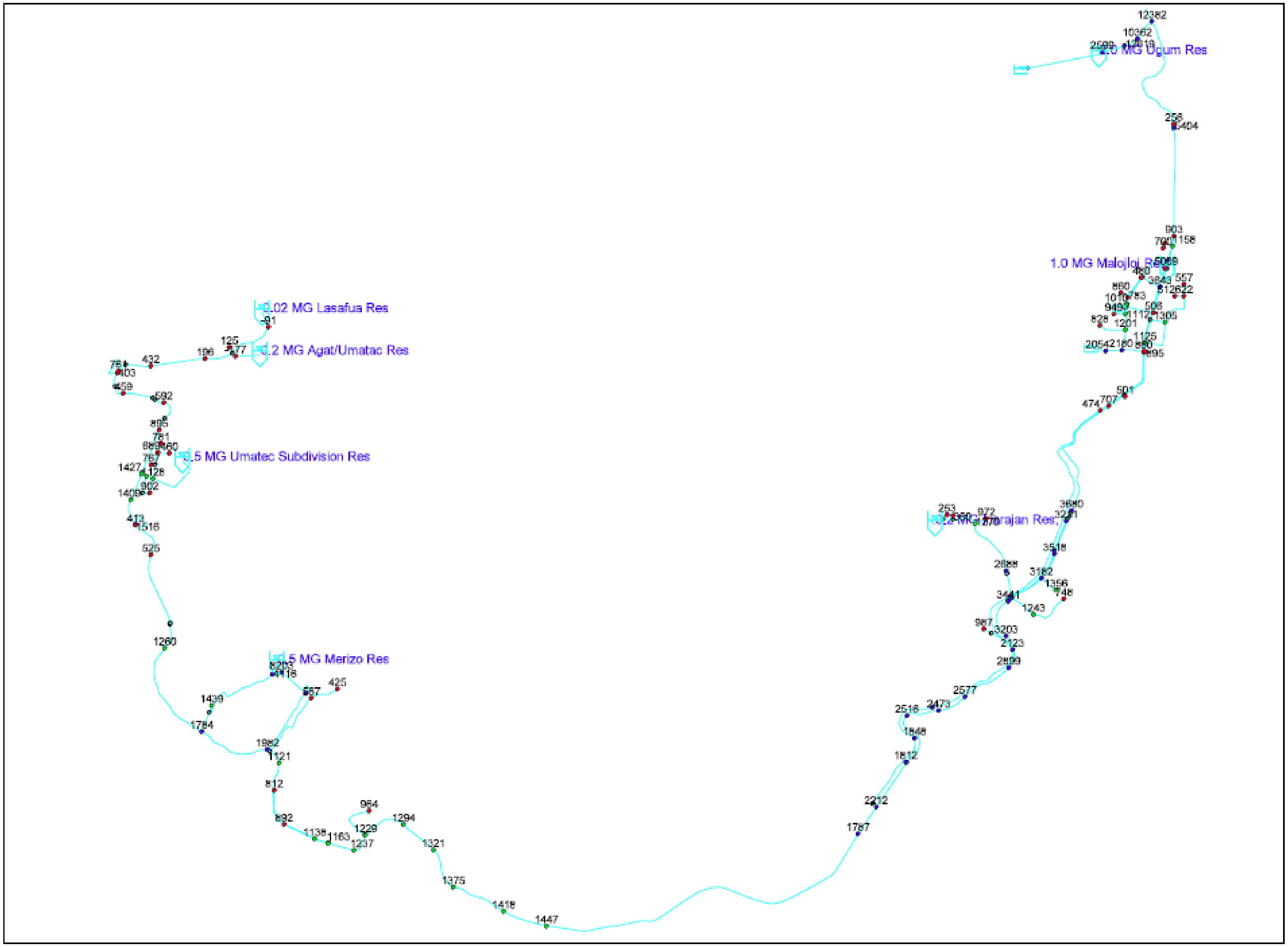
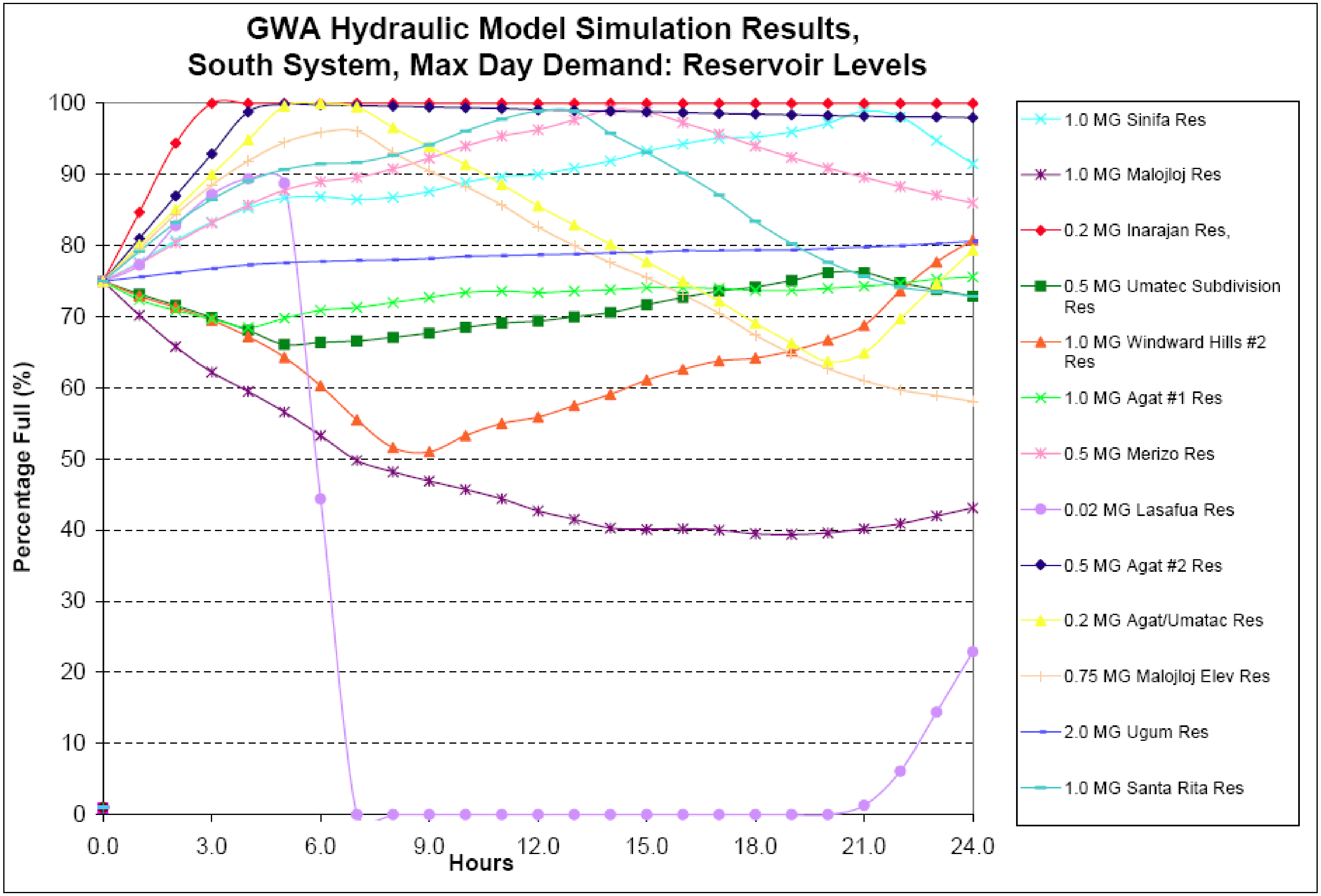


Figure 6-25 – Hydraulic Model Simulation, South System, Max Day Demand – Reservoir Levels



"This is a draft report and is not intended to be a final representation of the work done or recommendations made by Brown and Caldwell. It should not be relied upon; consult the final report."