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 CIP, which includes 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 transmission and distribution systems to utility standards.

6.1.2 Design

Network-analysis design applications include the sizing of various types of facilities. Wells, pipelines, pump stations, pressure-regulating valves, elevated tanks and ground 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 the 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 North System, the Central System and the South System as reflected on Figure 1-1, Water System Boundaries in Chapter 1 of this volume. A detailed description of the GWA water distribution system, along with deep wells, water reservoirs and water booster pump stations (BPS) that are a part of the water system model, can be found in Chapter 1 of this volume. The deep wells, water reservoirs and water booster pump stations are shown on Figures 1-3a thru 1-3e, 1-13 and 1-12, respectively in Chapter 1 of this volume.

GWA is responsible for supplying potable water to customers living in areas ranging from sea level to elevation over 700 feet. In order to provide customers with adequate water pressure, multiple pressure zones are needed due to the varying topography of the island. The existing pressure zone boundaries are depicted in Chapter 1 of this volume. These existing pressure zone boundaries were developed based on the known information about the GWA water system, especially the locations of PRVs and BPS. However, it is important to note that field verifications of these pressure zone boundaries have not been performed.

The hydraulic modeling program used for this project is H_2OMAP Water Version 6.0, a product of MWH Soft, Inc. H_2OMAP Water 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.

The GWA hydraulic model includes all distribution system facilities and pipelines (six inches in diameter and greater, as well as smaller pipelines where necessary to connect facilities and/or complete a loop.). 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 Water 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 (ECM)** – 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.
- **2005 CIP Planning Model (CPM)** – This is a modified version of the ECM. It was used to study different CIP alternatives to resolve the various system deficiencies identified by the ECM 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.
- **2025 CIP Investigating Model (CIM)** – This is a modified version of the 2005 CPM. It was mainly used for two purposes:
  1. To investigate the impacts of future population increases have on the GWA water system, and
  2. To investigate the feasibility of restructuring the North water system, so that most of the existing wells pump directly into reservoirs. Essentially, the North system capacity will be driven only by the reservoir hydraulic head without the added head from the well pumps.

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 patterns
- Submodel merging
- Modification of the model

In creating the 2005 ECM, the GWA water system was divided into three 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 three 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.

For the purpose of the hydraulic model, the North and South submodels are connected on the east side of the island by a 12-inch transmission main on Route 4. A valve on this pipeline is normally closed, which causes the two submodels to operate independently. The normally closed valve is located just south of the Route 4 and Route 17 junction. The boundary point between the North and Central submodels is defined as the Brigade BPS. All facilities downstream of the Brigade BPS are considered the Central submodel. The Central and South submodels are not connected on the west side of the island between Agat and Umatac. The Central and North submodels are not connected on the west side of the island between Piti and Santa Rita.

These three submodels were individually created and validated and then merged to form the full model. The full model was examined to ensure that hydraulic balance status was maintained after merging the three submodels. The merged full model formed the first complete version of the GWA water system model, titled the 2005 ECM. Following completion of this first version, CIP pipe and facility modifications were incrementally added to create a second version of the model titled 2005 CPM.

6.3 Model Network Development

The GWA model consists of a water system network, water supply and water demands. The water system network includes pipes, nodes, PRVs and pressure sustaining valves (PSVs), check valves, closed valves, elevated tanks, ground reservoirs and 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 a projected 2005 GWA customer population of over 157,000 and historical 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 hydraulic model. Primary data needs for the model development are the following:

- Water system infrastructure geometry
- Water demand quantity and diurnal patterns
- Ground surface elevation
- Water system operating procedures and controls

The model requires geo-referenced data for all pipelines in the water system as well as ancillary facilities including BPSs, PRVs, PSVs 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 pipe network. A geodatabase, using the ESRI ArcInfo software, was constructed by digitizing available water system as-built drawings. A detail description of the GWA geodatabase is provided in Volume 1, Chapter 9 – GIS Program. 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.

Pipes six inches 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% 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 required for the model to function properly, the missing pipes were digitized from the USGS or GWA/EPA map. In the south area about six 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 GIS database as well as the hydraulic model.

The hydraulic 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, transmission 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 most probable pressure zone the pipe is part of (generally, the maximum hydraulic grade).
- MATERIAL – This is a character field that identifies the pipe material.
- PHASE – This is a number field that holds the unique Phase identifier for each element in the model. The following phase numbers were used for this project and are typical for all elements in the model.
  - Phase 11: Existing water system elements that were modified for the CIP model.
  - Phase 12: New water system elements created for the CIP model. (Includes all reactivated wells).
  - Phase 13: New water system elements that were currently under design or construction.
  - Phase 30-70: Proposed projects.
  - Phase 96: Nimitz Hill water system (not included in the active model).
- LINING, YR_RETIRE, COST_ID – These are fields that are standard in the H_2OMAP software but are not currently used for this model.

6.3.1.2 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 Table 8-3 in Chapter 8, Water Distribution Systems of this volume.
- 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. Most of the pipes have a default 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 an "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.
- 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 2005 average day demand value assigned to the demand node. Units are gpm.
- PATTERN1 – This is a character field that identifies the name of the diurnal curve (PATN4) used to modify the demand for the junction to simulate hourly changes in demand over a 24-hour period.
- DEMAND2 – This is a number field that contains the 2005 population value (information only) assigned to the demand node based on the Development Polygon. Units are number of people.
- PATTERN2 – Zero diurnal pattern (PATN1) used to prevent the population value affecting the junction demand.
- DEMAND3 – This is a number field that contains the 2005 average 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 (PATN4) used to modify the demand for the junction to simulate hourly changes in demand over a 24-hour period.
- DEMAND4 – This is a number field that contains the 2005 CIP New Water Supply value assigned to the demand node. Units are gpm. This has to be a negative value in order to represent supply instead of demand.
- PATTERN4 – Normalized maximum day diurnal curve (PATN6) used to modify the new supply value for the junction.
- DEMAND5 – This is a number field that contains the 2025 CIP New Water Supply value assigned to the demand node. Units are gpm. This has to be a negative value in order to represent supply instead of demand.
- PATTERN5 – Normalized maximum day diurnal curve (PATN6) used to modify the new supply value for the junction.
- DEMAND6 – This is a number field that contains the 2025 population increases (information only) assigned to the demand node based on the scaling factor developed for each pressure zone. Units are number of people.
- PATTERN6 – Zero diurnal pattern (PATN1) used to prevent the population value affecting the junction demand.

- DEMAND7 – This is a number field that contains the 2025 average day demand increases @ 150 gpd per person. Units are gpm.
- PATTERN7 – This is a character field that identifies the name of the diurnal curve (PATN4) used to modify the demand for the junction to simulate hourly changes in demand over a 24-hour period.
- DEMAND8 – This is a number field that contains the five percent reduction of the 2005 average day demand. Units are gpm. This has to be a negative value in order to represent the reduction in demand.
- PATTERN8 – This is a character field that identifies the name of the diurnal curve (PATN4) used to modify the demand for the junction to simulate hourly changes in demand over a 24-hour period.
- DEMAND9 – This is a number field that contains the 2025 average demand increases assigned to the Large Water Users. Units are gpm.
- PATTERN9 – This is a character field that identifies the name of the diurnal curve (PATN4) used to modify the demand for the junction to simulate hourly changes in demand over a 24-hour period.
- DEMAND10 – This is a number field that contains the 2005 Navy Water Supply value assigned to the demand node. Units are gpm. This has to be a negative value in order to represent supply instead of demand.
- PATTERN10 – Normalized maximum day diurnal curve (PATN6) used to modify the supply value for the junction.

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 downstream pressure zones for the valve element.
- 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 pump 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 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 pump 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 discharge pressure zones for the pump element.
- 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. All pumps in this model are assigned type 1 when the pump 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.
- 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 in the model have initial status of "none". 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 BPSs locations were identified through the digitizing effort, field investigation and GWA staff input. Some PRV information, such as pressure settings, upstream and downstream pressure, remains unknown due to the age and conditions of the PRVs. Initial BPS information including number of duty and standby pumps, flow, horsepower, total dynamic head and rpm were collected from the asset inventory results. Limited operations mode information for the BPS was provided by GWA staff.

6.3.5 Tanks

Tanks were created in H_2OMAP to simulate elevated tanks, ground reservoirs, groundwater sources and Navy sources in the distribution system. The GIS geodatabase provided an initial source of information for locating reservoirs throughout the island. The GWA/EPA map and the 1968 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 Simplification and Improvement

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, six 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 six inches in diameter or shorter than 30 feet long were removed from the model.
- Deep wells in them 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. This is only a theoretical number, as the wells pump at varying rates based on the system hydraulic grade that they are experiencing throughout the extended period simulation. Considerable effort was made to adjust the pump design head to limit the well flow rate to below the EPA permit number during normal operating condition.
- 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 atypical "overflow relief valve" located between the Manengon and Pulantat Reservoirs.

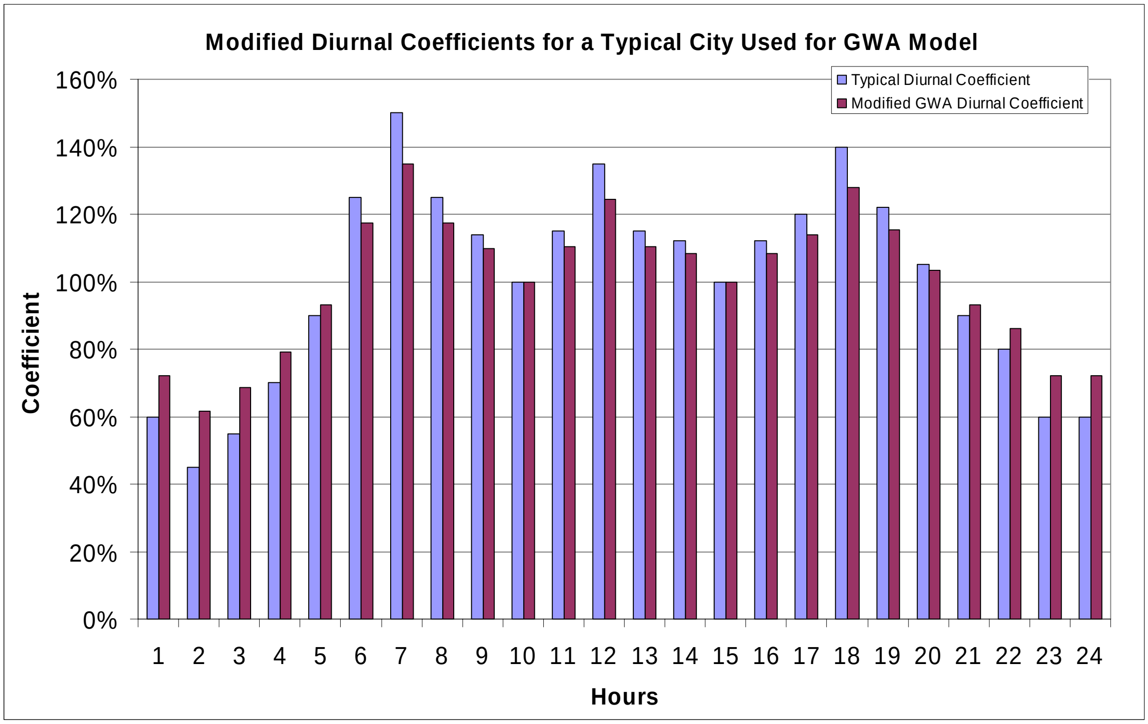
- Pumps and regulator stations with downstream check valves are modeled without a separate check valve because the valve and pump entities have built-in check valve functions within the software.
- The September 2004 monthly bill from the Air Force indicated four meter locations and the flow at each of these locations.
  - Agafa Gumas: 121 gpm
  - Marbo Power Plant: 0.48 gpm
  - Tarague (Castro's) Beach: 3.63 gpm
  - Ritidian Point: 0.00 gpm

  Subsequently, GWA confirmed that as of September 2006, the only major Air Force Meter, Agafa Gumas has been terminated. Therefore, the Air Force meters are not modeled because the remaining three Air Force meters have minimal impacts to the hydraulics of the entire system.
- Several small booster pump stations are not included in the model. For a planning model, the following small pump stations have minimal impacts to the hydraulics of the entire system.
  - Chalan Paluan (Astumbo) Booster
  - Northern Treatment Plant Booster
  - Santa Rosa Booster
  - Camacho's Booster
  - Pale Kiren Booster
  - Ulloa/Untalan Booster
  - Pigua Booster
  - Santa Ana Lower Booster
- 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 the tank entity has built-in altitude valve function within H_2OMAP, altitude valves were 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 Navy supply connections are modeled as either a negative demand node or a virtual tank/pump system similar to the wells. Virtual tanks with fixed heads

set at the hydraulic grades of the Navy supply 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 turned 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 detail information is not available; a standard diurnal curve for a typical city was modified to account for the atypical water loss percentage of the GWA system. This modified diurnal curve was used to simulate water usage patterns throughout the GWA system as shown on Figure 6-1.
- The typical diurnal curve is based on a water system with approximately five percent water losses and the actual GWA water losses exceed 50%. It is assumed that the GWA system leaks are constant throughout the day and out of the 50% water losses, 30% is estimated to be actual system leakage and 20% to be water theft. Therefore, the standard diurnal curve was modified to simulate the effect of a constant 30% system leakage.
- The "Trace Network" tool in H_2OMAP was used to identify and resolve connectivity problems. Connectivity is necessary for the model to run 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 6-1 – Diurnal Model



6.5 Water Supply

The model water supply included deep wells, springs, military supplies and Ugum WTP in the south. The water supply sources are discussed in details in Chapter 1 of this volume.

6.5.1 Deep Wells

There are 119 wells in the North, none in Central and 2 standby wells in the South. In February 2006 there were 97 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 February 2006.

6.5.2 Navy (FENA) Water Supply

A list of Navy supply connections and their locations were presented in Table 1-2 in Chapter 1 of this volume. The metered Navy supply connections were modeled as either source nodes or virtual tank/pump. Unmetered and small connections are not included in the model due to their negligible impact on the overall water system.

6.5.3 Ugum WTP

The Ugum WTP was modeled as a virtual tank/pump and a variable head reservoir. This configuration represents a steady flow of 2.2 mgd water supply located in the southeastern part 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/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 the water systems are based on the year 2005 GWA population. 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 (Andersen Air Force Base and Apra Harbor Navy Base) 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. Developed areas were identified in the census tracts by review of aerial photos.

The population projections for each municipality were divided into census block groups. The census block group's current and future populations were provided as part of the Guam Population and Land Use Projections Report by D.E. Consulting, April 2005.

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 buildings present. In addition, a shapefile with partial land use information was used to supplement the aerial to draw the polygons. The model 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. Figures 6-2 to 6-5 shows the development polygons color coded with the 2005 population for the South, Central and North Systems, 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 (0.17 gpm per person) to get the average day water demand. The demand per capita was determined by calculating an overall water mass balance for the GWA system as described in Section 6.7.

Figure 6-2 – 2005 Populations, Development Polygons and Large Water Users (South and Central)

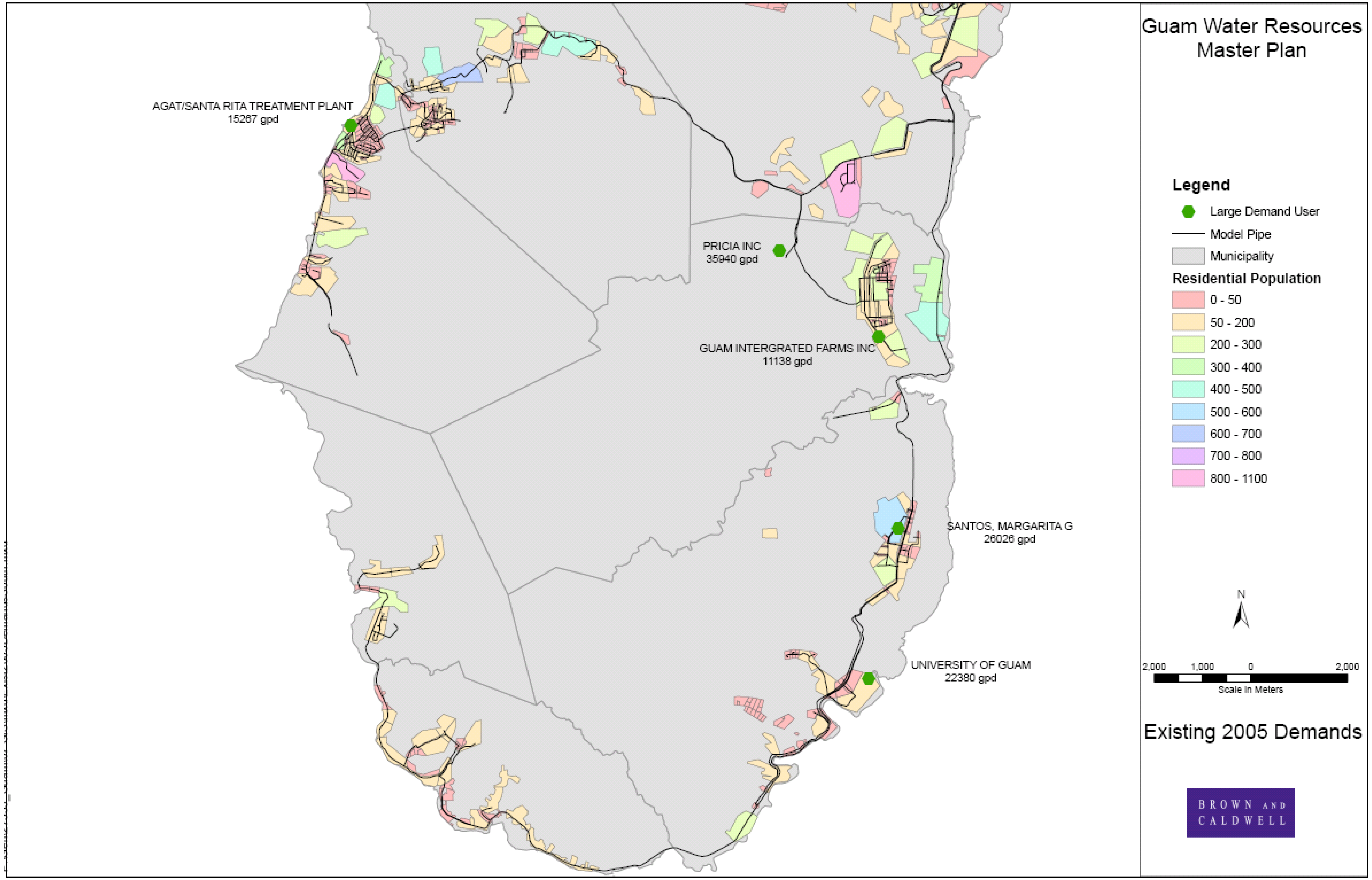


Figure 6-3 – 2005 Populations, Development Polygons and Large Water Users (North 1)

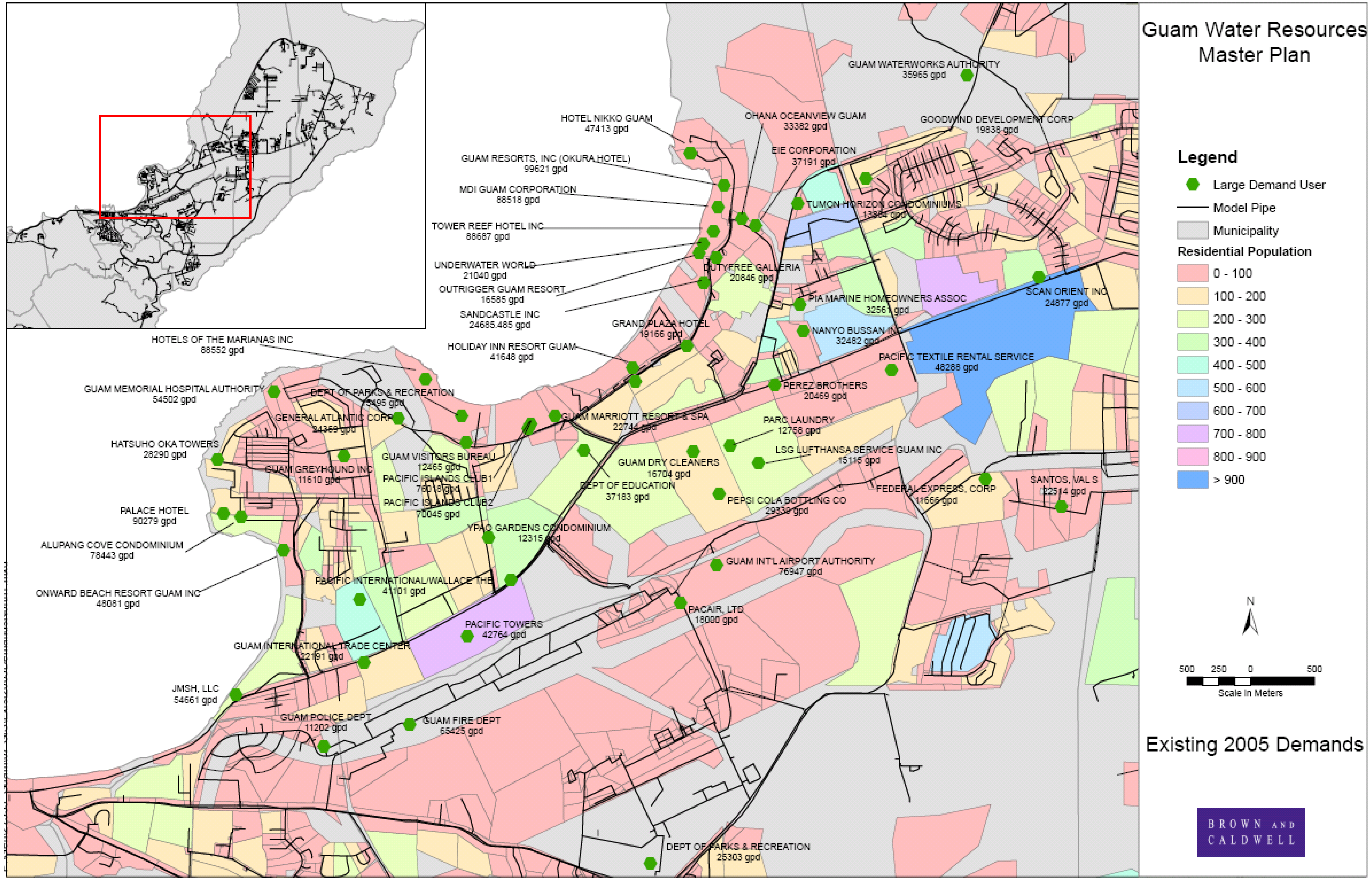


Figure 6-4 – 2005 Populations, Development Polygons and Large Water Users (North 2)

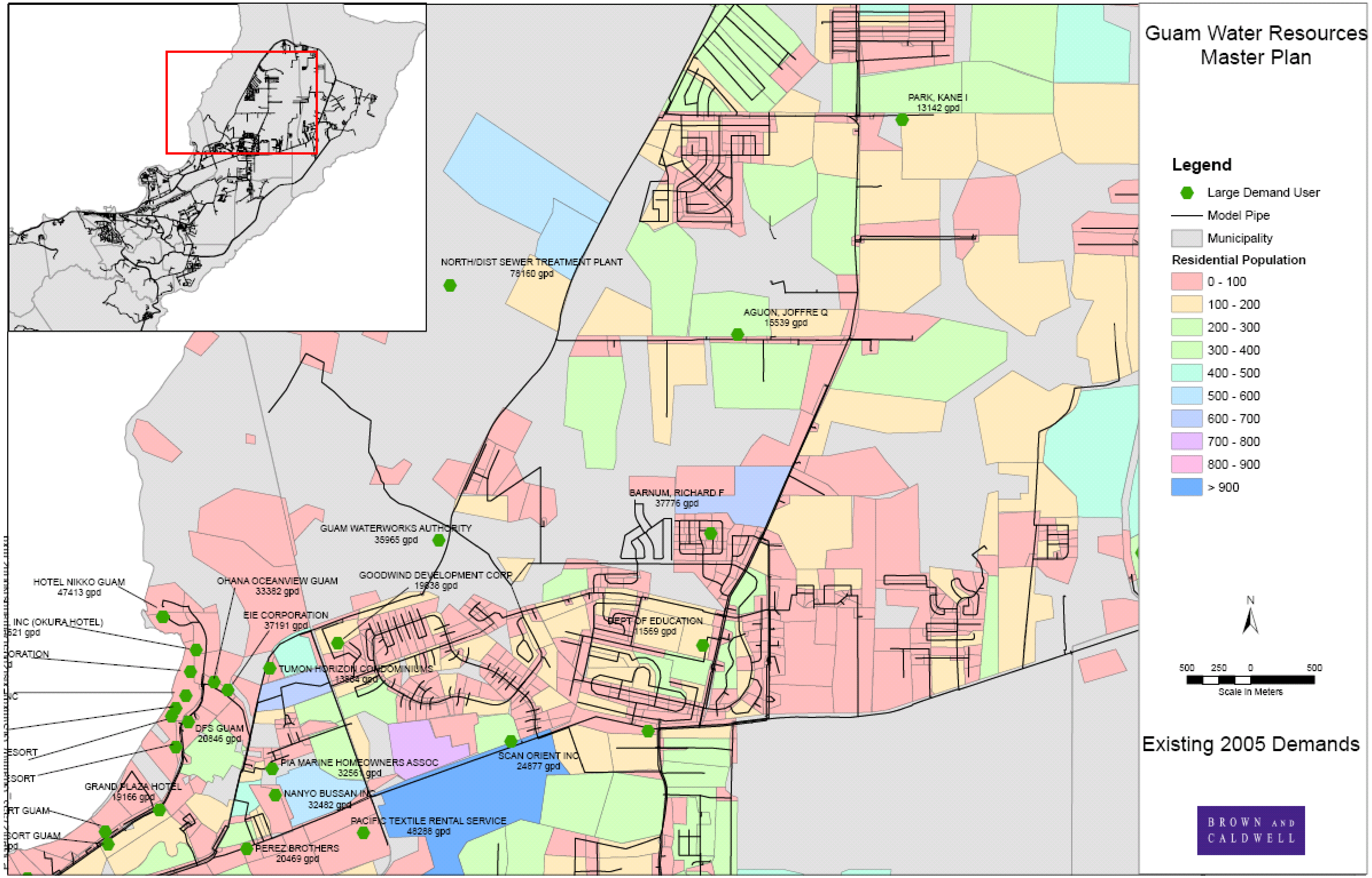
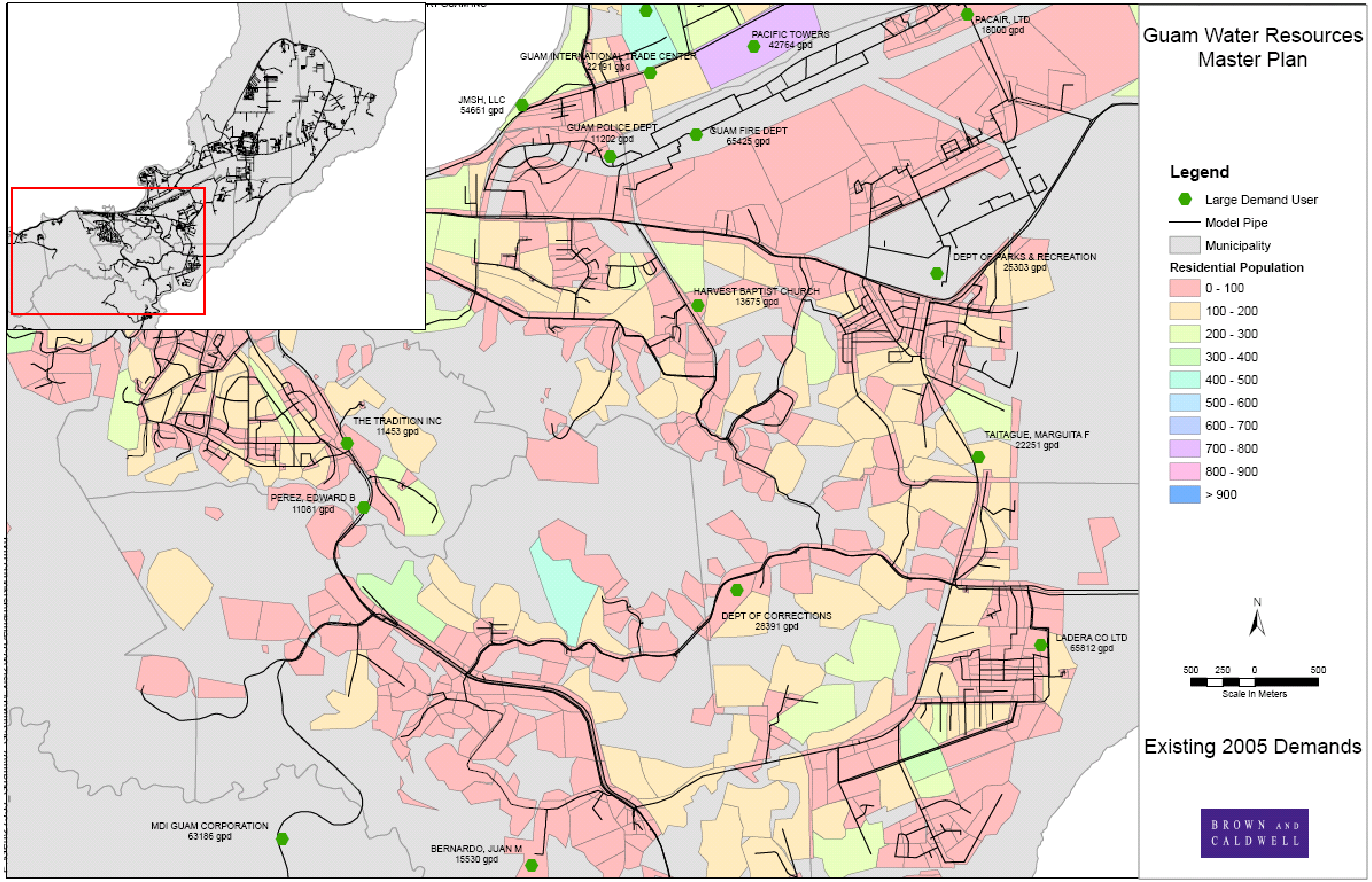


Figure 6-5 – 2005 Populations, Development Polygons and Large Water Users (North 3)



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 11,000 gpd. In total, 80 large users were selected and their locations are shown in Figures 6-2 to 6-5. The daily demand identified 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 inputted into 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

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

ID	Name	Demand (gpm)
24	DEPT OF EDUCATION	25.82
25	GUAM WATERWORKS AUTHORITY	24.98
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

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

ID	Name	Demand (gpm)
60	GREGORIO F PEREZ INC	11.06
61	AGUON, JOFFRE Q	10.79
62	BERNARDO, JUAN M	10.78
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 Demand 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 Average Day), and peak hour (= 3.0 x Average Day). It is assumed that the GWA system leaks are constant throughout the year and out of the 50% water losses, 30% is estimated to be actual system leakage and 20% to be water theft. Therefore, the standard peaking factors were modified to simulate the effect of a constant 30% system leakage. The peak hour multiplier (3.0 x Average Day) is considered to be relatively high and thus create an overly conservative system design. Due to the absence of any actual demand data to support the high peak hour multiplier, a more realistic multiplier (2.25 x Average Day) is recommended.

6.6.4 Fire Flows

The fire flow requirements are based on the Hawaii Water System Standards as presented in Table 8-2, Fire Flow Requirements found in Chapter 8 of this volume.

6.7 Mass Balance and Demand per Capita

The GWA water supply is attributed to five sources, each of which provides varying quantities of potable water. Table 6-2 breaks down the water supply sources. 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% of the water supply. Data for this source was provided by the GWA for all available 2005-2006 months. 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% of the GWA water supply. The former Earth Tech wells provide about eight percent of the total GWA water supply. The water supply contribution for the Ugum WTP was provided in monthly total flows by GWA for the months of May and June 2005. The water contribution from the Santa Rita Spring was based on the GWA WRMP June 2005.

Table 6-2 – Guam Water Supply Sources

Source	South Quantity (mgd)	North Quantity (mgd)	Total (mgd)
Deep Wells[1]	0.1	31.7	31.8
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
Former Earth Tech Wells[5]	n/a	3.5	3.5
Total	3.2	38.8	42.0

1. Average production over the period from January 2005 to February 2006 based on the GWA Monthly Deep Wells Production Report for Feb 2006.
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. 2004-2005 production report by GWA

Based on customer billing records from April 2005, GWA was able to account for 21.0 mgd. The remaining balance, 21.0 mgd, was considered "unaccounted-for" water and was not billable to the customers. "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 approximately 50% of the total system production, which is relatively high compared with the prevalent range of 10-15% 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 from the census block group shapefile (157,000 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 (42.0 mgd) and dividing by the 2005 GWA population. The 117 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, 251 gpcd (0.17 gpm per capita), 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.

Table 6-3a to Table 6-3c summarized the water demand and supply by pressure zones. Table 6-3d summarized the water demand and supply by water systems as defined specifically for the GWA hydraulic model.

Table 6-3a – Water and Supply by Pressure Zones, South System

ZONE	Ugum	Proposed Inarajan	Pigua	Umatac Sub	Malojloj	Malojoloj Elevated	Proposed Agat/ Umatac
Description	S256	S297	S334	S360	S410	S450	S500
D1, 2005 Demand, gpm	186	229	173	106	274	252	61
D2, 2005 GWA Population	1068	1314	995	609	1571	1445	348
D3, 2005 Large User, gpm		16				18	
D4, 2005 New Supply, gpm					-150		
D10, Navy/AF Supply, gpm							
2005 CIP Well Supply, gpm	0	0	0	0	0	114	0
2005 Existing Storage, MG	2.0	0.2	0.5	0.5	1.0	0.1	0.0
2005 CIP Storage, MG	2.0	0.2	0.5	0.5	1.0	0.1	0.1
2005 CIP BPS Transfer, gpm	-1280	0	50	100	930	200	250
2005 CIP PRV Transfer, gpm	0	244	123	6	-244	0	0

Table 6-3b – Water and Supply by Pressure Zones, Central System

ZONE	Santa Ana Lower (Agat #1)	Truman #2	Santa Rita	Windward Hills	Santa Ana Upper (Agat #2)	Prop Talofofo	Truman #1	Sinifa
Description	C236	C275	C392	C444	C470	C510	C517	C725
D1, 2005 Demand, gpm	1013	313	245	272	6	459	181	158
D2, 2005 GWA Population	5819	1799	1409	1562	33	2640	1041	907
D3, 2005 Large User, gpm	11			25		8		
D4, 2005 New Supply, gpm				-250				
D10, Navy/AF Supply, gpm			0					
2005 CIP Well Supply, gpm	0	0	0	0	0	0	0	0
2005 Existing Storage, MG	1.0	0.0	1.0	1.0	0.5	0.0	0.0	1.0
2005 CIP Storage, MG	1.0	0.0	1.0	1.0	0.5	0.1	0.0	1.0
2005 CIP BPS Transfer, gpm	-350	0	1300	500	350	500	200	600
2005 CIP PRV Transfer, gpm	1023	313	-1336	0	0	0	181	-442

Table 6-3c – Water and Supply by Pressure Zones, North System

ZONE	Piti/ Tumon	Mangilao /Chaot	Kaiser	Pulantat	Manen-gon	Barri-gada	Yseng-song	Yigo	Hyundai	Yigo Elevated/ Santa Rosa	Proposed Mataguac
Description	N236	N381	N408	N420	N434	N481	N570	N658	N670	N724	N740
D1, 2005 Demand, gpm	3853	5545	3111	843	71	1098	4018	3594	305	635	297
D2, 2005 GWA Population	22137	31861	17872	4845	408	6311	23083	20650	1752	3648	1707
D3, 2005 Large User, gpm	1083	283	185		44	8	108	29	16		
D4, 2005 New Supply, gpm						-1250		-750			
D10, Navy/AF Supply, gpm	-816	-993									
2005 CIP Well Supply, gpm	317	7930	2556	0	0	2142	7496	5686	755	600	0
2005 Existing Storage, MG	3.1	3.0	2.5	1.0	2.0	3.0	3.0	3.1	1.0	1.1	0.0
2005 CIP Storage, MG	4.1	4.0	2.5	1.0	2.0	5.0	3.0	3.1	1.0	1.1	0.1
2005 CIP BPS Transfer, gpm	0	-1550	-400	600	450	-200	0	-850	600	550	300
2005 CIP PRV Transfer, gpm	4618	-552	1139	243	-335	-836	-6390	-1213	-1034	-515	-3

Table 6-3d – Water and Supply by Water Systems

	2005 CIP Planning Model			
	Total	Central	North	South
2005 Existing Storage, MG	31.8	4.6	22.9	4.3
2005 CIP Storage, MG	36.2	4.7	27.1	4.4
Ave Day Demand, gpm	29128	2690	25125	1313
Ave Day Demand, MGD	41.9	3.9	36.2	1.9
Max Day Demand, MGD	56.6	5.2	48.8	2.6
New CIP Supply. gpm	2400	250	2000	150
New CIP Supply, MGD	3.5	0.4	2.9	0.2
Other Supply, gpm	1400	1600	0	1400
Other Supply, MGD	2.0	2.3	0.0	2.0
Navy Supply, gpm	4042	1500	2542	0
Navy Supply, MGD	5.8	2.2	3.7	0.0
Well Supply, gpm	27596	0	27482	114
Well Supply, MGD	39.7	0.0	39.6	0.2
Total Supply, gpm	35449	3350	32024	1664
Total Supply, MGD	51.0	4.8	46.1	2.4

Notes and Assumptions:

1. The 5% demand reduction for the 2025 model is over the 2005 average day demand (5% * D1 = 5% * 39.3 = 1.97 mgd).
2. PRV Inter-PZone Transfer flow rates are estimates only.
3. For the BPS and PRV inter-Pzone Transfer, negative number indicates net output from the Pressure Zone while positive number indicates net Input to the Pressure Zone.
4. The supply number shown here are theoretical only, thus it may or may not be the same as simulated in the hydraulic model.

6.8 Conceptual Model Calibration

A conceptual model calibration effort has been carried out on the 2005 Existing Condition Model using field measured pressure data from multiple days during the months of April 2006 to June 2006. It is important to note that this is not the typical or standard method of calibrating a hydraulic model. Nonetheless, it is a good start and appears to be appropriate for this stage of the model building effort. Finally, the conceptual calibration results were surprisingly encouraging especially when taking into consideration of the inherent limitations of the GIS data, which the models were built on.

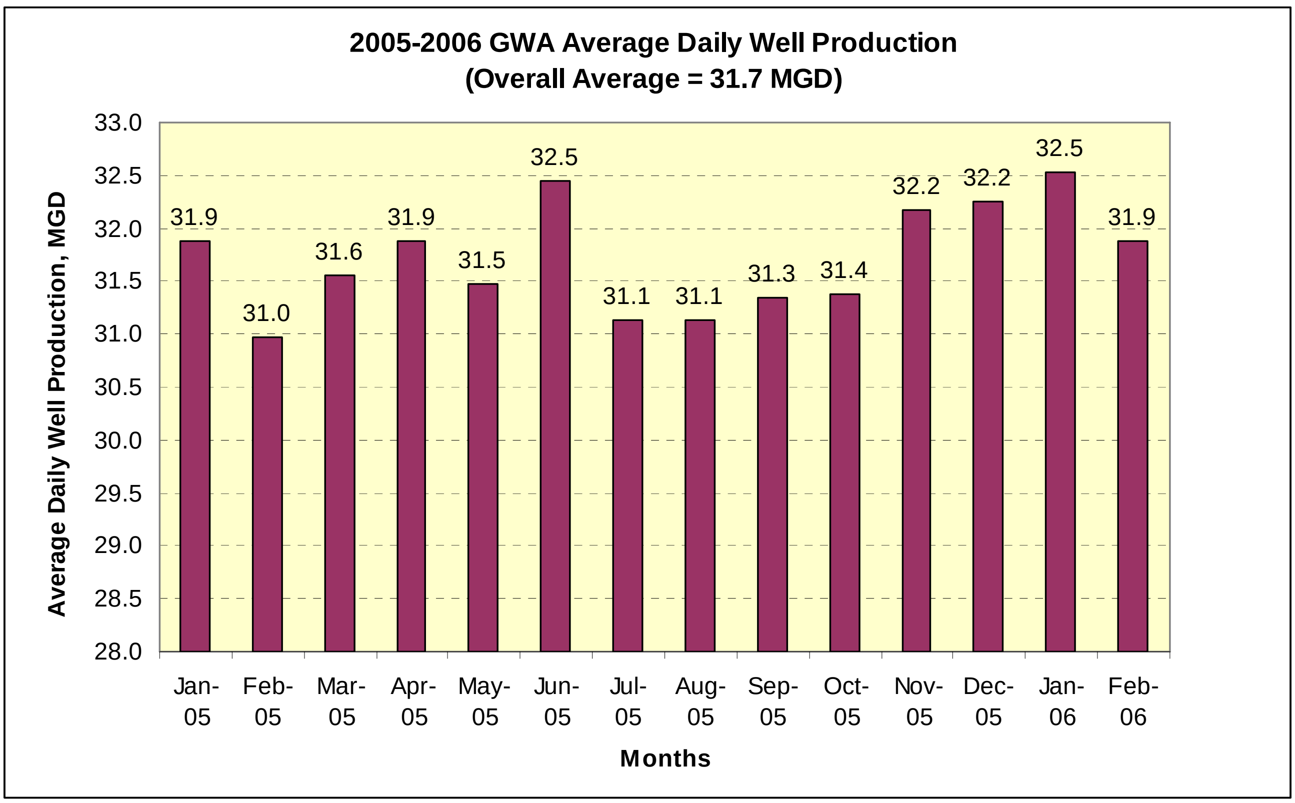
6.8.1 Field Data Collection

Field data collection should be accomplished in two phases. In the first phase, system physical data is collected to confirm data in the ECM. In the second phase, system operational data is collected for calibration. Physical data should be collected when demands are low to minimize interference in system operations. Operational data, on the other hand, should be collected during periods of greatest demand. The model calculates head losses at specific flow or demand conditions. At periods of greatest demand, the system experiences the greatest system head losses. Thus, more effective field measurements can be made of operational conditions because there is more head loss to measure at higher flows. The operational data should, therefore, be collected during or approaching maximum day demand conditions. Figure 6-6 shows the average daily water production from the GWA wells (excluding the former Earth Tech wells) from January 2005 to February 2006. The monthly variations in well production are remarkably minor (<3% variation from the average production rate), therefore it is unclear when is GWA's greatest demand period. Theoretically, the greatest demand period should coincide with Guam's dry period, which is from December to June of every year. The relatively high percentage of "Unaccounted-for water" may be the contributing factor of an overall even water production rate. For this reason, it may be necessary to artificially create high-demand conditions by conducting fire-flow tests.

Field data collected – During the months of April 2006 to June 2006, GWA staff collected the following field data in support of the conceptual model calibration effort.

- Continuous pressure monitoring data at multiple reservoir locations and key pressure zone locations.
- Instantaneous pressure reading data at the following key locations:
  - Downstream and upstream of the various booster pump stations.
  - At the base of various reservoirs.

Figure 6-6 – GWA Average Daily Well Production



6.8.2 Preliminary Calibration

The continuous pressure monitoring data were analyzed for two main purposes. First, each reservoir pressure monitoring data was examined to see if the subject reservoir was functioning properly. Table 6-4 presents the preliminary reservoirs calibration data and observations. Under normal demand condition, a reservoir should be filled over night to its normal operating level (over 75%) by the early morning (5 to 6 am) and then its water level should fluctuate over the next 24-hour period, roughly following the typical diurnal pattern.

Table 6-4 – Preliminary Reservoirs Calibration Data

Reservoir Name	Height, feet	General Calibration Comment
Northern System		
Airport (Tumon #1)	40.0	Normal fluctuation, low water level.
Barrigada #3	40.0	Normal fluctuation, low water level.
Hyundai	40.0	Normal fluctuation, low water level.
Kaiser Dededo	40.0	No data
Mangilao #1 & #2	40.0	Normal fluctuation, low water level.
Nissan (Tumon #2)	40.0	Out of service
Santa Rosa	40.0	Abnormal or No fluctuation, retest.
Yigo #1 & #2	40.0	Abnormal or No fluctuation, May be overflowing, retest.
Yigo Elevated	--	No Data
Ysengsong #1 & #2 (Astumbo #1 & #2)	40.0	Not enough data points, retest.
Central System		
Agana Heights	40.0	Normal fluctuation, low water level.
Chaot	32.1	Abnormal or No fluctuation, retest.
Manengon	40.0	Normal fluctuation, artificial low water level, overflow to Pulantat Reservoir @ 20 feet.
Piti	40.0	No data
Pulantat (Yona)	65.0	Abnormal fluctuation, low water level, retest.
Southern System		
Agat-Umatac	24.0	Abnormal or No fluctuation, May be overflowing, retest. Out of service?
Inarajan (Gura)	24.0	Erroneous data, retest.
Lasafua	8.	Pressure data inconsistent with instantaneous pressure reading, retest. Out of service?
Malojloj	40.0	No data
Malojloj Elevated	--	No Data
Pigua (Merizo)	40.0	Abnormal fluctuation, low water level, retest.
Santa Ana Lower (Agat #1)	40.0	No Data
Santa Ana Upper (Agat #2)	40.0	No Data
Santa Rita	40.0	No data
Sinifa	40.0	No data
Ugum	40.0	No data
Umatac Subdivision	40.0	Abnormal or No fluctuation, Low water level, retest.
Windward Hills #2	40.0	Not enough data points, seems normal fluctuation, retest.

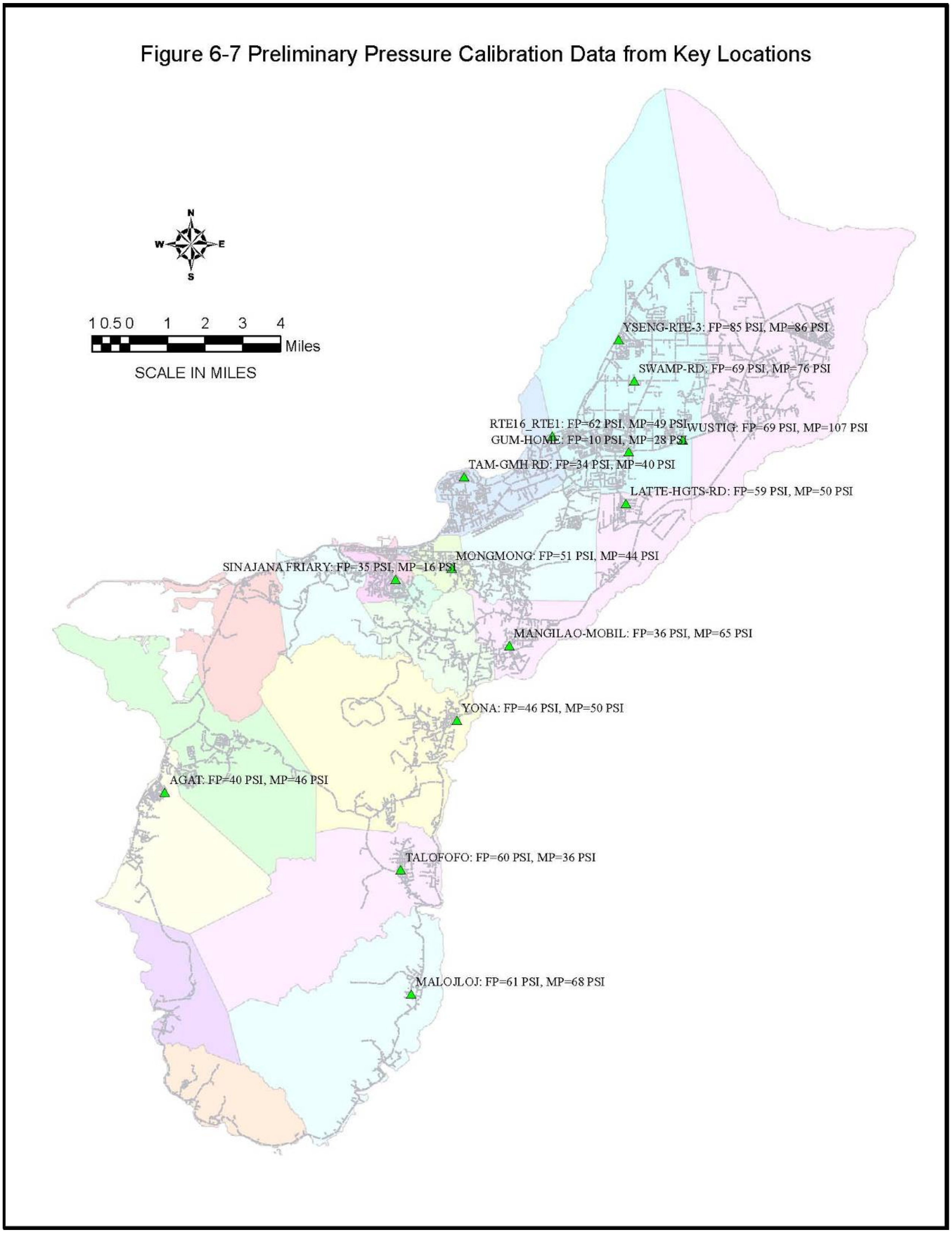
In general, most of the tested reservoirs were having low water level throughout the day and many of them showed abnormal or no fluctuation in water level. The only exceptions are the Yigo #2 and Agat-Umatac reservoirs, both of their pressure readings indicated that they might be overflowing during the monitoring period.

Secondly, the continuous pressure monitoring data from various key locations were used to study the system pressure variation over an extend period of time. The average pressures at each of these key locations were then compared with the corresponding 2005 ECM output. Overall, if the model simulation result is within 10 psi or 20% of the field measurement, then the calibration point is classified as acceptable. Table 6-5 and Figure 6-7 present the preliminary calibration data for these key locations and anomalies were found at 6 out of the 14 field locations.

Table 6-5 – Preliminary Pressure Calibration Data from Key Locations

Field Location Name	Field Elev. (Feet)	Model Elev. (Feet)	Field Pressure (PSI)	Model Pressure (PSI)	Pressure Delta (PSI)	Pressure Delta (%)	Comment
Yseng-Rte-3	341	356	85	86	-1	-1	Acceptable (Within 20%)
Agat	108	121	40	46	-6	-15	Acceptable (Within 20%)
Latte-Hgts-Rd	407	435	59	50	9	15	Acceptable (Within 20%)
Malojloj	290	288	61	68	-7	-11	Acceptable (Within 20%)
Mangilao-Mobil	211	211	36	65	-29	-81	Unaccounted-for headloss between the Yigo Reservoir and field reading location. Field investigate and Retest.
Mongmong	113	124	51	44	7	14	Acceptable (Within 20%)
Rte16_Rte1	258	245	62	49	13	21	PRV located at the intersection of Marine Dr. and A. Sanchez may affect this pressure reading. Unknown PRV settings.
Sinajana Friary	209	180	35	16	19	54	Field Pressure may be taken downstream of the Pale Kiren BPS.
Swamp-Rd	386	390	69	76	-7	-10	Acceptable (Within 20%)
Talofofo	286	287	60	36	24	40	Pipe Headloss between Windward Hill Reservoir and field reading location may be less then the model predicted. (Smoother pipe)
Tam-Gmh Rd	134	115	34	40	-6	-18	Acceptable (Within 20%)
Yona	289	270	46	50	-4	-9	Acceptable (Within 20%)
Wustig	392	392	69	107	-38	-55	Unaccounted-for headloss between the Yigo Reservoir and field reading location. Field investigate and Retest.
Gum-Home	343	335	10	28	-18	-180	Low pressure as expected for areas around Kaiser Reservoir.

Figure 6-7 Preliminary Pressure Calibration Data from Key Locations



6.8.3 Preliminary Calibration Limitation and Additional Calibration Needs

It should be noted that, the calibration efforts carried out so far are indeed a good start but they are not comprehensive and are only preliminary in nature. Likewise, information obtained from pressure tests should be recognized as a limited indication of system capabilities for several reasons. It measures pressure at a specific location in the system at a particular point in time. It does not recognize or indicate whether this is a limiting condition. It also does not indicate storage status (that is, elevation, fill demand, or output), demands of adjacent users, status of or relationship to the diurnal demand and other related factors. Further, surrounding areas may have lower pressures than the pressures at the testing location because the ground elevation is higher, localized demands, piping limitations, or other factors.

One of the major shortcomings that undermine the validity and usefulness of the preliminary calibration was the lack of continuous 24-hour flow monitoring within the GWA system. For this reason, the following additional calibration tasks are recommended:

Physical data collection

- Testing of supply pumps and booster pumps to establish curve characteristics.
- Loss-of-head testing to determine pipe-roughness coefficients.
- Geocoding the average customer demand using actual meter addresses. This task will greatly improve the model demand distribution accuracy and will be the logical step to implement following the completion of the current water meter replacement program.

Operation data collection

- Continuous 24-hour flow recordings at selected key locations, such as:
  - Water production facilities,
  - Major transmission mains,
  - Large-demand customers,
  - PRVs and PSVs between pressure zones,
  - Booster pump stations,
  - Wells and
  - Navy meters.
- Continuous pressure monitoring at all continuous-flow recordings and key fire hydrants. Instantaneous pressure monitoring at key locations.
- Continuous storage-level (hydraulic-elevation) and influence (inflow/outflow) monitoring.

Operational data should be collected over a short period, typically one to two weeks, during relatively high demands. The purpose of collecting operational data is to provide measurements and observations of actual system performance under specific demand conditions. The operational data should be collected to provide information on each key system component at each point in time, similar to a series of photographs. The distribution system should be divided into major geographical areas for monitoring demand and diurnal variations.

6.9 Model Simulation

This section contains information on working with the GWA hydraulic model. It is envisioned that the 2005 Existing Condition Model will be used mainly for reference while the 2005 CIP Planning Model and the 2025 CIP Investigating Model will be used for planning analysis. The information presented in this section addresses model usage topics specifically associated with the GWA Model. This section does not cover standard usage of the H_2OMAP modeling software. For instructions on the modeling software, please refer to the H_2OMAP user's manual.

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 "un-calibrated" hydraulic model. The existing condition model is run at the average-day demand and maximum-hour demand to debug the model and to obtain some initial predictions of distribution system performance. At this point, a functioning mathematical computer model of the GWA distribution system is established. Frequently, a calibrated model will be used to assess the impact of large demands, for example fire flows, under various conditions.

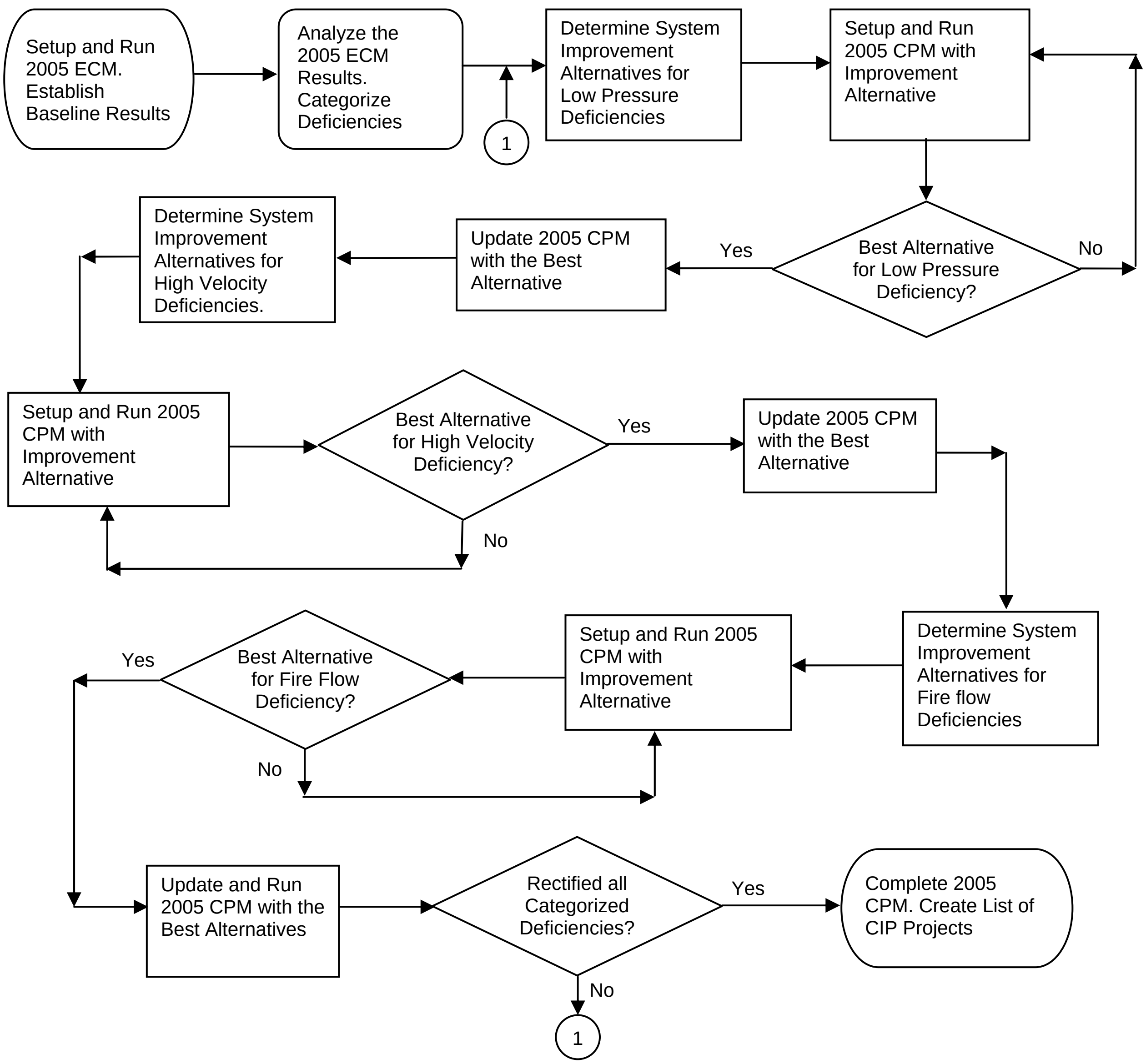
2. Extended Period Simulation (EPS)

The second type of model analysis is an EPS that 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. It is also commonly used to identify the deficiencies in the water system, such as low service pressure and high pipeline velocity.

Simulation Work Flow – This subsection describes the typical work flow from model setup to CIP projects recommendation. The hydraulic simulation analysis is an iterative process as illustrated in Figure 6-8 and consists of the following steps:

1. Setup and run the 2005 ECM. Establish baseline results of the existing GWA system.
2. Analyze the 2005 ECM results and categorize pressure, velocity and fire flow deficiencies.
3. Determine system improvement alternatives to rectify deficiencies identified in Step 2.
4. Setup and run the 2005 CPM with each improvement alternatives identified in Step 3.
5. Analyze the 2005 CPM results and identify the best alternatives for each categorized deficiencies.
6. Update the 2005 CPM with the best alternatives.
7. Complete the 2005 CPM and create list of CIP projects.

Figure 6-8 – Hydraulic Simulation Analysis Process Flow Diagram



6.9.1 Simulations Scenarios

Multiple modeling scenarios of the water distribution system have been developed using the scenario management feature of H_2OMAP. These scenarios can be used to run either the entire model or portions of the model. Each scenario activates only those elements of the model that are associated with the selected scenario.

Customized Scenarios

Both the 2005 ECM and the 2005 CPM contains the following scenarios:

1. Base Network Scenario – contains all active and inactive elements of the model, including all GWA and Non-GWA facilities. This scenario SHOULD NOT BE USED for any analysis, since all facilities are incorporated, including the inactive and virtual elements.

2. 2005 Existing Condition Model Scenario – contains all known existing elements of the GWA system except all inactive elements, such as the Navy facilities and known abandoned facilities. This scenario is the most complete version of the 2005 ECM that can be used and contains all submodels.
3. 2005 CIP Planning Model Scenario – contains all of the elements in the 2005 ECM with the following additions and modifications:
    - Inactivated the abandoned facilities.
    - Activated the new CIP facilities.
    - Updated element properties for the "to be upgraded" facilities. Typically, the modified properties are pipe diameter and pump flow rate and design head.
    - Activated all the "inactive or standby" Wells that were identified in the February 2006 Well Production Record.

The Base scenario was set up first and referred to as the "parent" scenario. The remaining scenarios were set up such that they automatically draw certain data from the Base scenario; thus, these two scenarios are referred to as the "child" scenarios. Similarly, each of the "child" scenarios also has additional "sub-scenarios" to further define a simulation for a specific purpose. For example the "2005 ECM Fire Flow Scenario" is a "sub-scenario" under the 2005 Existing Condition Model Scenario to simulate the 2005 existing fire flow condition.

Each scenario is a unique combination of one facility set, one of each type of data sets (there are a total of eleven types of data sets) and one of each type of option sets (there are a total of three types of option sets). These sets are further described as follows:

- Facility Set: Facility sets define the model elements to be used in a simulation. One unique facility set has been written for each of the scenarios. The facility sets are based on the "Intelli-Selection" option. All elements that are not selected with this option become inactive and are excluded from the model analysis. By default, these inactive elements will be gray out from the screen.
- Data Sets: Data sets store modeling data associated with each facility. There are eleven different data set types: demand, tank, pipe, pump, valve, control, logical, energy, fire flow, operation and quality. Currently, the last five data sets are not used in the Model.
- Option Sets: Option sets define simulation options. For all versions of the Model, different option sets can be selected depending on the purpose of each individual scenario.

6.9.2 2005 Existing Condition Model Simulations

Simulations were performed to analyze the existing GWA system under the 2005 Existing Condition Model 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 demand, were investigated and deficiencies in the GWA water system were identified. The typical simulation conditions are summarized as follows:

Simulation assumptions:

- A constant supply of 2.2 mgd from the Ugum WTP was used for the 2005 Existing Condition Model scenarios.
- Tank levels were started at 75% full condition for all reservoirs.
- Booster 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.

6.9.3 Simulations Results

This subsection summarizes the hydraulic model simulations results for the 2005 ECM and the 2005 CPM.

2005 Existing Condition Model

Figures 6-9 through 6-15 show the 2005 ECM simulation results for the water distribution system and reservoir water levels over a 24-hour period. These figures identify the general locations of the deficiencies in the GWA distribution system. These deficiencies were discovered through numerous hydraulic model simulations.

Figure 6-9 – 2005 Existing Condition Model: Max-Day, Min Pressure (<40 psi)

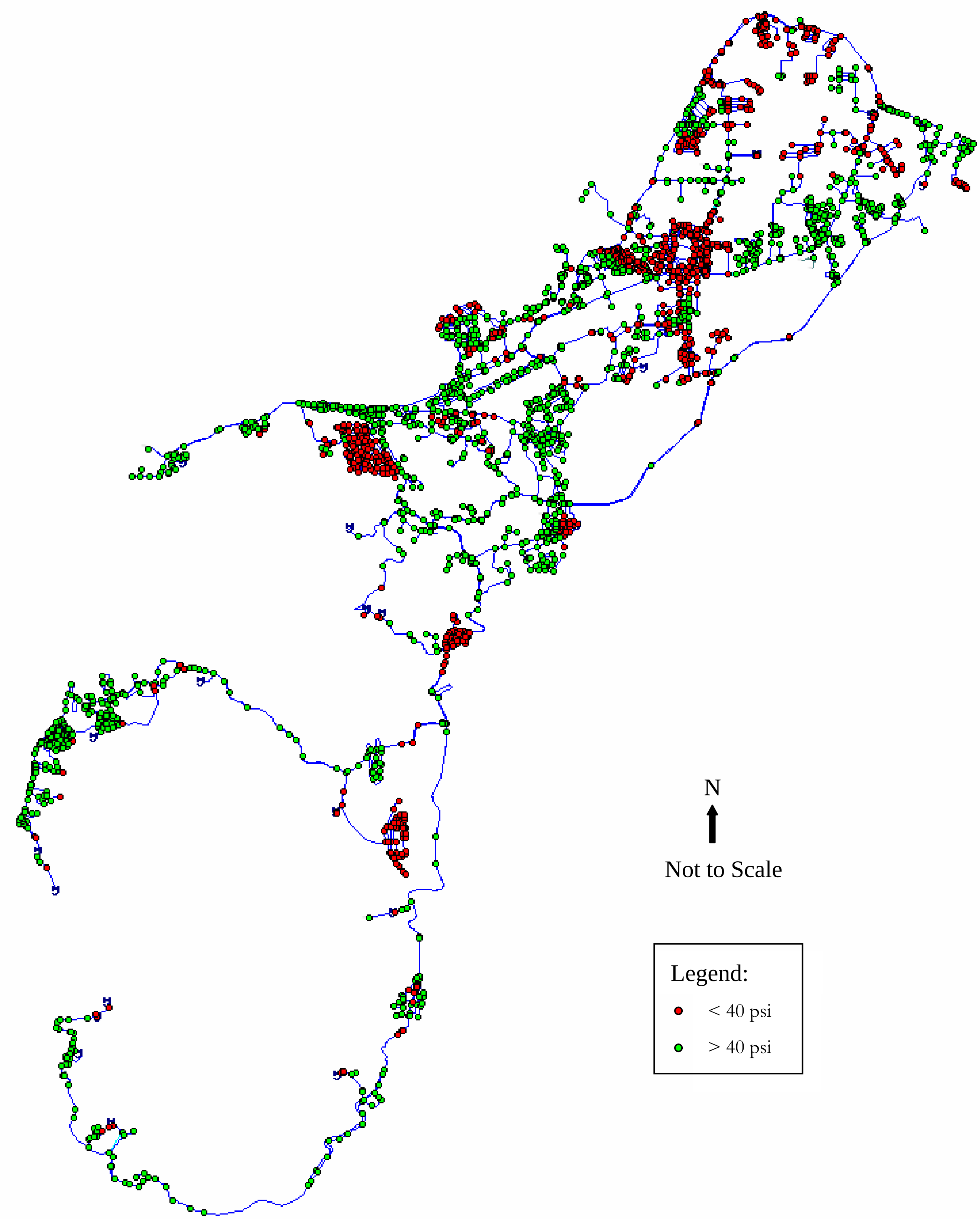


Figure 6-10 – 2005 Existing Condition Model: Max-Day, Max Velocity (>6 fps)

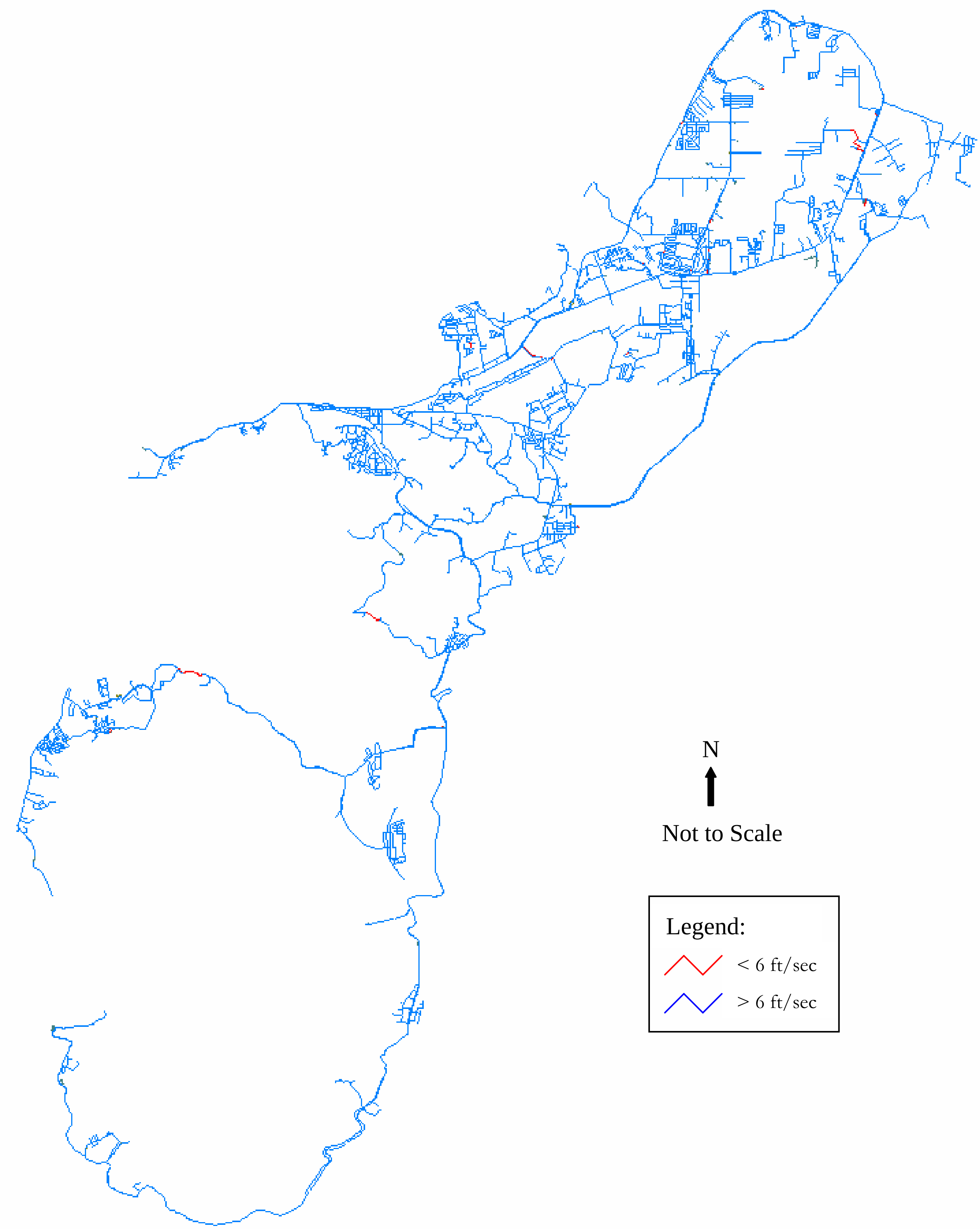


Figure 6-11 – 2005 Existing Condition Model: Max-Day, Available Fire Flow (Min 20 psi residual pressure)

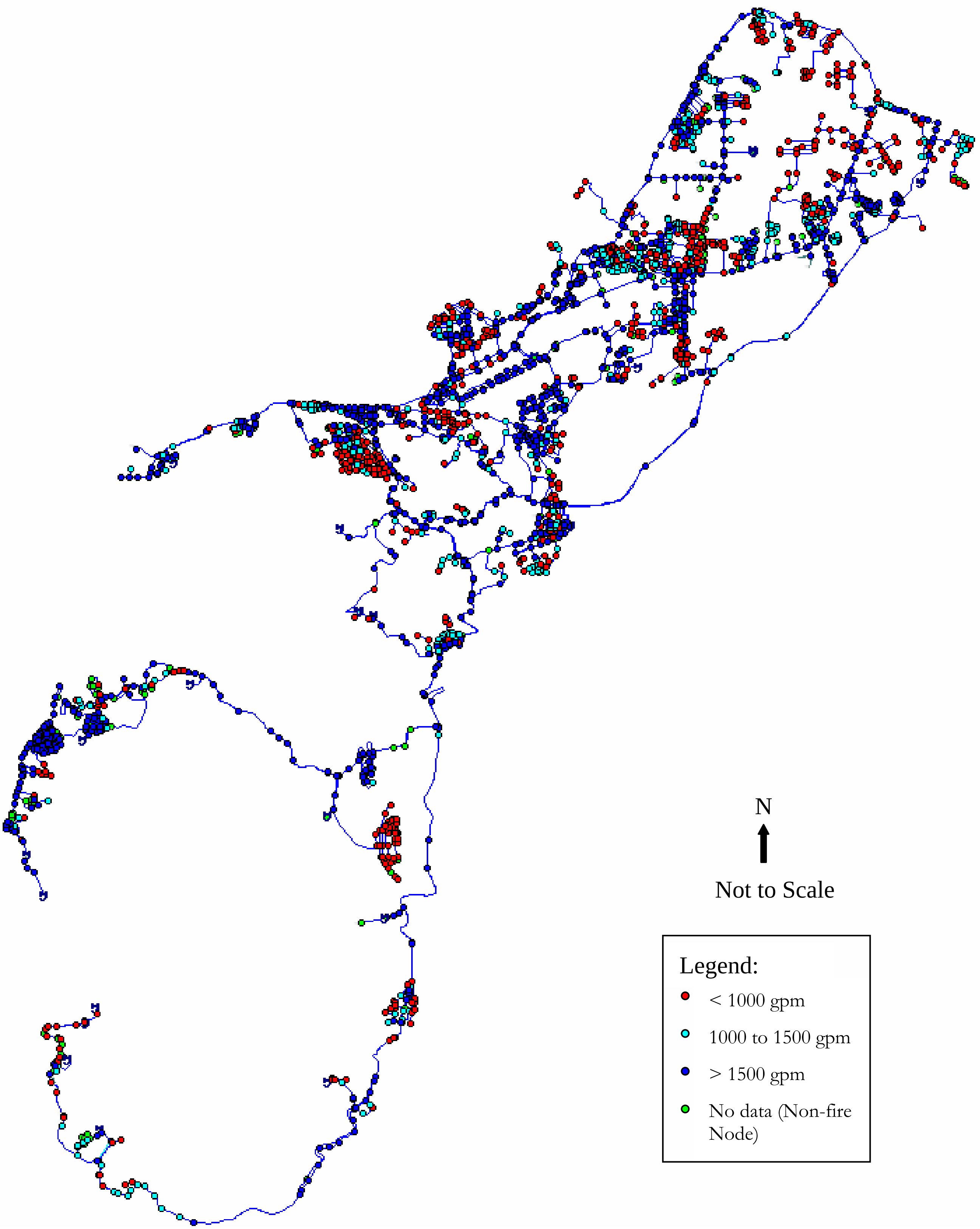


Figure 6-12 – 2005 Existing Condition Model: South-Central Reservoir Levels, Max-Day Scenario

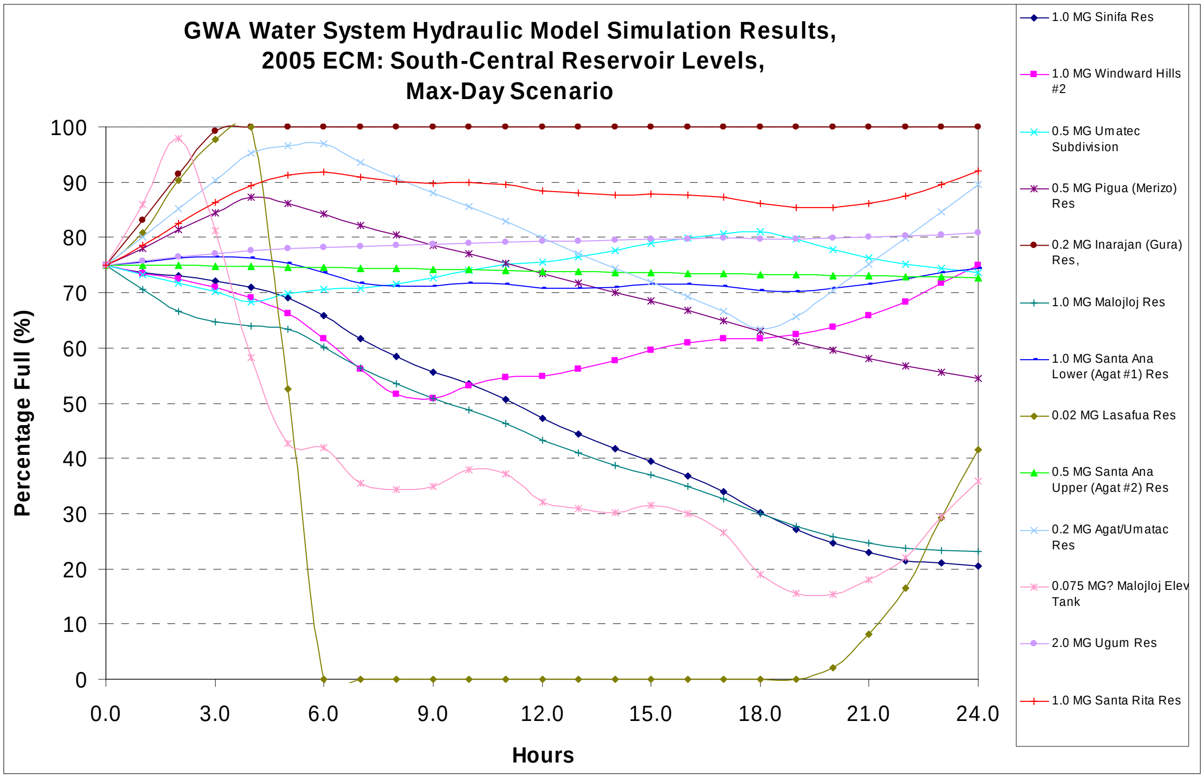


Figure 6-13 – 2005 Existing Condition Model: North Reservoir Levels, Max-Day Scenario, Part 1 of 2

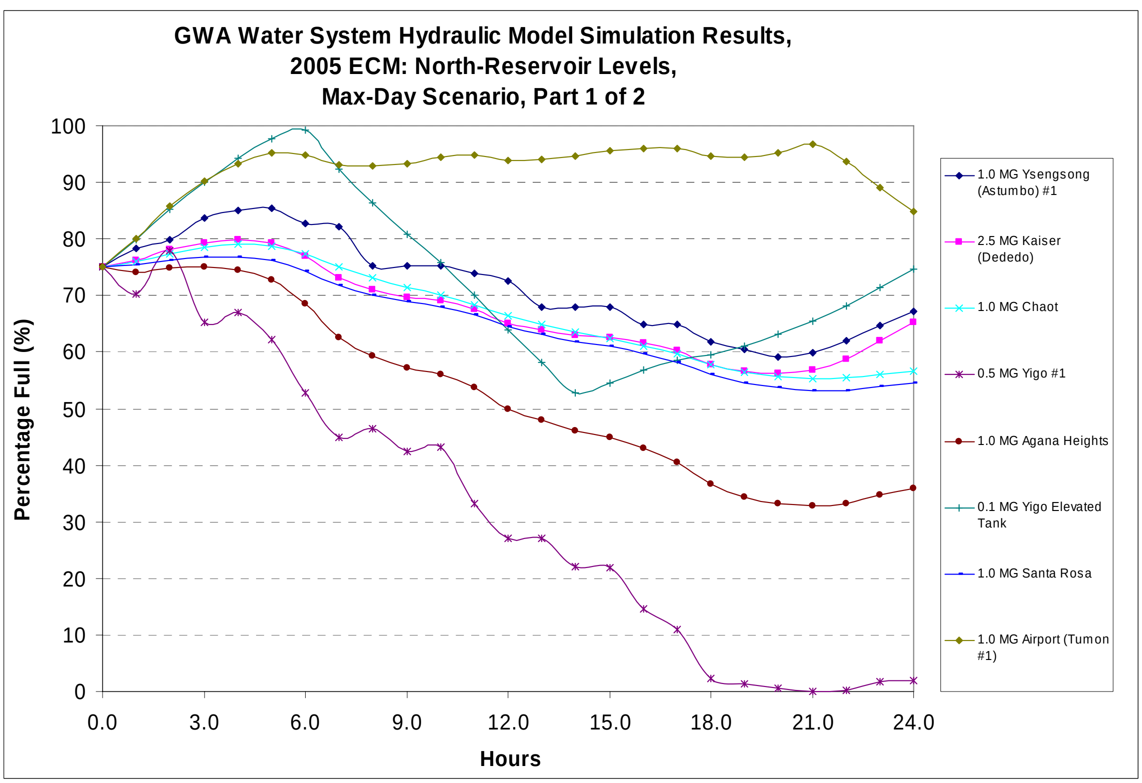


Figure 6-14 – 2005 Existing Condition Model: North Reservoir Levels, Max-Day Scenario, Part 2 of 2

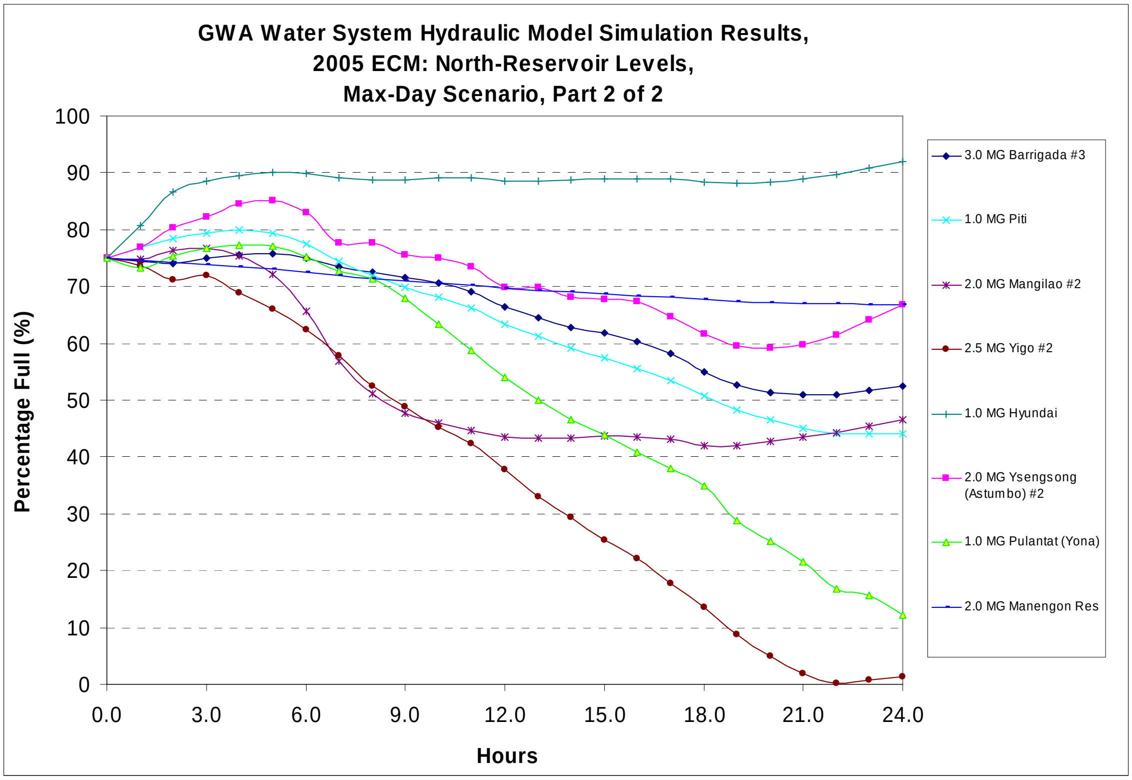
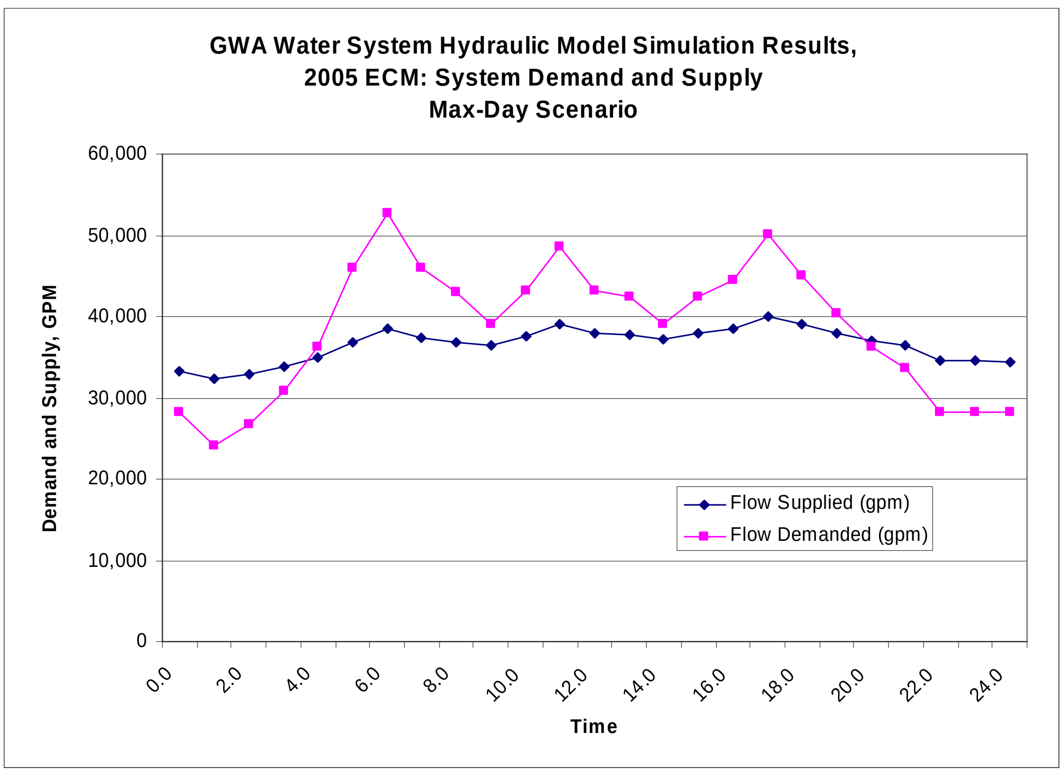


Figure 6-15 – 2005 Existing Condition Model: System Demand and Supply, Max-Day Scenario



In general, system deficiencies can be grouped into the following six categories:

1. Fire flow deficiency due to undersized distribution pipes. In most cases, pipes with six-inch or smaller diameter cannot provide adequate fire flow under normal operating conditions.
2. Fire flow deficiency due to insufficient elevation difference from reservoirs.
3. Poor flow circulation due to existing pipe configuration (dead end pipes, etc.).
4. Pressure deficiency due to undersized distribution pipes.
5. Pressure deficiency due to insufficient elevation difference from reservoirs. Deficiencies under this category are difficult to remedy because new higher elevation reservoir or booster pump station are usually the only viable solutions besides modifying the pressure zones.
6. Velocity deficiency due to high flow and/or undersized pipes.

Areas with low-pressure: During the Max-day simulation, system pressures below 40 psi were observed at various locations. These low-pressure areas are located throughout the island. Based on the hydraulic model simulation results, low water supply pressure is a significant issue that requires GWA's immediate attention.

Areas with low available fire flow: During the Max-day steady-state fire flow simulation, low available fire flows (less than 1000-2500 gpm) were observed at various locations throughout the island. Based on the hydraulic model simulation results, low available fire flow is also a significant issue that requires GWA's immediate attention.

Pipelines with high velocity: During the Max-day simulation, multiple pipelines in the distribution system had velocities above six feet per second. These high-velocity pipelines are scattered around the island. Based on the hydraulic model simulation results, pipeline with high velocity is not a significant problem for the GWA system.

A list of the deficiencies identified in the 2005 ECM are presented in Table 6-6a to Table 6-6c. For each of the deficiencies, a number of alternative improvements were formulated and tested in the hydraulic model.

Table 6-6a – Deficiencies in the 2005 Existing Condition Model – Central System

Def. No.	CIP No.	Area	Description	Category	Comment
CD1	C1, C2, C3, B2, R2	Talofofo	Fire flow and pressure deficiency in multiple locations around Talofofo.	1, 2, 4, 5	Verify C-value and flow rate on the existing 8-inch pipe between Windward Hill Reservoir and Talofofo. Calibration data indicated higher field pressure than the model prediction.
CD2	C4	Santa Rita	Fire flow and velocity deficiency on 8-inch waterline along Route 17 from Chalan J. Kindo intersection and eastward along Route 17 to Sinifa Reservoir.	1, 6	-
CD3	C5	Agat	Fire flow deficiency along S16.	1	-
CD4	C6	Agat	Fire flow deficiency along Umang	1	-

Table 6-6b – Deficiencies in the 2005 Existing Condition Model – South System

Def. No.	CIP No.	Area	Description	Category	Comment
SD1	S1	Malojloj Elevated	Fire flow deficiency along Fangualoan St.	1	-
SD2	S2	Malojloj Elevated	Fire flow deficiency along Kalamasa and Barcinas St.	1	-
SD3	S3	Malojloj Elevated	Poor flow circulation around Malojloj Well and Route 4	3	Need to verify dead end pipes location.
SD4	S4	Malojloj Elevated	Fire flow deficiency around Ates St.	1	-
SD5	S5	Malojloj	Poor flow circulation and Fire flow deficiency around Quinene to Baza to Santiago.	1, 3	-
SD6	S6	Malojloj	Poor flow circulation and Fire flow deficiency at the intersection of Acfalle and Route 4	1, 3	Need to verify dead end pipes location.
SD7	S7	Inarajan	Poor flow circulation and Fire flow deficiency at the ends of Chagamin St. and Y Peca Lane	1, 3	Need to verify dead end pipes location.
SD8	S8	Inarajan	Fire flow deficiency at interconnection of parallel 8-inch and 12-inch lines about 1900 feet south of As Quede St.	1	-
SD9	S9	Merizo	Fire flow deficiency along Chalan Joseph A Cruz from Route 4 south of Mata Ave to Merizo Reservoir.	1	-
SD10	S10	Umatac	Fire flow deficiency along Road A from Jesus A. Quidachay.	1	-
SD11	S11	Umatac	Fire flow deficiency along Route 4 from Bile St. to the transition from the 6-inch to 12-inch waterline about 1000 feet south of Jesus A. Quidachay St.	1	-
SD12	S12	Umatac	Fire flow deficiency along Route 4 and Route 2, from Jesus A. Quidachay St to Lasafua Reservoir and to Agat/Umatac Reservoir.	1	Need to verify if there are any segments of 12-inch line along this length of line.
SD13	B1, R1	Umatac	Fire flow and pressure deficiency around Lasafua and Agat-Umatac reservoirs.	1, 2, 4, 5	Need to verify the pump capacity and head of the Umatac #1 BPS.

Table 6-6c – Deficiencies in the 2005 Existing Condition Model – North System

Def. No.	CIP No.	Area	Description	Category	Comment
ND1	N1	Santa Rosa	Poor flow circulation and fire flow deficiency along north end of Tun Thomas Dongo.	1, 3	-
ND2	N2	Santa Rosa	Fire flow and pressure deficiency around the area east of Santa Rosa Reservoir.	1, 2, 4, 5	Verify the ground elevation at this area.
ND3	N3	Santa Rosa	Fire flow deficiency on Tun Luis Tugong and Rosa	1	-
ND4	N4	Santa Rosa	Fire flow and pressure deficiency on Anao and S-1.	1, 2, 4, 5	-
ND5	N5, N6, N7, N8	Yigo Elevated	Fire flow deficiency in the Yigo Elevated Pressure Zone.	1, 2	-
ND6	N9, N10, N11, R3	Mataguac Zone	Fire flow and pressure deficiency in the multiple locations around Mataguac Pressure Zone.	1, 2	-
ND7	N12	Yigo Zone	Fire flow and pressure deficiency along Chalan La Chanch to Ton Jose.	1, 2, 3, 4, 5	-
ND8	N13	Yigo Zone	Fire flow deficiency along Chalan Langet, from Route 1 to Ree. (Near lower portion of Route 1, southwest of Well Y-10)	1	-
ND9	N14	Yigo Zone	Poor flow circulation and fire flow deficiency around Chalan Islas Marianas and Aababang from Aapacha to Road K (adjacent to Route 1, north of Wells Y-5).	1, 3	-
ND10	N15	Yigo Zone	Fire flow deficiency along Milalak from Marine Drive westward. (West of Well Y-23)	1	-
ND11	N16	Yigo Zone	Velocity deficiency along the 12-inch lines on Highway 15 between Road B. Wendy and Gayinero Dr.	6	Need to verify PRV settings at the intersection of Route 15 and Rd. B. Wendy.
ND12	N17	Yigo Zone	Fire flow and pressure deficiency along Chaguian Machananao (East of Well AG-01)	1, 2, 4, 5	-
ND13	N18	Yigo Zone	Fire flow and pressure deficiency around Chalan Santa Bernadita. (Southeast of Well AG-01)	1, 2, 3	-
ND14	N19	Yigo Zone	Poor circulation and fire flow deficiency at the ends of Quezon and Magsaysay. (Near Well F-09)	1, 3	-
ND15	N20	Astumbo	Fire flow deficiency around Chiote and Kamute. (South of Well F-06)	1, 3	-

Table 6-6c – Deficiencies in the 2005 Existing Condition Model – North System (continued)

Def. No.	CIP No.	Area	Description	Category	Comment
ND16	N21	Astumbo	Fire flow and pressure deficiency around Chalan Ibang, Chalan Pakpak, S-13, Chalan Bongbong and Chalan Puegue Matchena. (East of F-13)	1, 2, 4, 5	-
ND17	N22, N24, N25	Kaiser	Poor circulation, fire flow and pressure deficiency around Lada, Adora, Fatima and Santa Monica. (Near Well D-18)	1, 2, 3, 4, 5	-
ND18	N23	Kaiser	Fire flow and pressure deficiency along Chalan Liguan. (Near M-14)	1, 2, 4, 5	-
ND19	N26	Kaiser	Fire flow and pressure deficiency in multiple locations around Kaiser reservoir.	1, 2, 3, 4, 5	Verify pressure zone boundary.
ND20	N27, N28	Tumon *	Fire flow and pressure deficiency around Hospital, Pale San Vitores St., Duenas Dr, Gov. Skinner St., Gov. Bradley St. and Father Ramon St.	1, 2, 3, 4, 5	-
ND21	N29	Hyundai	Fire flow along Bello Road (north of Hyundai Reservoir).	1, 2	-
ND22	N30	Hyundai	Fire flow and pressure deficiency along Corenso, North Sabana Barrigada and South Sabana Barrigada (west of Hyundai Reservoir).	1, 2, 4, 5	Verify the existing pipe size and connection location.
ND23	N31	Mangilao/C haot	Fire flow deficiency along Jesus Mariano. (Southwest of Mangilao Reservoir).	1, 3	-
ND24	N32	Mangilao/ Chaot	Fire flow deficiency around Lalo, Costat and Bilmar. (North Well A-14).	1, 3	-
ND25	N33	Mangilao/ Chaot	Fire flow deficiency around Guzman and Lizama (Near Well A-15).	1, 3	-
ND26	N34	Mangilao/ Chaot	Fire flow deficiency along Campus (Near Well A-17).	1	-
ND27	N35	Mangilao/ Chaot	Fire flow and pressure deficiency around Mangilao Reservoir.	1, 2, 3, 4, 5	-
ND28	N36, N37, N38	Piti/Agana *	Fire flow and pressure deficiency around Agana Heights.	1, 2, 3, 4, 5	
ND29	N39, N40, N41, N42, N43	Pulantat	Fire flow and pressure deficiency at the area south of Pago Bay booster.	1, 2, 3, 4, 5	Improve available fire flow in this area.
ND30	R4	Barrigada	Fire flow and pressure deficiency in multiple locations around Barrigada reservoir.	1, 2, 3, 4, 5	Verify pressure zone boundary.

2005 CIP Planning Model

The most effective improvements for each of the deficiencies were subsequently input into the 2005 CPM. These improvements are shown in Figures 6-16 to 6-17 and include the following type of projects:

1. Replacing an undersized pipeline with a larger diameter pipe.
2. Eliminating dead end pipes by installing new pipes to complete a hydraulic loop.
3. Installing new reservoirs to provide more storage capacity as well as creating a more stable water supply pressure.
4. Installing new booster pump stations to transport water between pressure zones.
5. Reconfiguring pressure zone boundary in order to improve water supply pressure.
6. Putting out of order facilities (wells and reservoirs) back online to access the full potential of the water system.

Figures 6-18 through 6-24 show the 2005 CPM simulation results for the water distribution system and reservoir water levels over a 24-hour period. Overall, significant improvements in system deficiencies were observed throughout the GWA system when the recommended improvements were activated in the 2005 CPM. However, it is important to note that not every deficiency can be mitigated by the recommended CIP improvements due to the inherent system configuration limitations, for example, pipelines with a diameter six inches or smaller are unlikely to be able to provide the required minimum fire flow rate of 1,000 gpm. Moreover, low water supply pressure around the Mangilao Reservoirs, Yigo Reservoirs, Ysengsong Reservoirs and Kaiser Reservoir is not easily remedied due to the insufficient elevation differences between the reservoirs and the areas they service.

Figure 6-16 – 2005 CIP Planning Model: Modified and New Facilities, Part 1 of 2

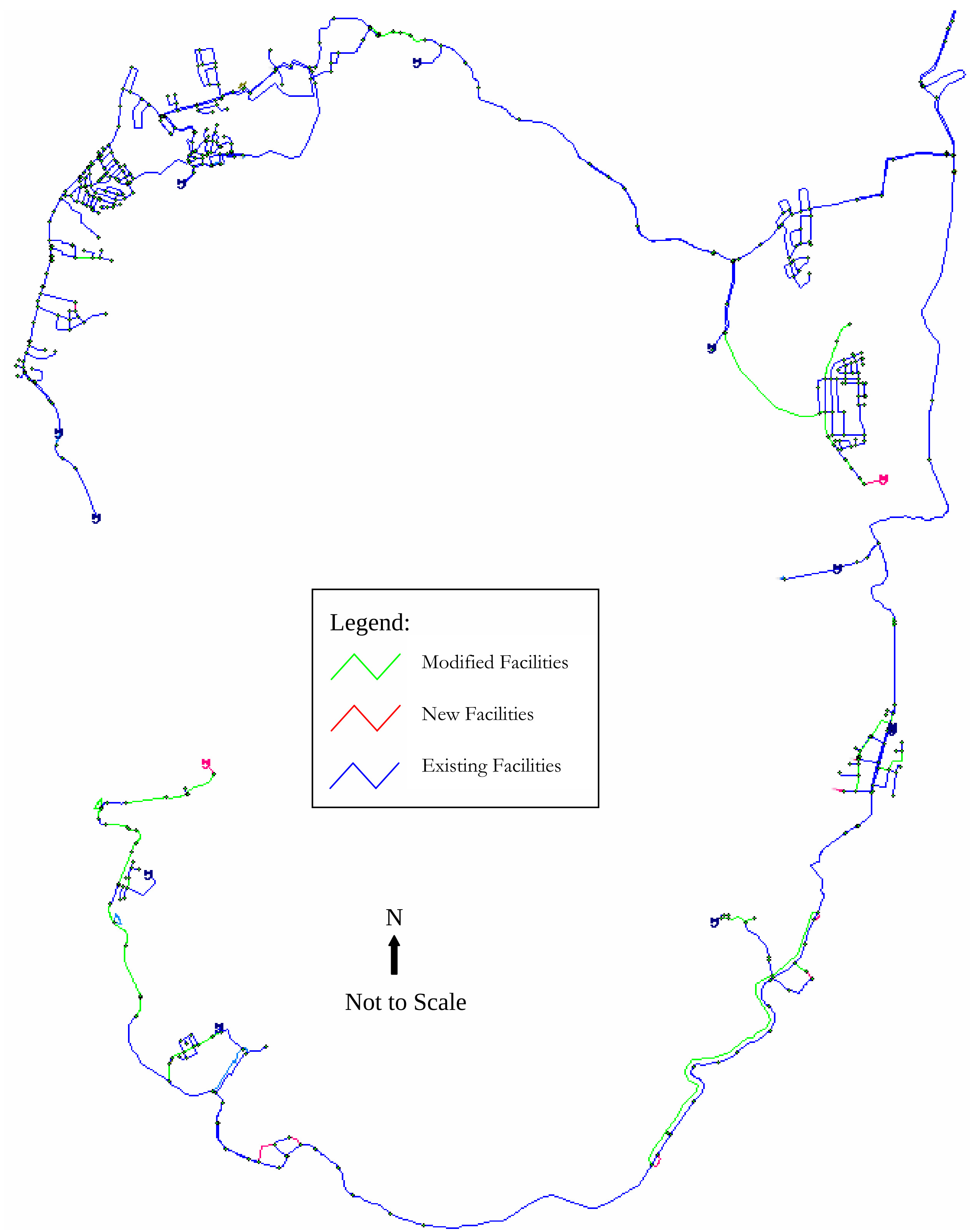


Figure 6-17 – 2005 CIP Planning Model: Modified and New Facilities, Part 2 of 2

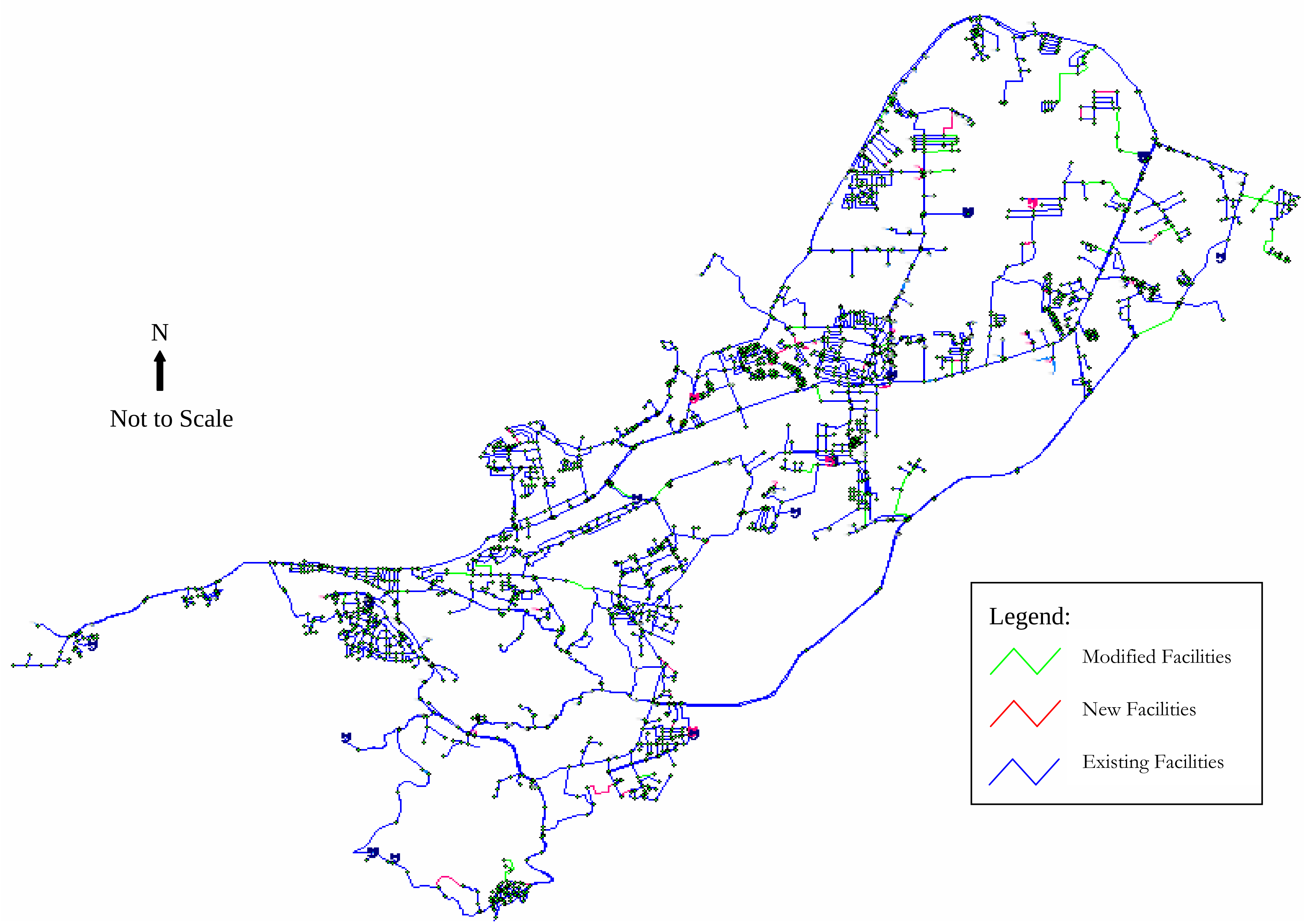


Figure 6-18 – 2005 CIP Planning Model: Max-Day, Min Pressure (<40 psi)

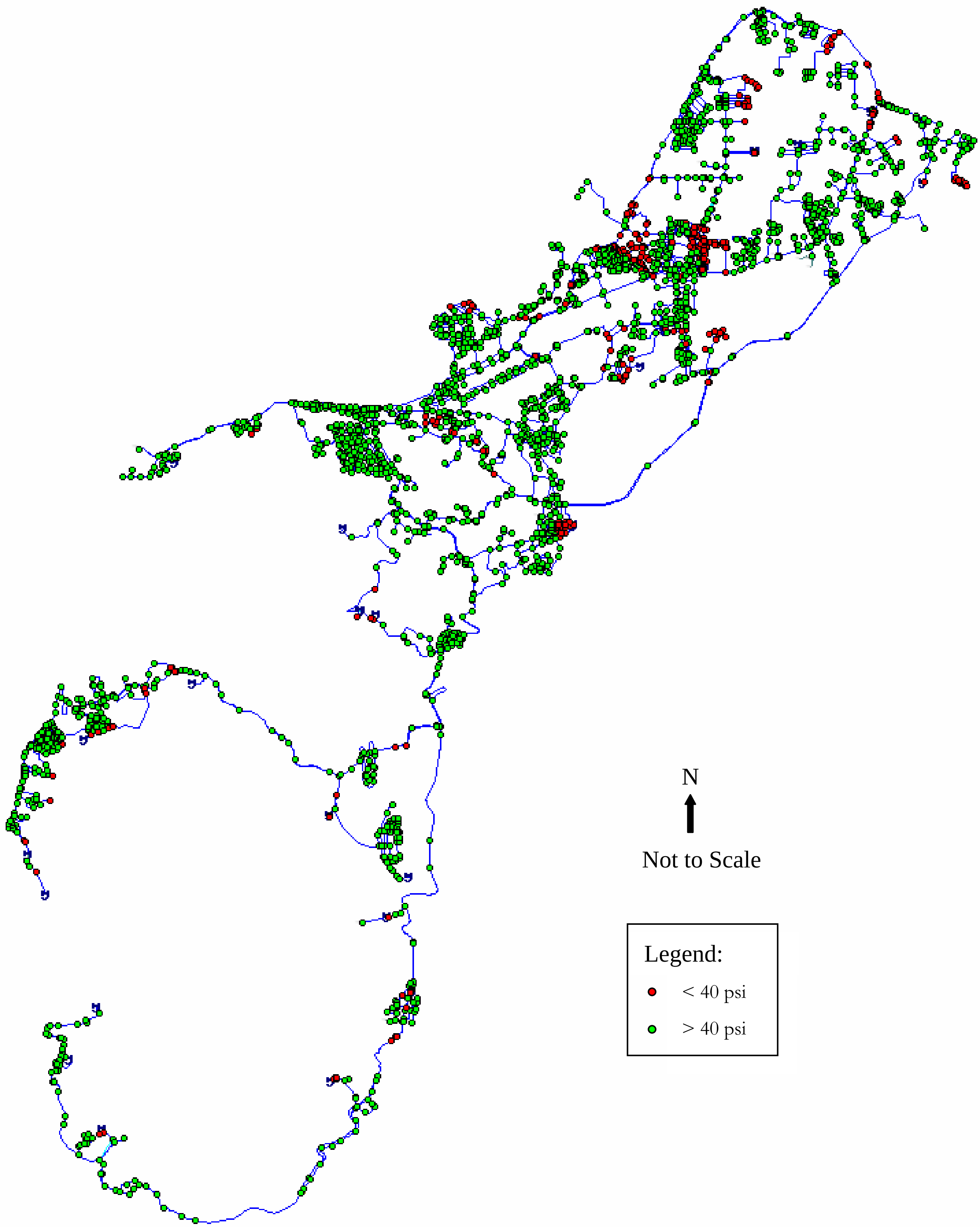


Figure 6-19 – 2005 CIP Planning Model: Max-Day, Max Velocity (>6 fps)

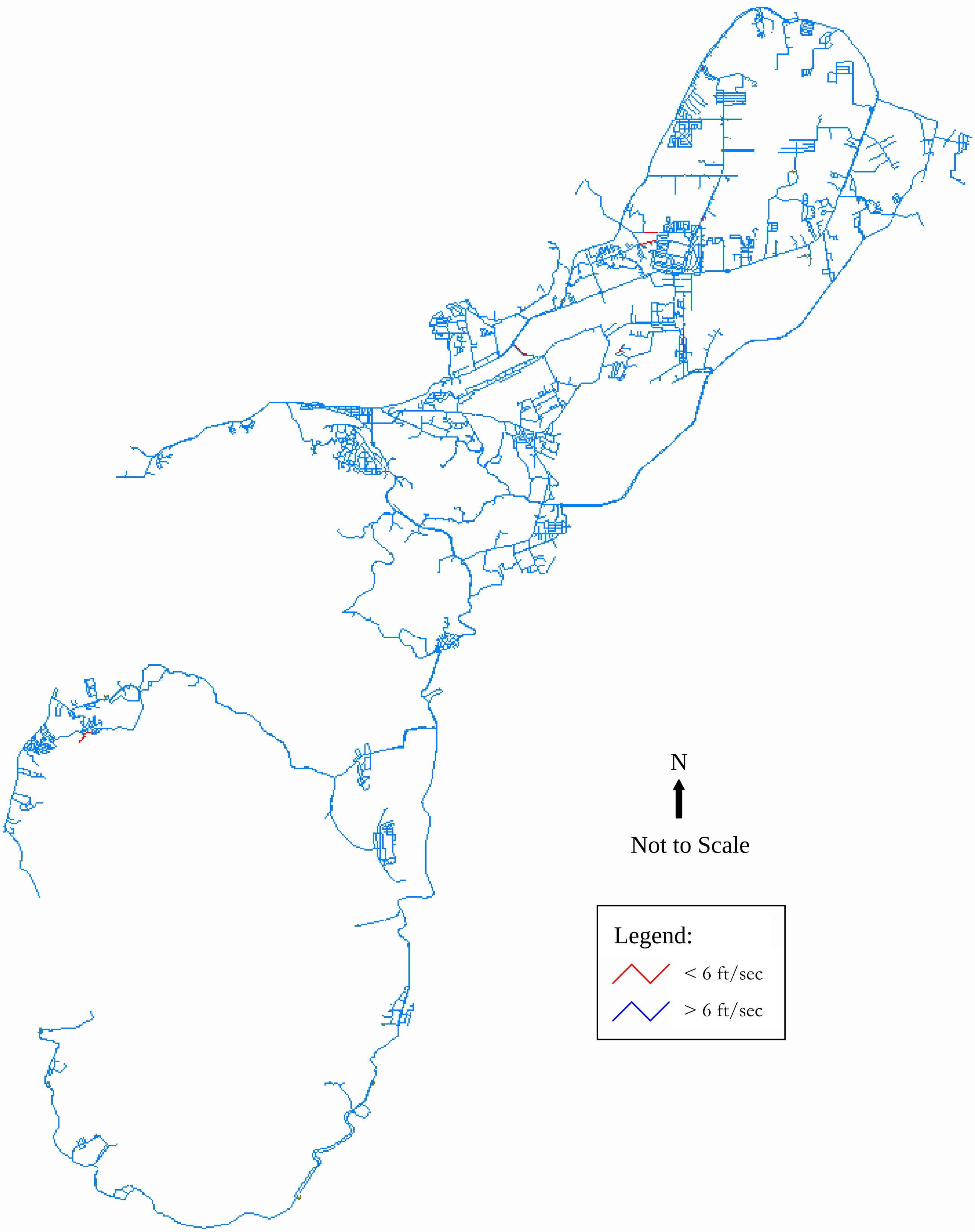


Figure 6-20 – 2005 CIP Planning Model: Max-Day, Available Fire Flow (Min 20 psi residual pressure)

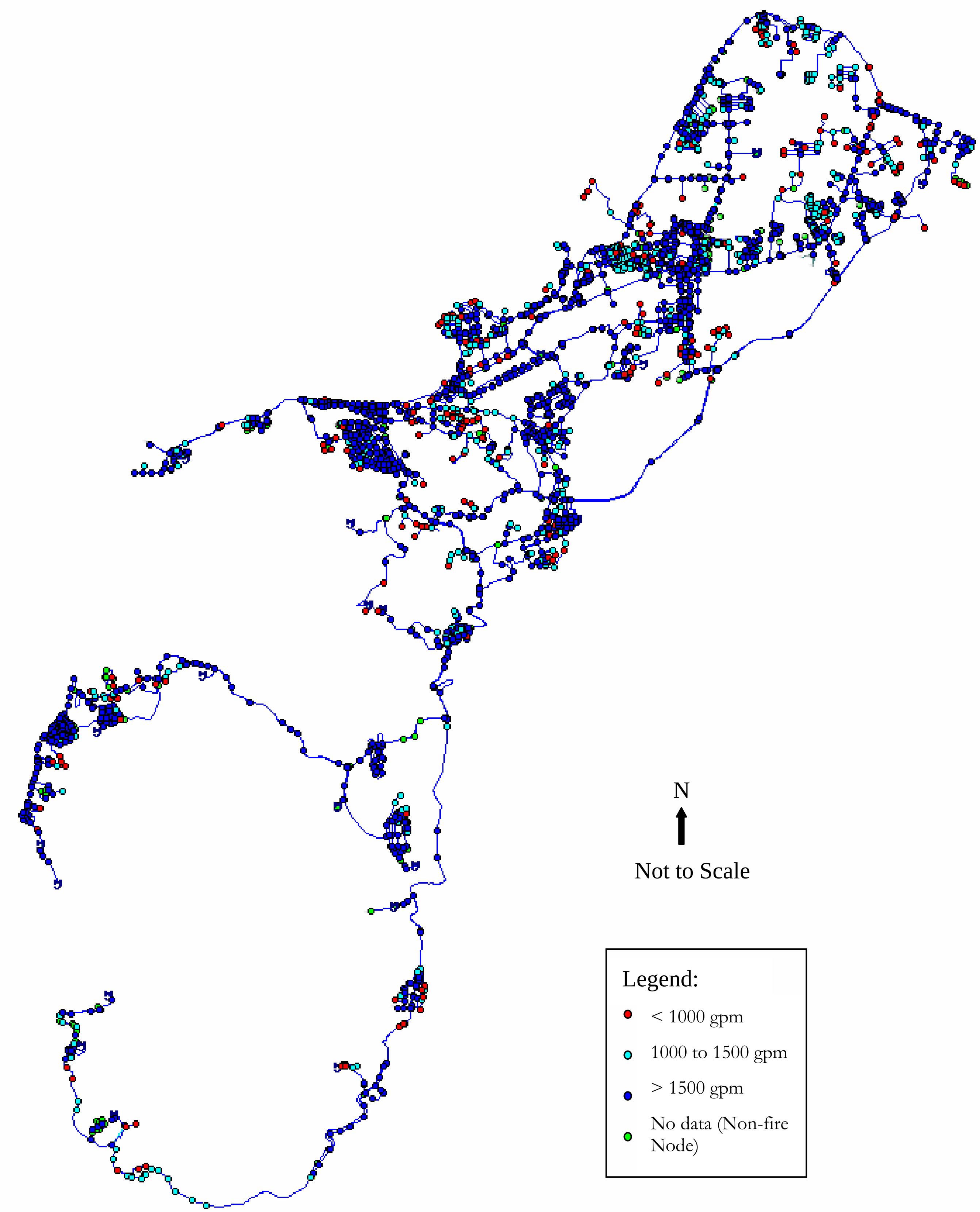


Figure 6-21 – 2005 CIP Planning Model: South-Central Reservoir Levels, Max-Day Scenario

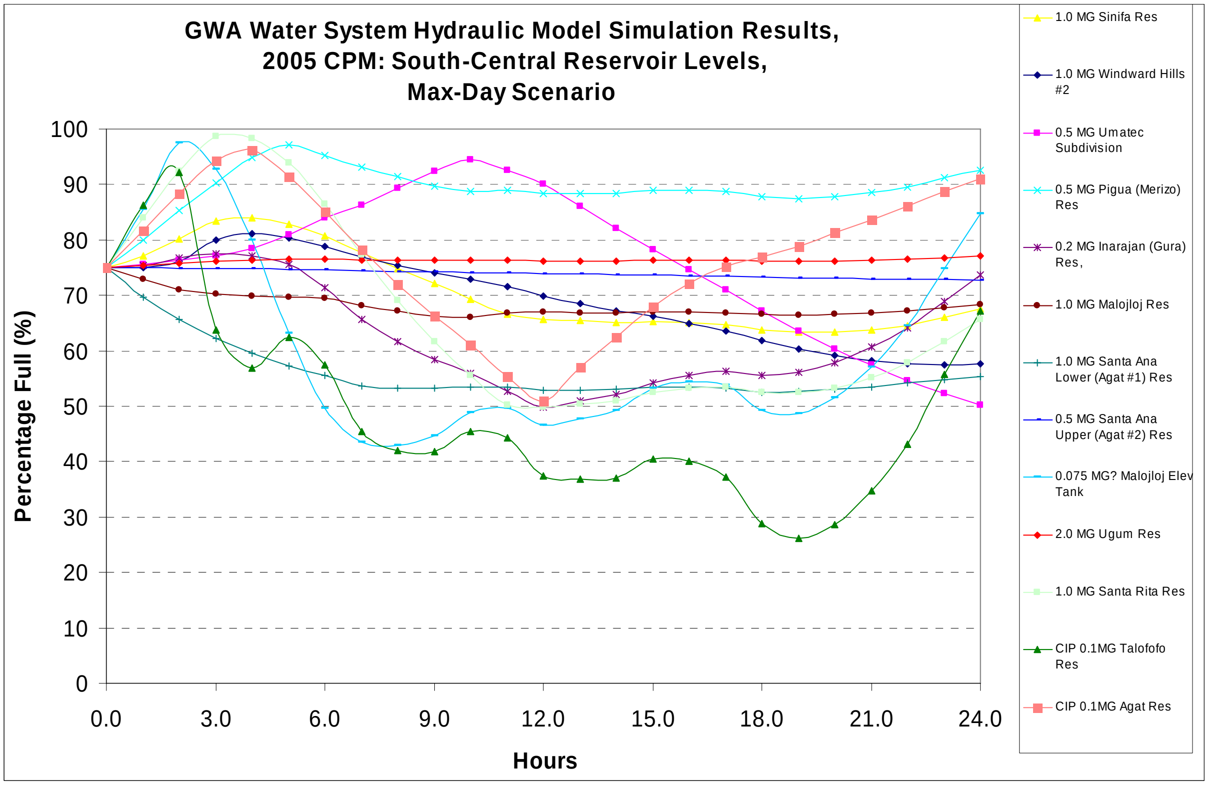


Figure 6-22 – 2005 CIP Planning Model: North Reservoir Levels, Max-Day Scenario, Part 1 of 2

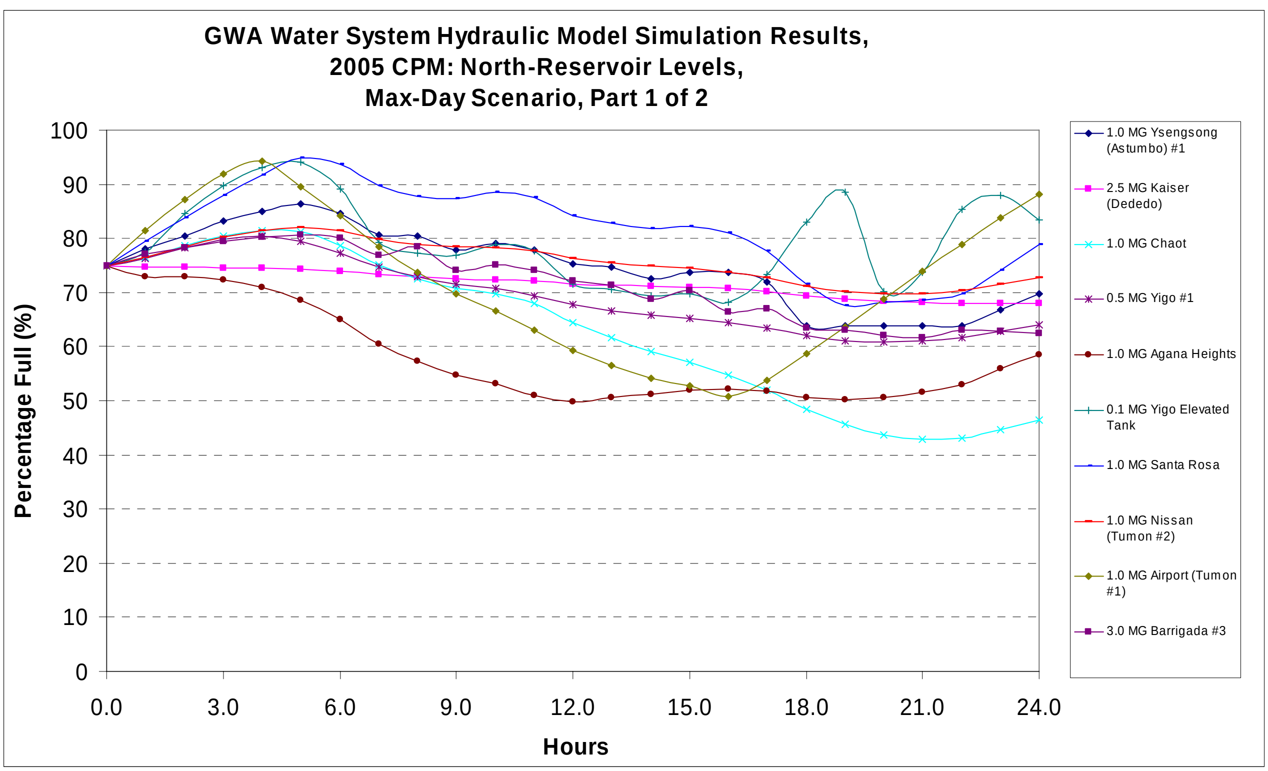


Figure 6-23 – 2005 CIP Planning Model: North Reservoir Levels, Max-Day Scenario, Part 2 of 2

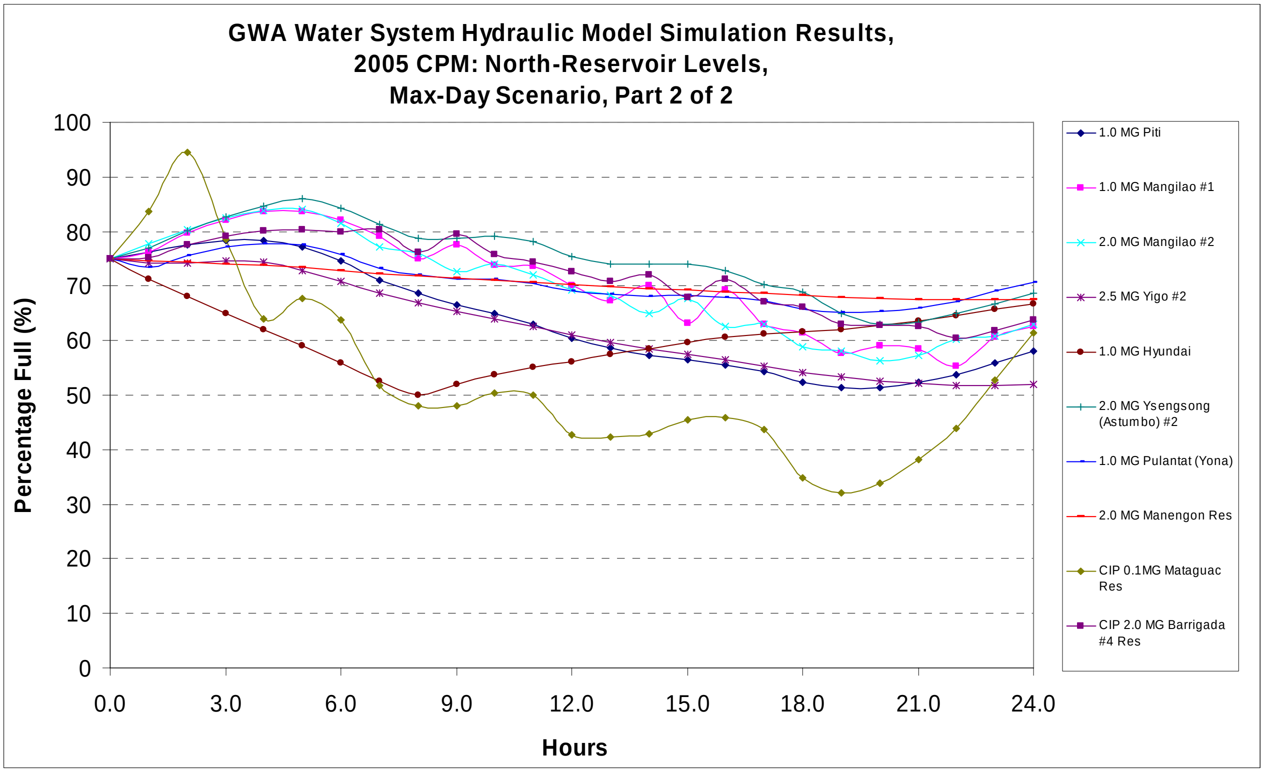
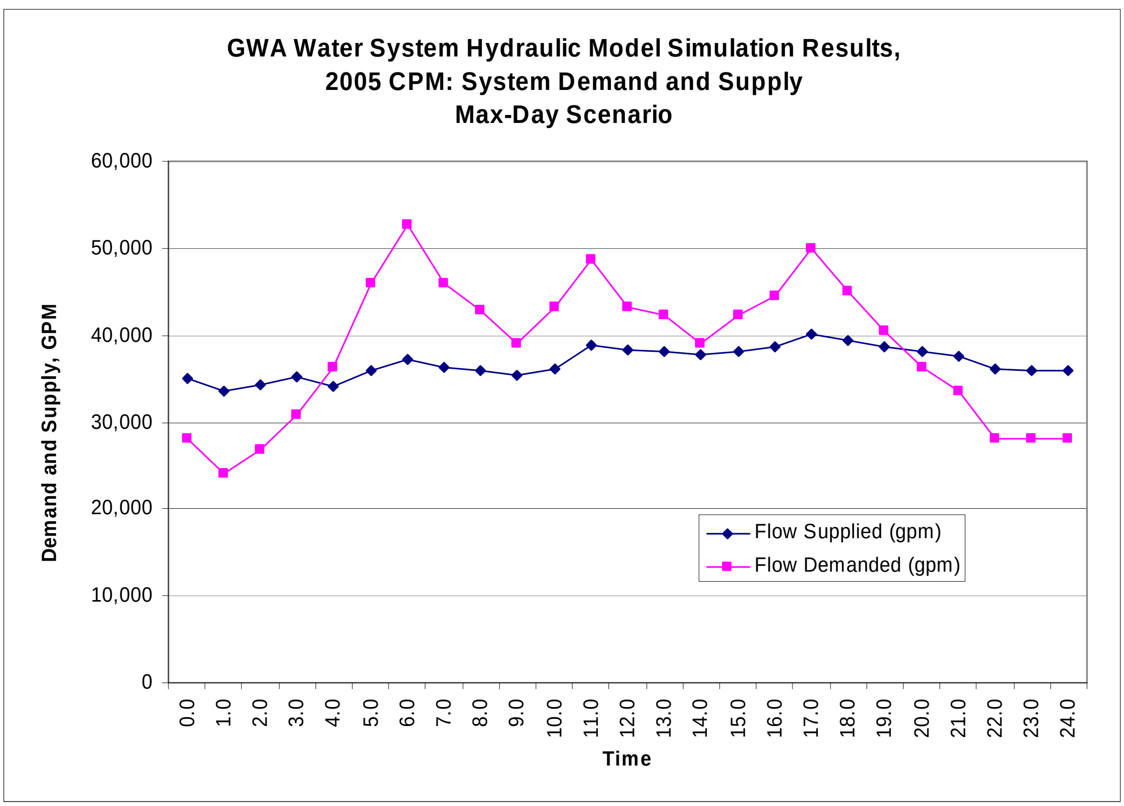


Figure 6-24 – 2005 CIP Planning Model: System Demand and Supply, Max-Day Scenario



6.9.4 System Improvement Recommendations

A number of system CIP improvement alternatives were evaluated in the model to remedy aforementioned deficiencies, improve system hydraulics and increase storage tank capacity. The lists of recommended CIP projects are shown in Table 8-5 to Table 8-9 in Chapter 8 of this volume.

6.10 Model Update and Maintenance

It is vital that the Hydraulic Model be kept up to date by trained GWA staffs or experienced consultants. Without regular proper maintenance, the model will quickly become outdated and inaccurate, thus rendering it useless. A model maintenance plan should be developed to establish procedures for regular update and maintenance. The first and utmost important step of the plan will be to identify the GWA staffs that will be in-charge of the hydraulic model. Given the size and complexity of the GWA system, it is recommended a dedicated modeler be appointed to take ownership of the model as soon as possible. The modeler should be required to take at least two training courses; a standard two-day H_2OMAP training course offered by MWHSoft; and a training workshop designed specifically around the GWA model, provided by Brown and Caldwell.

In general, the maintenance plan should require that new pipes and facilities be added to the model annually. It is also recommended that new controls be implemented every five years. Every five 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.

When new model elements (junctions, pipes, tanks, pumps, or valves) are added to the model, the database columns that are used for scenario management should be populated properly. If these columns do not contain the correct data, problems such as disconnectivity or unbalanced hydraulic condition, can occur.

6.10.1 Addition of New Pipes and Junctions

New pipes and junctions should be added to the model yearly in order to keep the model up to date. It is recommended that all new pipes six-inches in diameter and greater be added to the model. As changes are made, the model should be saved under a new name. In this way, the old model is not lost and is saved for reference if needed. All subsequent updates will be performed on the new model. When a pipe is removed from service, the pipe and the associated junctions, if needed, should be completely deleted from the model. In this way, the model is current and up to date. If there are any demand nodes to be deleted, they should be moved to another junction in the same demand area and pressure zone. When new pipes are added, junctions should be inserted at each change of diameter or material. Care should be taken to see that new pipes are hydraulically connected to the model. The database fields for each pipe and junction should be populated.

6.10.2 Facilities Updates

The existing facilities in the model should be updated every five years or as soon as information is available. Information that needs to be gathered for facility updates varies by facility type. The items listed for each facility type should be checked for changes. For facilities that are changed, the parameters should be adjusted in the model and all changes should be documented in one central place.

Tanks and Reservoirs:

Status: Remove from model if completely demolished, close inlet pipe if abandoned only.

Controls: Altitude valve settings on the tank inlet pipe

Pumps Stations:

Status: Remove from model if completely demolished, close pumps if abandoned only.

Pump curves: Update with latest pump tests.

Controls: Check the control settings with the operation staff. If values are different from the model, update controls as necessary.

Regulator Stations and Other Valves:

Status: Remove from model if completely demolished, close valves if abandoned only.

Settings: Check valve setting with field personnel.

Controls: Check the operation of regulator stations and other valves with field personnel

Navy Connections:

Bottom Elevation: For those Navy connections that are modeled as a Pump and Virtual Tank, the design flow rate and pump head should be updated. For those Navy connections that are modeled as a Negative Demand Node (Supply), the demand setting and pattern have to be updated.

6.10.3 Addition of New Facilities

Newly constructed and proposed facilities should be added to the model yearly in order to keep the model up to date. Creation of model facilities should include populating of all database fields for each model element. All elements that form the new facility should have the facility name in its description. For single criteria pump controls, the standard H2OMAP controls can be used. However, if a new pump station is operated by multi-criteria controls (pressure and tank level), it should be modeled with PLCs. A combination of PLCs and standard controls is possible if it is desired to force a pump on or off at a certain time. The time controls will overrule the PLCs.

6.10.4 New Pressure Zones

Pressure zone changes have to be maintained in both the model and in the graphic files. Pressure zone boundary adjustments should first be made to the pressure zone boundary shapefile. The adjusted shapefiles can then be reloaded into H2OMap. All nodes that are located within an adjusted pressure zone have to be checked and re-labeled, if necessary, in the Zone column of the information databases. Depending on the magnitude of the pressure zone change, the demand allocation process should be repeated for the affected pressure zones. Since, pressure zone boundaries will not change on a regular basis, a yearly review of pressure zone changes is recommended.

6.10.5 Update of Diurnal Curves

The update of diurnal curves involves extensive field data collection. It is recommended that the diurnal curves be updated every five years. Maximum Day flow has to be selected based on the daily production data of the period 2005-2010. All inflows, outflows and water level data need to be gathered to create new diurnal curves for this selected maximum day. However, it is expected that in five years time, most of these data will not be available unless a new SCADA system is installed. Furthermore, usage information should be gathered for the top 30 large users to create the specific large user diurnal curves.

6.10.6 Update of Demands

It is recommended that demands be updated every five years. The demands allocated in the 2005 Planning Model are based on April 2005 billing data; thus, the next scheduled update should occur in 2010. For the 2010 update, it is recommended that the Geocoding method be used for matching the model demand node to the average customer demand using actual meter addresses. This task will greatly improve the accuracy of the existing demand distribution. This is also a logical next step for GWA to implement following the completion of the current meter replacing program.

To update the demands, the following steps must be followed. These steps are:

1. Extract customer billing data.
2. Extract the SCADA data on inflow, outflow and water level data, if available.
3. Upscale billing data to match production data.
4. Match the data of Step 3 with the meter service address.
5. Geocode the upscaled user data of Step 3 to the demand nodes in the model.
6. Calculate the total demand by pressure zone using the SCADA data of Step 2
7. Calculate the factor between the total demand allocated in Step 5 and Step 6 for each pressure zone.
8. Factor the model demands according to the factor calculated in Step 7.

6.10.7 Calibration Update

It is recommended that calibration be updated every five years when demands are updated. To update the calibration of the model, a large amount of field data needs to be collected. Calibration can be updated when data for new diurnal curves is gathered. Besides the data collected for the update of diurnal curves, pressure readings need to be collected at all regulator stations, pump stations and Navy meters in the system, where available. It cannot be stressed enough that a successful model calibration is largely depending on the availability of accurate operation data (inflows, outflows and water level etc.) from a functional and calibrated SCADA system.

6.11 2025 CIP Investigating Model (CIM)

As stated in Section 6.2, the purpose of the 2025 CIM is to determine the effects of the following influences on the water distribution system:

- Future population increases
- Restructuring of the North water system, so that all of the existing wells pump directly into water reservoirs

The idea behind the second item is to provide a means of distributing water of consistent quality throughout the North water system. Because of the possibility that at least some of the North well sources could be deemed groundwater under the direct influence (GWUDI) of surface water, some form of filtration and disinfection may be required prior to distribution into the water system. In this scenario, groundwater collected from all the wells would be conveyed through dedicated transmission mains to centralized treatment systems installed at reservoir sites. The groundwater would be treated and stored in reservoirs to achieve adequate contact time prior to distribution to GWA customers. The installation of dedicated transmission mains between wells and reservoirs eliminates the need for individual treatment systems at each well site, and would greatly reduce the capital and O&M costs associated with multiple treatment systems.

The planned use of dedicated transmission mains from source to storage differs greatly from how the existing system functions, where the wells pump directly into the distribution system to supply water in addition to filling reservoirs. By eliminating the direct feed from wells into the distribution system, the reservoirs become the only source for the distribution system. Trying to maintain minimum distribution system pressures during fire and domestic demands becomes a challenge, especially for those services located near reservoirs where there is insufficient elevation difference. Areas that are located a considerable distance from reservoirs can also have difficulty achieving adequate pressures due to high friction losses through long lengths of pipe. The 2025 CIM aims to minimize these negative impacts by eliminating the direct feed of wells into the distribution system, and identifies the necessary improvements that will allow the system to operate in compliance with the water service standards identified in Chapter 8.

6.11.1 Water Demand Projection

Water demand projections for the 2025 CIM are based on the corresponding estimated population increases for Guam. Figures 6-2 through 6-5 depict the 2005 development polygons and their population densities throughout the island. Scaling factors were developed to appropriate population increases for each pressure zone in order to establish 2025 average day demands. The GWA service area population is expected to be about

195,000 people by the year 2025, which is an increase of 38,000 people. However, it is also reasonable to expect that GWA's leak detection program will reduce the amount of unaccounted-for water enough to have an impact on reducing the water demand. For the 2025 CIM, the following assumptions are made:

- The large user average day demands from Table 6-1 increase by 24% (3.2 mgd total)
- The existing (2005) average day demand (excluding large users) is reduced by 5% due to leak detection efforts (37.6 mgd total)
- The additional average day demand imposed by an increase of 38,000 people will be estimated at a rate of 150 gpcd (5.7 mgd total)

Therefore, the total 2025 estimated average day demand that results from these three assumptions is 46.5 mgd.

The same values for peaking factors and fire flow discussed in Sections 6.6.3 and 6.6.4 are used for the 2025 CIM.

6.11.2 2025 CIM Simulations

Simulations for the 2025 CIM 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. The typical simulation conditions are summarized as follows:

Simulation assumptions:

- A constant supply of 2.2 mgd from the Ugum WTP was used for the 2025 Existing Condition Model scenarios.
- Tank levels were started at 75% full condition.
- Booster Pumps were controlled by tank level through telemetry.
- Well pumps are set to run 24 hours a day and flow rates are variable depending on the system hydraulic grade downstream of the well pumps.
- The design flow for all well pumps is initially inputted at their EPA permitted flow rates as shown in Table 1-3 in Chapter 1 of this volume.
- 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.

6.11.3 Simulation Work Flow

The 2025 CIM is a modified version of the 2005 CPM. This subsection describes the typical work flow from model setup to CIP projects recommendation. The hydraulic simulation analysis is an iterative process as illustrated in Figure 6-8 and consists of the following additional steps to those described in Section 6.9:

1. Setup and run the 2005 CPM with the 2025 estimated demands inputted throughout the system.
2. Analyze the results and categorize supply, pressure, velocity and fire flow deficiencies.

3. Determine system improvement alternatives to rectify deficiencies identified in Step 2.
4. Setup and run the 2025 CIM with each improvement alternatives identified in Step 3.
5. Analyze the 2025 CIM results and identify the best alternatives for each categorized deficiencies.
6. Update the 2025 CIM with the best alternatives.
7. Complete the 2025 CIM and create a list of CIP projects.

6.11.4 Initial Simulation Results

As expected, using the 2005 CPM as a base model while disconnecting the wells from the distribution system, connecting them to dedicated transmission mains that lead to reservoirs and imposing 2025 population demands on the system, causes a wide array of hydraulic problems if no further improvements are made. In fact, the 2025 CIM will not run to completion because of the hydraulic imbalances that occur. The major deficiencies are comprised of the following:

- Existing well pumps do not have sufficient head capacity to lift water to reservoirs;
- Existing distribution piping does not have sufficient conveyance capacity;
- Existing reservoirs do not have sufficient storage to meet demands; and
- Existing wells do not produce sufficient supply to meet demands.

6.11.5 CIP Methodology

The improvements used to alleviate the system deficiencies were tested in the following steps:

1. Increase the well pump output to current 30-day average pumping rates as shown in Table 1-3 in Chapter 1 of this volume. (This is done only for wells without a history of chloride problems as shown in Tables 1-4a thru 1-5b, also listed in Chapter 1 of this volume). If records can show that the water quality for a given well has not degraded over time by pumping more than the permitted EPA rates, then a request should be made to increase the permitted rate to the corresponding higher flow rate. This will reduce the number of new wells required to meet system demands.
2. Place out of order facilities (wells and reservoirs) back online to access the full potential of the water system.
3. Increase the well pump head capacities to allow filling of storage reservoirs. Most well pumps will need to be upgraded or replaced in order to achieve the necessary lifting capacity to fill the reservoirs.
4. Increase storage volume for fast-draining reservoirs. Adding redundant reservoirs at existing storage sites that drain quickly may be enough to meet system demand.

5. Insert new wells where reservoirs continue to drain rapidly. If necessary, install new wells in areas where the groundwater management zones show extra capacity. See Table 3-6 in Chapter 3, Water Budget of this volume.
6. Increase the size and looping of distribution system piping where velocities remain high and pressures remain low.
7. Adjust valve settings or pressure zone boundaries where pressures continue to remain low. This applies especially to those areas that are near in elevation to the reservoirs that serve them, in which are represented by low static pressures. Problem areas may need to be moved into the next higher pressure zone.

6.11.6 Final Simulation Results

The most effective improvements for each of the deficiencies were subsequently input into the 2025 CIM. These improvements are shown in Figure 6-25 as discussed in the aforementioned CIP Methodology.

Figures 6-26 through 6-36 show the 2025 CPM simulation results for the water distribution system and reservoir water levels over a 24-hour period. Overall, significant improvements in system deficiencies were observed throughout the GWA system when the recommended improvements were activated in the 2025 CIM. However, it is important to note that not every deficiency can be mitigated by the recommended CIP improvements due to the inherent system configuration deficiencies, for example, pipelines with diameter six inches or below are unable to provide the required minimum fire flow rate of 1,000 gpm at a 20 psi residual pressure. Moreover, low water supply pressure around areas served by the Mangilao, Ysengsong and Kaiser Reservoirs are not easily remedied due to the insufficient elevation differences and in some cases long lengths of distribution piping. However, many of the demand nodes that fail to meet the 40 psi minimum pressure do so only by a small margin. Many of them are able to meet a minimum pressure of between 30-35 psi during max day demand. Therefore, it would be prudent to evaluate the adequacy of this lower pressure in sustaining reasonable water service, as opposed to incurring large capital improvement costs by upgrading the infrastructure to meet a minimum pressure of 40 psi.

The recommendations contained in Section 6.10 regarding hydraulic model maintenance apply to the 2025 CIM as well. Any changes or improvements made to the system should be reflected in the model in order to accurately represent the most current infrastructure. Also, changes in design criteria should be inputted into the model to determine if the existing or proposed conditions meet the imposed standards.

Figure 6-25 – 2025 CIP Investigating Model: Modified and New Facilities

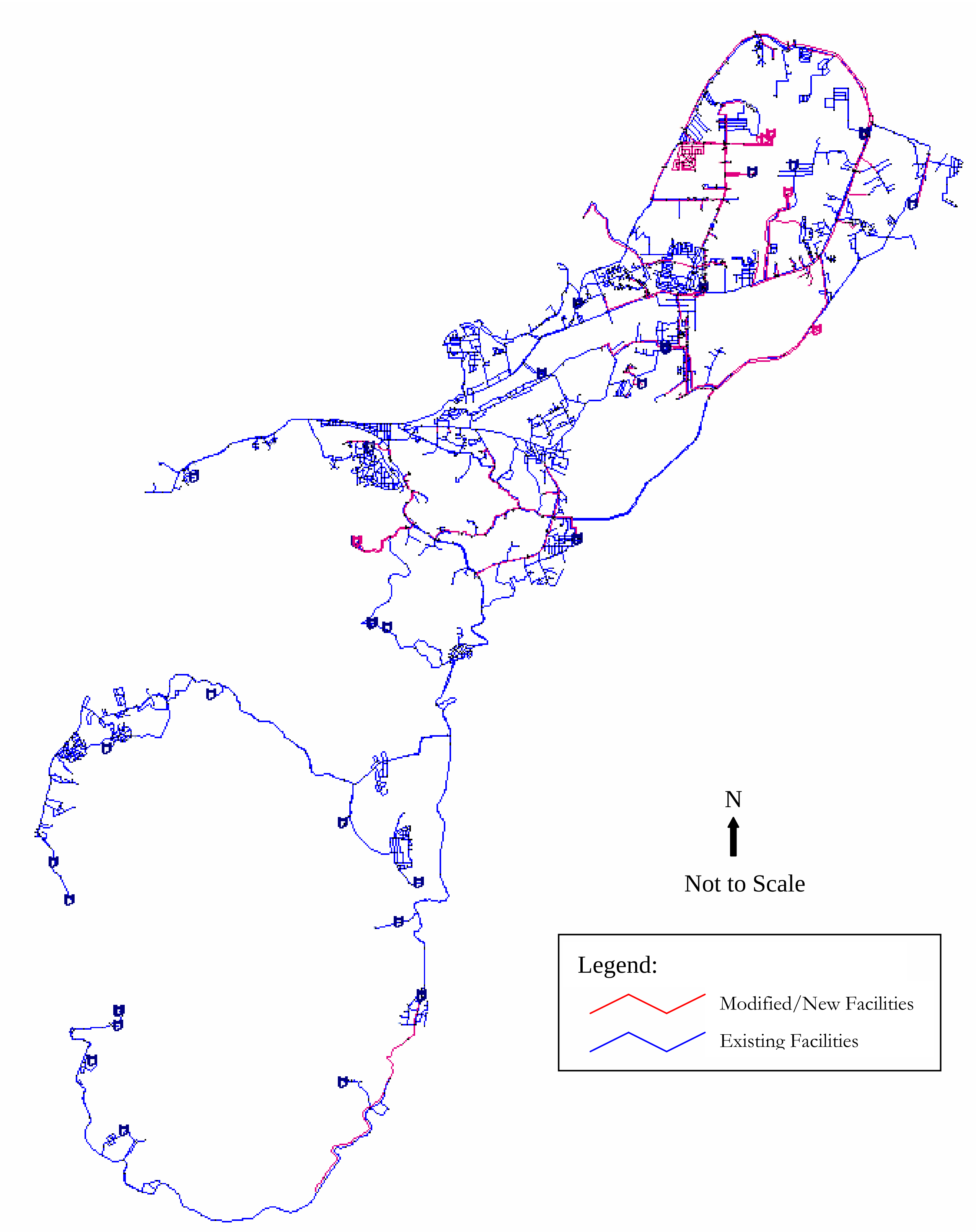


Figure 6-26 – 2025 CIP Investigating Model: Max-Day, Min Pressure (<40 psi)

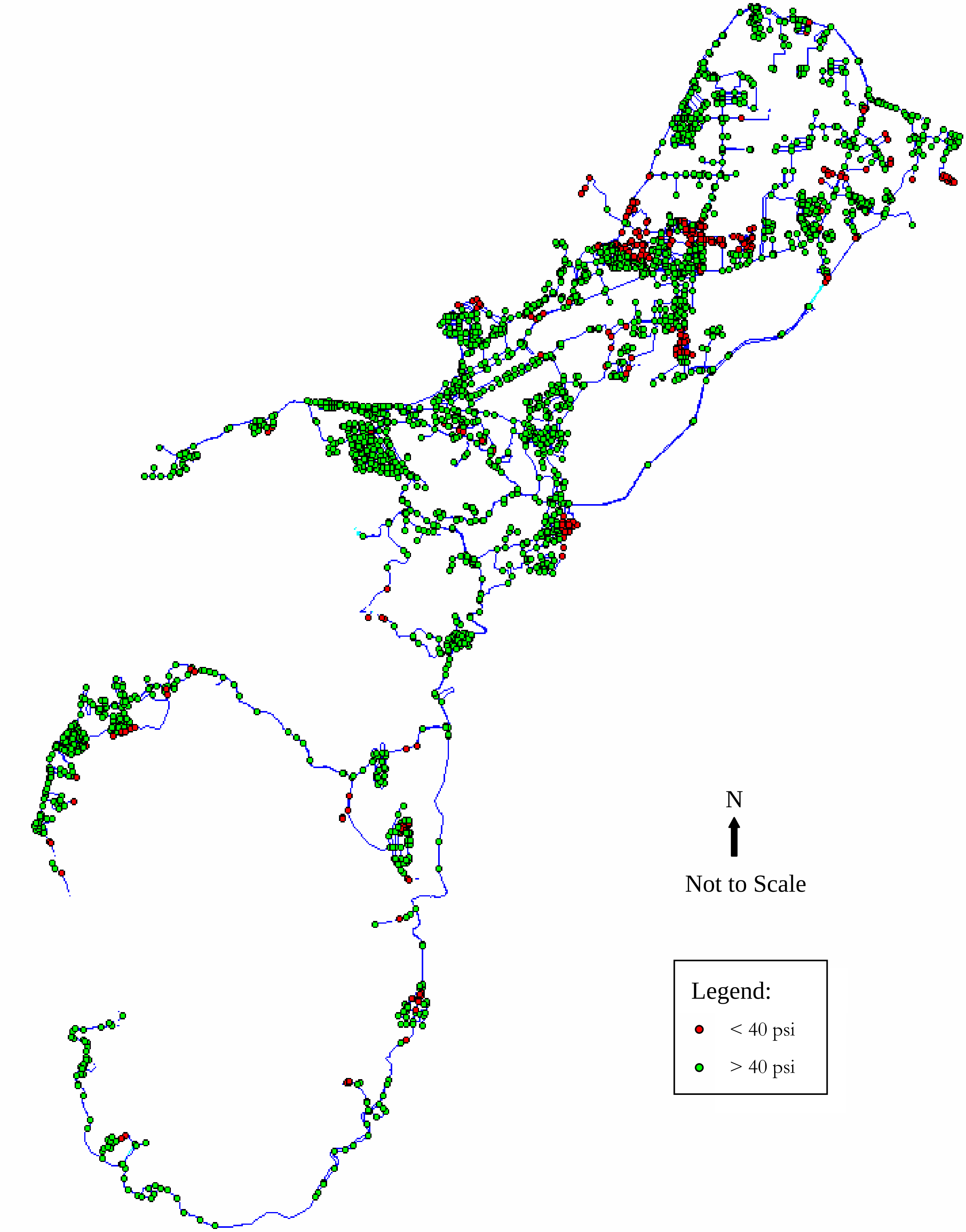


Figure 6-27 – 2025 CIP Investigating Model: Max-Day, Max Velocity (>6 fps)

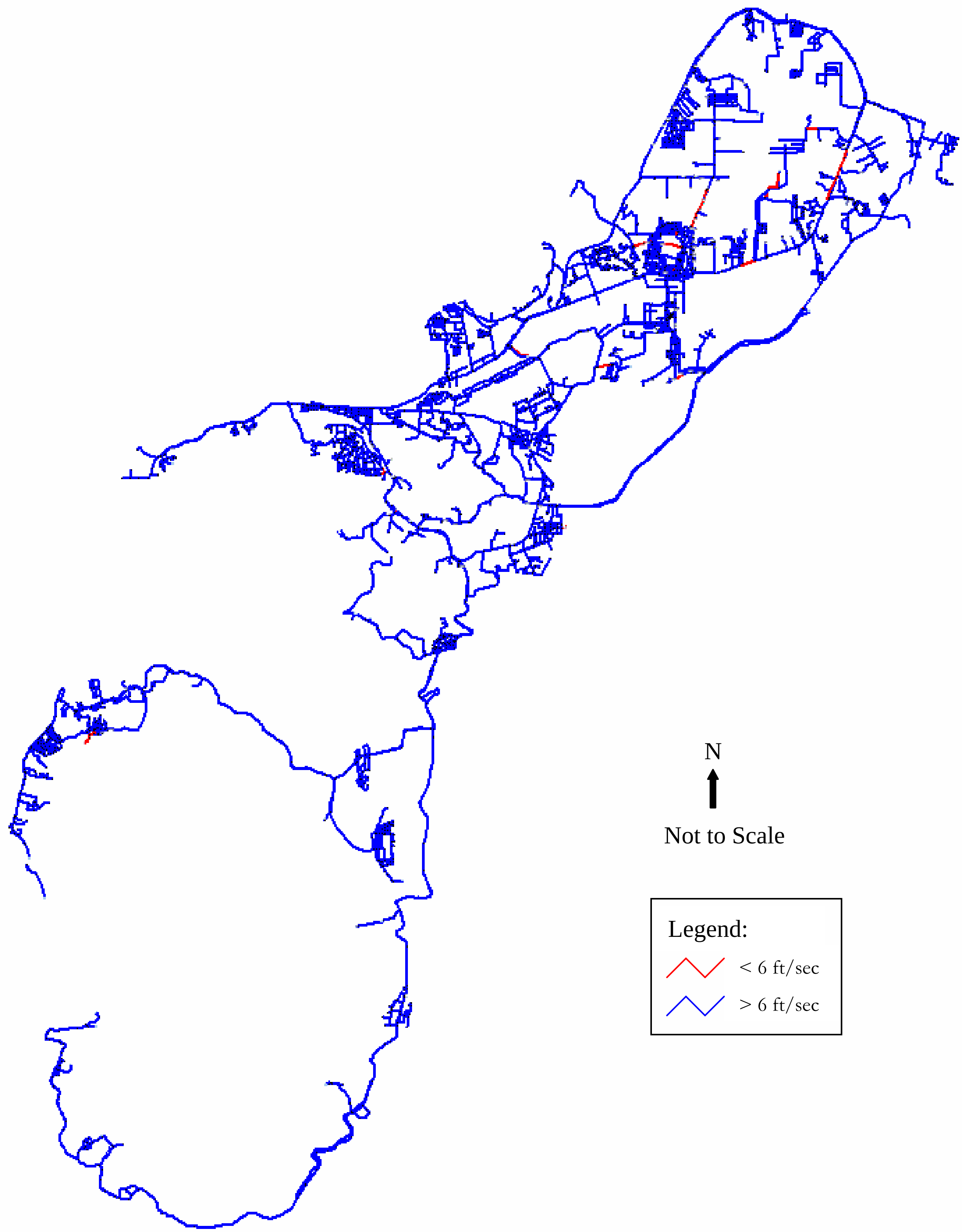


Figure 6-28 – 2025 CIP Investigating Model: Max-Day, Available Fire Flow (Min 20 psi residual pressure)

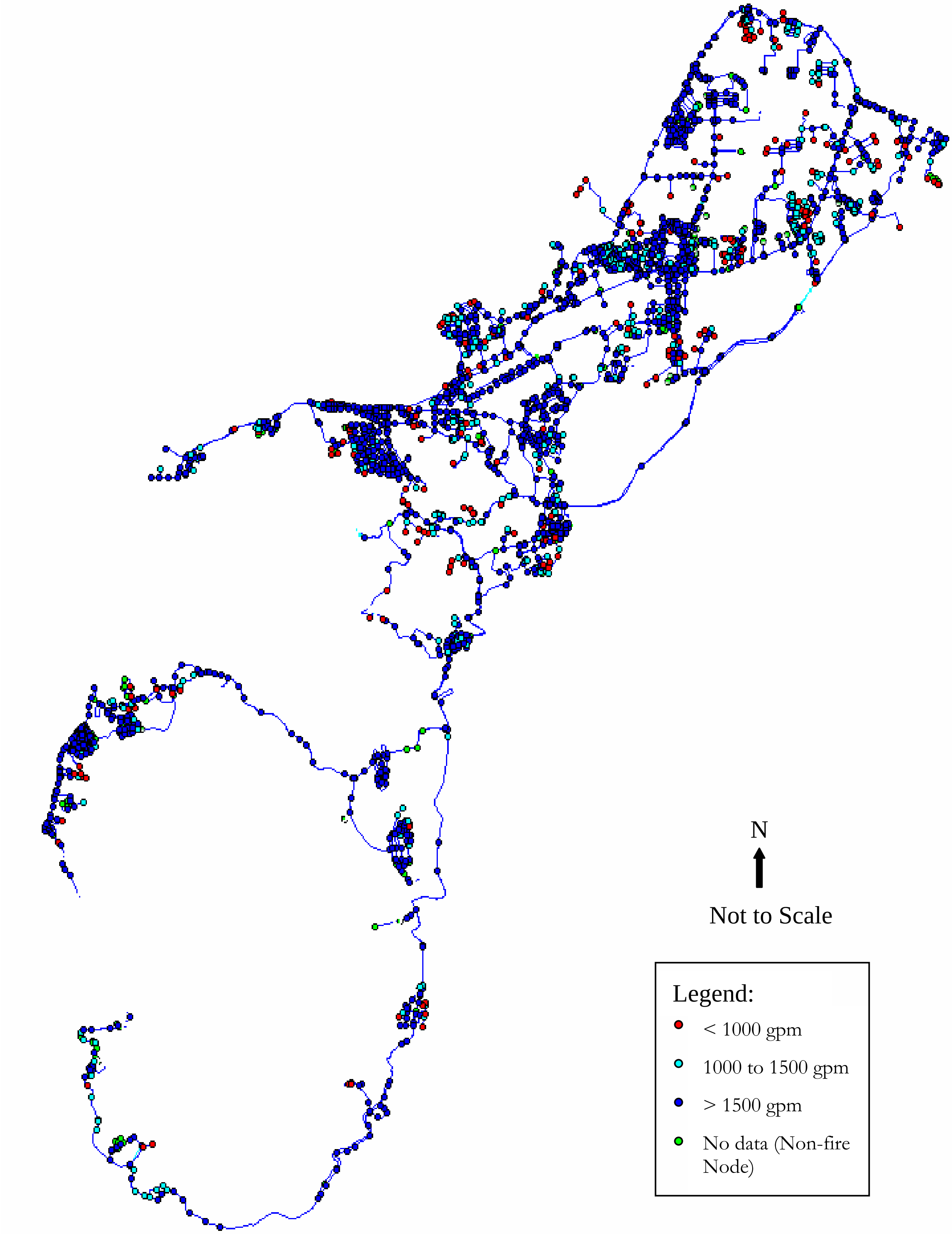


Figure 6-29 – 2025 CIP Investigating Model: North Reservoir Levels, Max-Day Scenario

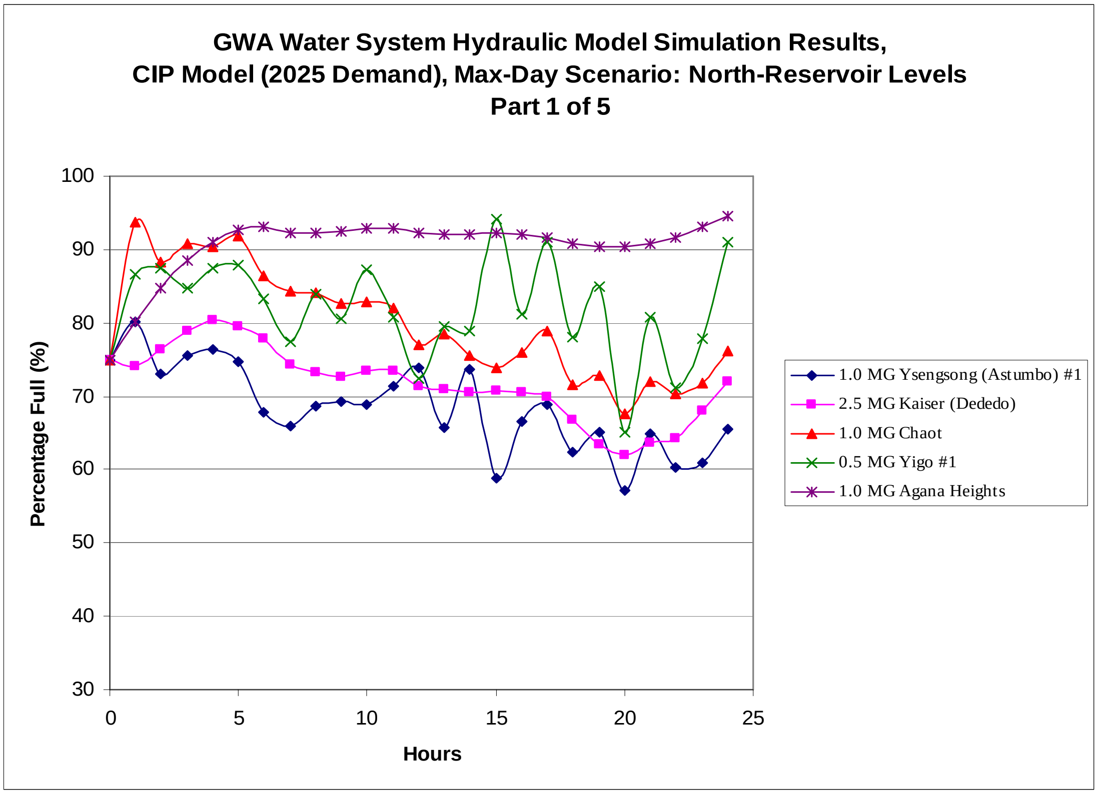


Figure 6-30 – 2025 CIP Investigating Model: North Reservoir Levels, Max-Day Scenario

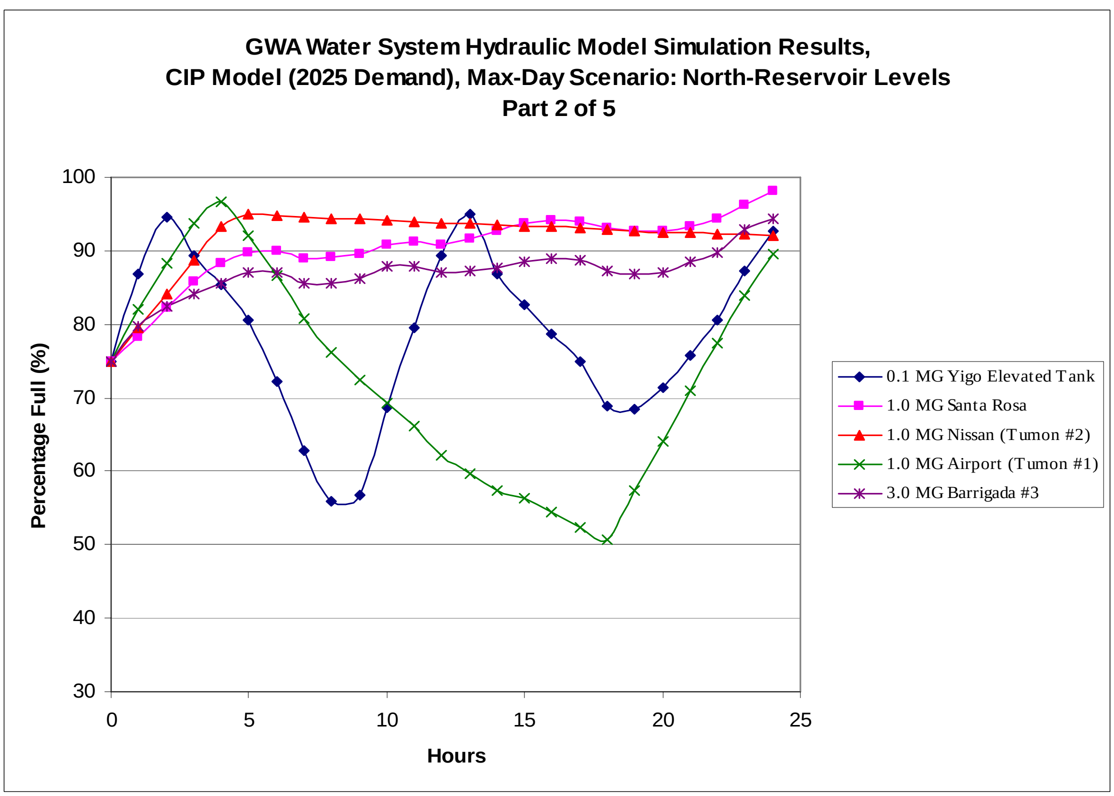


Figure 6-31 – 2025 CIP Investigating Model: North Reservoir Levels, Max-Day Scenario

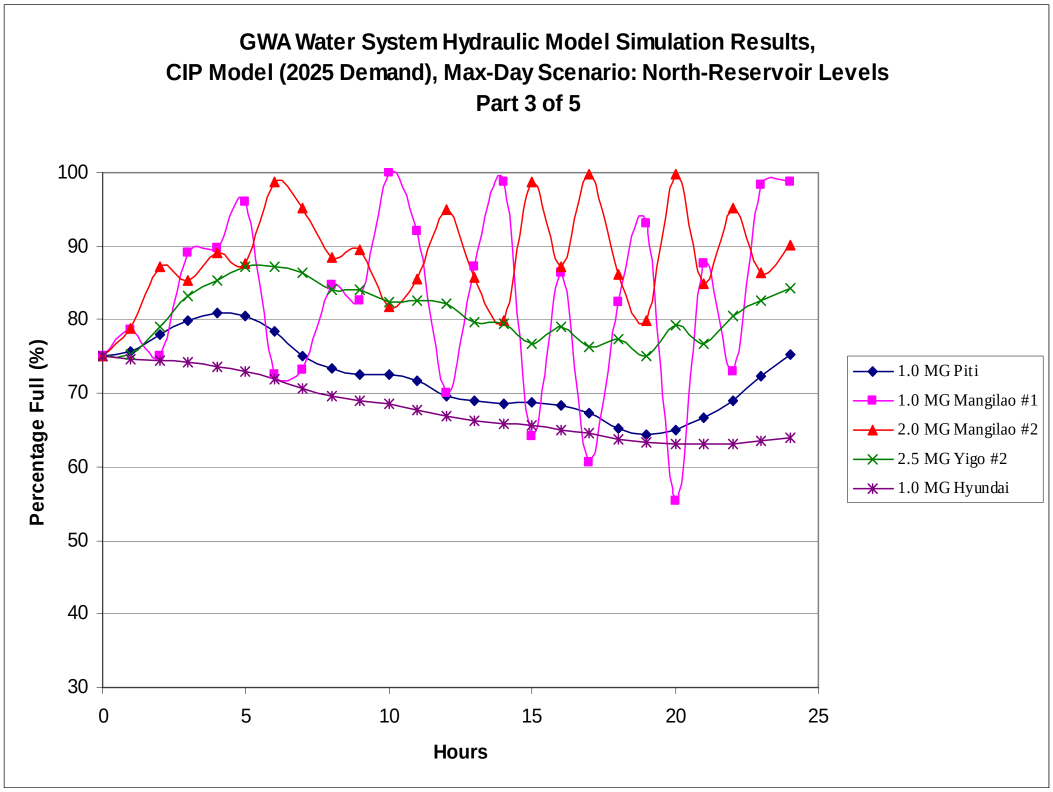


Figure 6-32 – 2025 CIP Investigating Model: North Reservoir Levels, Max-Day Scenario

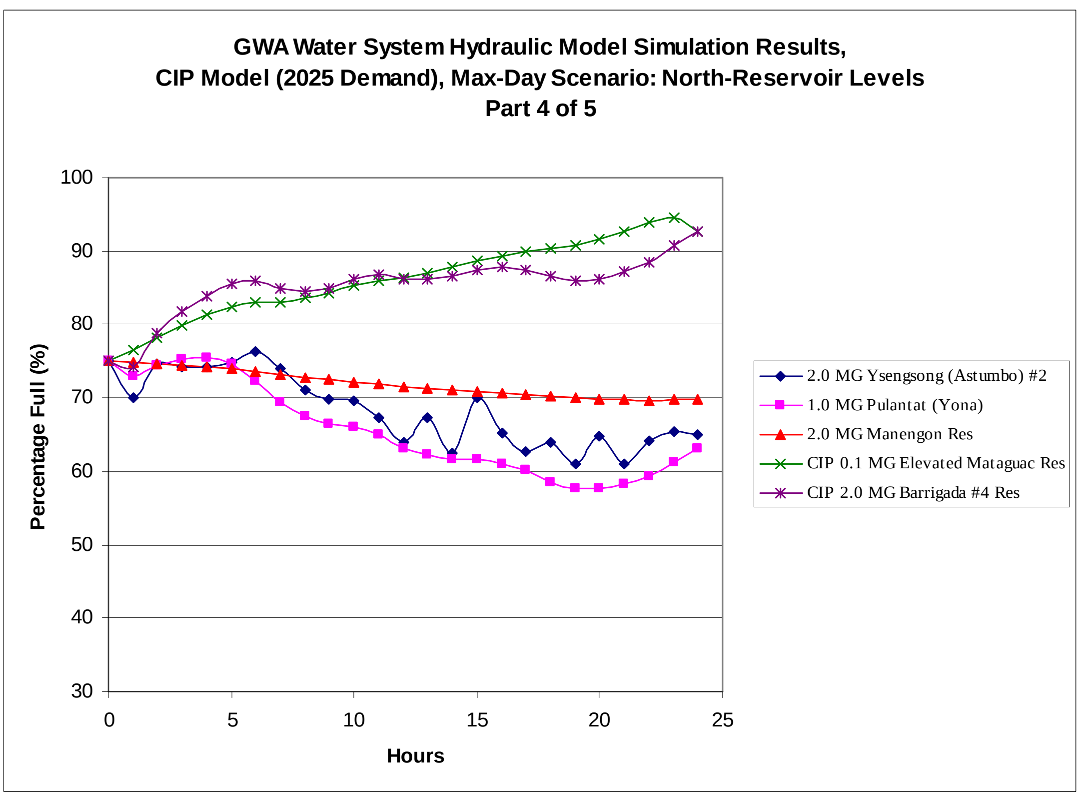


Figure 6-33 – 2025 CIP Investigating Model: North Reservoir Levels, Max-Day Scenario

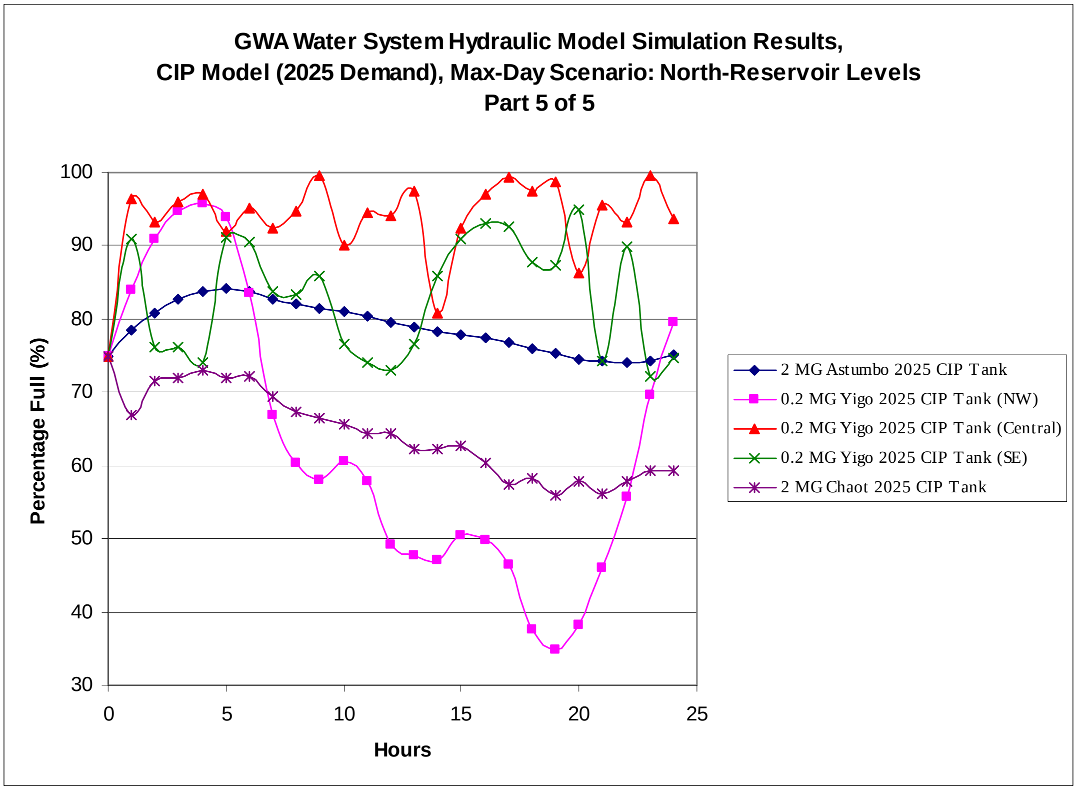


Figure 6-34 – 2025 CIP Investigating Model: South-Central Reservoir Levels, Max-Day Scenario

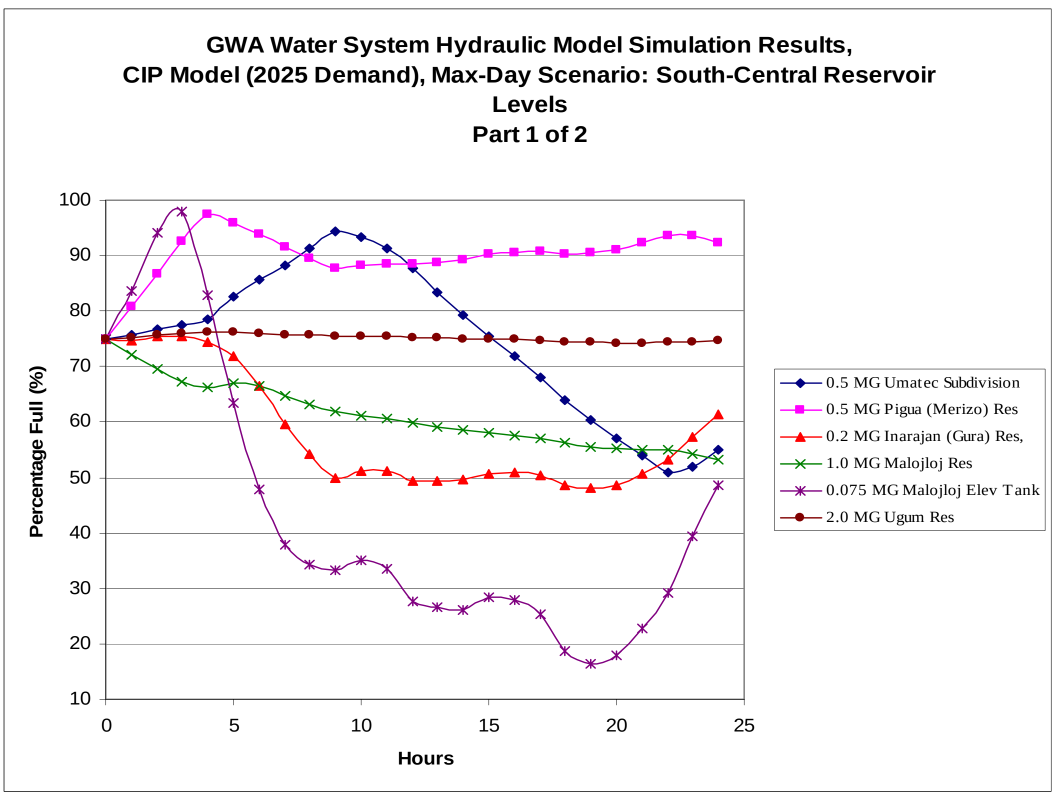


Figure 6-35 – 2025 CIP Investigating Model: South-Central Reservoir Levels, Max-Day Scenario

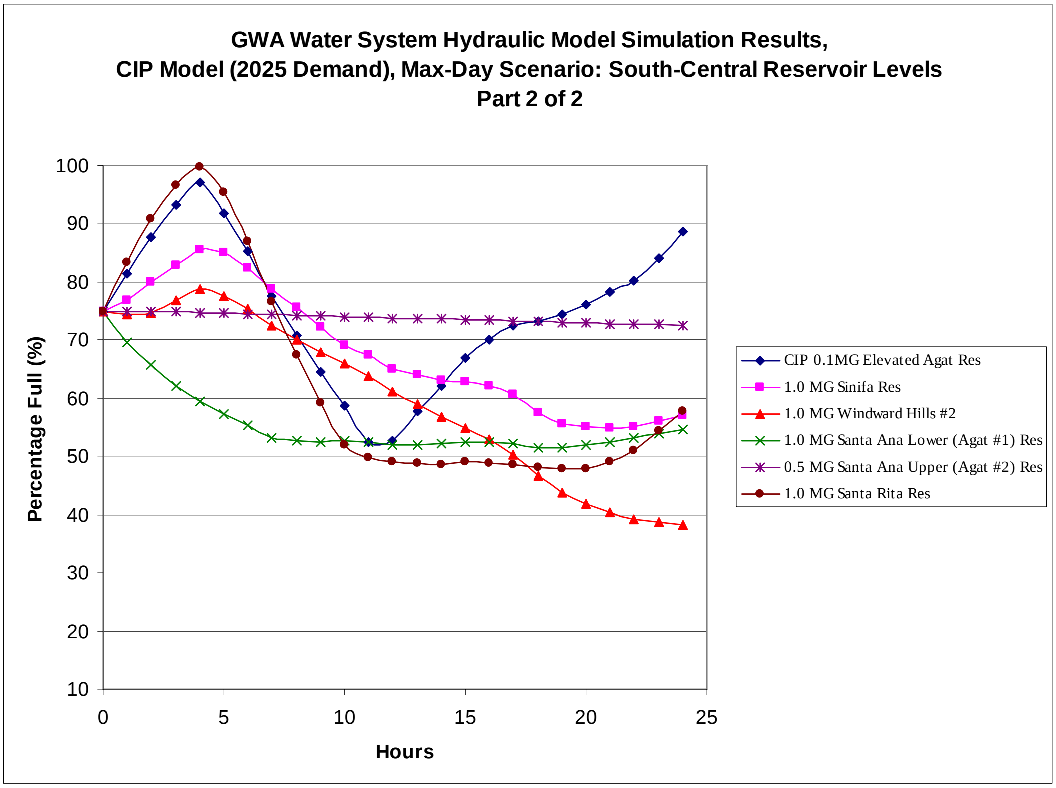


Figure 6-36 – 2025 CIP Investigating Model: System Demand and Supply, Max-Day Scenario