Task G: Temporary Flow Monitoring

Comprehensive Water Master Plan
DWSD Contract No. CS-1278

Final Report

For Submittal to

Detroit Water and Sewerage Department

April 2001

CH2MHILL

IN ASSOCIATION WITH CDM

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Abbreviations

Avg.	Average
CG	Community Group
CGDF	Community Group Demand Factor
CGDFA	Community Group Demand Factor Approach
CWMP	Comprehensive Water Master Plan
DWSD	Detroit Water and Sewerage Department
EPS	Extended Period Simulation
HDF	Hourly Demand Factor
ICI	Industrial, Commercial, Institutional
MGD	Million Gallons per Day
QA/QC	Quality Assurance/Quality Control
Rec.	Recorded
SCC	System Control Center
TYJT	Tucker, Young, Jackson, Tull, Inc.
WQ Model	Water Quality Model

1. PURPOSE

The purpose of Task G: Temporary Flow Monitoring was to collect hourly flow rate information to use in developing customer diurnal use for the EPANET mathematical models. These models will be used in the Comprehensive Water Master Plan (CWMP) to simulate demands on the water system by decade through 2050. These models will simulate water use under three different demand conditions: maximum day, average day, and minimum day. All three of the demand conditions will simulate 24-hour durations in one-hour increments.

The models that will be used in the CWMP employ the Community Group Demand Factor (CGDF) approach. This approach was developed in the previous modeling project for the DWSD water system: CS-1171, Water Quality Model of the DWSD Transmission System. A brief summary of the CGDF approach is found in Appendix A. The basis of the CGDF approach is to group wholesale communities with meters that record hourly flow rates (chart recorders) with community meters that only record a volume of use over a two-week period (totalizers). Other criteria are used in grouping the communities such as water use, close proximity of each other, if they are in a water authority, etc. The Community Groups are shown in Figure 1.

The original intent of the temporary flow-monitoring program in the summer of 2000 was to collect data for maximum day water use pattern. In fact, earlier in the year all indications from weather forecasters indicated a high probability that the summer of 2000 would be hotter and drier than 1988, the year of the maximum day of record. Task G proposed to monitor flows at suburban master meters during the course of the summer of 2000 to capture the water use under hot and dry conditions. Additional meters would also be monitored as part of the project to refine existing community groups by reducing the size of some of the larger community groups. Water use patterns for the community groups would then be refined using the collected data.

Unfortunately, the summer of 2000 was not one of the hottest on record in Michigan. In fact only June 13, the maximum day for 2000, experienced a high temperature greater than 90 degrees F. The high rainfall and low temperatures resulted in lower than expected water use in the region.

The high rainfall did, however, result in a greater range of system pumpage than was expected. The system pumpage varied from a high of 935 MGD to a low of 565 MGD. As a result of this the project team modified the goals of Task G. Instead of using the data collected to only revise the maximum day demand model, the data was used to revise the average day and minimum day models as well.

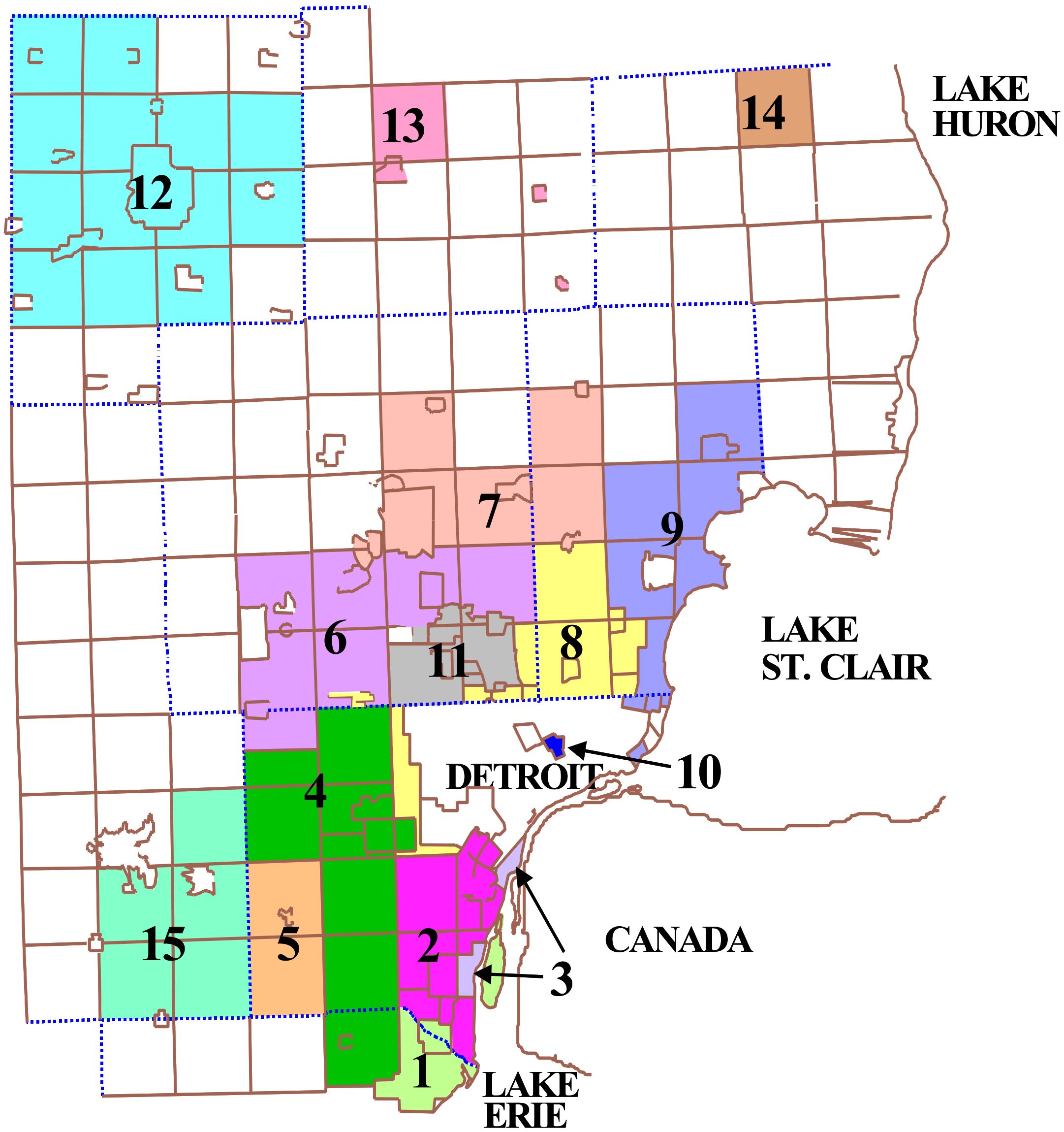

Figure 1 Community Group Map

2. PROCEDURES AND METHODOLOGY

This section discusses the procedures and methods used in the Task G work. The work included meter selection, equipment installation and data collection, review, and analysis.

Meter Selection Process

The flow monitoring program selection process was based on using the DWSD data loggers that had been used in the previous flow monitoring studies. To maximize the use of the DWSD data loggers, the meter selection process attempted to ensure than the three highest water use meters within a community group (CG) would either be measured by an existing chart recorder or a data logger installed for the monitoring program. Furthermore, master meters with chart recorders that were considered to be critical to the analysis were equipped with a data logger.

In selecting meter locations, a three-tiered approach was used to classify potential monitoring sites. Tier One meters were classified as high use meters used in previous CG analysis. These meters were judged to be essential for the analysis.

Tier Two meters were selected as alternates to Tier One meters in case field circumstances did not allow a data logger to be connected. Tier Three meters were only utilized if the requirements for Tier One or Tier Two meters were met. The Tier Three locations were also selected as a possible means of reducing the size of some of the existing CG's.

From this process a total of 34 meters were selected for Task G monitoring. Six of the 34 meters monitored were mechanical meters while 28 were venturi meters. Ten of the venturi meters had existing working chart recorders. A total of 28 data loggers were installed as part of Task G because six of the meter locations already contained data loggers previously installed for use in the 1997 and 1998 temporary flow-monitoring project.

Table 1 shows the meters monitored, their location, the type of meter and to which CG each meter was assigned. Locations with existing data loggers included FL-1, RD-9, NH-1, OT-1, NV-4, and HR-1. Both FL-1 and RD-9 data loggers were different from all other data loggers used in this study. These meters used a different interface and data logging procedure than the other data loggers called Hart protocol. The data loggers still collected data in 15-minute averages. Additional meter information can be found in Appendix B.

Table 1 Task G Master Meters Information

ID #	Community	Location	Meter Type	Cabinet Device	CG
AH-3	Auburn Hills	Walton and Squirrel	BIF Venturi / Orifice	Chart recorder	7
CH-1	Chesterfield Twp.	24 Mile and Fairchild	Venturi	RTU	9
CT-4	Clinton Twp.	16 Mile W of Utica	BIF Venturi	Chart recorder	9
EC-1	Ecorse	Visger and Bassett	Simplex Venturi	Chart recorder	3
FL-1	Flint	Potter and Baxter	Penn. Flow Tubes	Existing data logger	12
GI-3	Grosse Ile	GI Parkway E of Jefferson	Venturi	Chart recorder	1
GK-3	Grosse Pointe Park	Essex and Barrington	Sensus (Mechanical)	None	9
HK-10	Hamtramck	Gallagher and Trowbridge	Venturi	RTU	10
HR-1	Harrison Twp.	Union Lk Rd and Metro Pky	BIF Venturi	Existing data logger	9
LA-2	Lapeer	Oregon and Saginaw	Venturi	RTU	13
LA-3	Lapeer	Oregon and Milleville	Sensus (Mechanical)	None	13
LV-15	Livonia	West Chicago ant Hartell - in Station	BIF Venturi	Chart recorder	4
NE-4	Northville Twp.	8 Mile and Meadowbrook	Venturi	RTU	6
NE-5	Northville Twp.	6 Mile and Sheldon	Venturi	RTU	6
NH-1	New Haven	26 Mile E of Gratiot	BIF Venturi / Orifice	Existing data logger	9
NV-4	Novi	14 Mile W of Decker	BIF Venturi / Orifice	Existing data logger	6
OP-2	Oak Park	Coolidge N of 8 Mile	Venturi	RTU	8
OT-1	Orion Twp.	Brown and Giddings	Venturi	Existing data logger	7
PO-1	Pontiac	Opdyke and 20 Mile	BIF Venturi	Chart recorder	7
RC-2	Rochester Hills	Walton E of Squirrel	BIF Venturi / Orifice	Chart recorder	7
RD-9	Redford Twp.	8 Mile E of MacArthur	BIF Venturi	Existing data logger	8
RK-1	Rockwood	Fort N of Huron River Dr	Sensus (Mechanical)	None	1
RR-2	River Rouge	Anchor and Jefferson	Venturi	RTU	3
SN-1	St. Clair County	Det. Ed. Greenwood Energy Center	BIF Venturi / Orifice	Chart recorder	14
SS-3	Saint Clair Shores	8 Mile and Harper	Venturi	RTU	9
TA-6	Taylor	Allen and Northline	BIF Venturis	Chart recorder	2
VB-3	Van Buren Twp.	Tyler and Belleville	Venturi	RTU	5
VB-4	Van Buren Twp.	Bemis and Savage	Sensus (Mechanical)	None	5
WB-2	West Bloomfield	14 Mile and Farmington	BIF Venturi / Orifice	Chart recorder	6
WG-2	Washington Twp.	26 Mile and GTW RR	Venturi	RTU	7
WL-8	Westland	Newburgh and Glenwood	Sensus (Mechanical)	None	4
WN-7	Warren	8 Mile and Groesbeck	BIF Venturi	Chart recorder	8
WO-2	Woodhaven	Allen and King	Sensus (Mechanical)	None	2
YT-1	Ypsilanti	Ecorse and Penn Central RR	BIF Venturi / Orifice	Chart recorder	15

Data Logger Installation

A roving installation crew made up of personnel from CH2M Hill, TYJT, and Dynalogic accomplished data logger installation. DWSD crews from the System Operations Control Division and the Meter Operations Division assisted the installation crew during data logger installation. Data logger installation for all venturi type meters commenced on June 13, 2000 and was completed by June 27, 2000. Data logger installation at mechanical meter locations was completed between July 20 and July 24, 2000. The delay in data logger installation at mechanical meter sites was the result of delays in obtaining required specialized equipment for these locations.

DWSD Field Engineering Services requested that detailed records be kept at each meter location visited during Task G data logger installation due to the DWS-805 meter project currently in progress. Field Engineering requested that a detailed field report be completed at each installation location. This report included totalizer readings at the start and end of work, arrival and departure times, a detailed list of all equipment installed, and a wiring diagram that included the installed equipment. A copy of a sample field report form is included in Appendix C.

Pictures of the meter cabinets and connections were taken before and after installation. Additional pictures of the meter pits and metering devices were also taken for project reference. All pictures were developed in electronic format and forwarded to Field Engineering. Electronic copies of the pictures can be found in Appendix D.

Equipment Installed

The equipment installed was dependent on the meter type: mechanical or venturi type. The twenty-eight locations with venturi type meters had the following equipment installed: A three-channel data logger, a two-channel signal isolator, and a twelve-volt power source. The six mechanical meter locations also installed a three-channel data logger and a twelve-volt power source. However, these locations required a signal converter instead of a signal isolator. A photo of a typical data logger setup is shown in Figure 2.

A typical wiring diagram utilized by the project team can be found in Appendix E. A brief discussion of each piece of equipment follows:

Data Loggers

Data loggers manufactured by VTM Industries were utilized for Task G. They were capable of monitoring three distinct four to twenty milliamp signals simultaneously. During setup each monitored signal is identified and given an expected range of use. The data loggers recorded a signal value every second but were setup to only log the fifteen-minute average to memory. This setup resulted in four data points per hour.

Each data logger has a limited memory. Once the available memory is filled, the data logger stops collecting data. Collected data is retrievable via a serial cable interface. A laptop computer using a terminal emulator like HyperTerminal can be connected to the data logger to collect stored data. Once data is collected, the stored memory is cleared so that data collection can continue.

Data values recorded every fifteen minutes included the date, the time (Note: time recorded was the actual time data was written to memory), the fifteen minute average recording, the highest data value recorded during the fifteen minute interval, and the lowest data value recorded during the fifteen minute interval. Data values were written to a text file in comma delimited format.

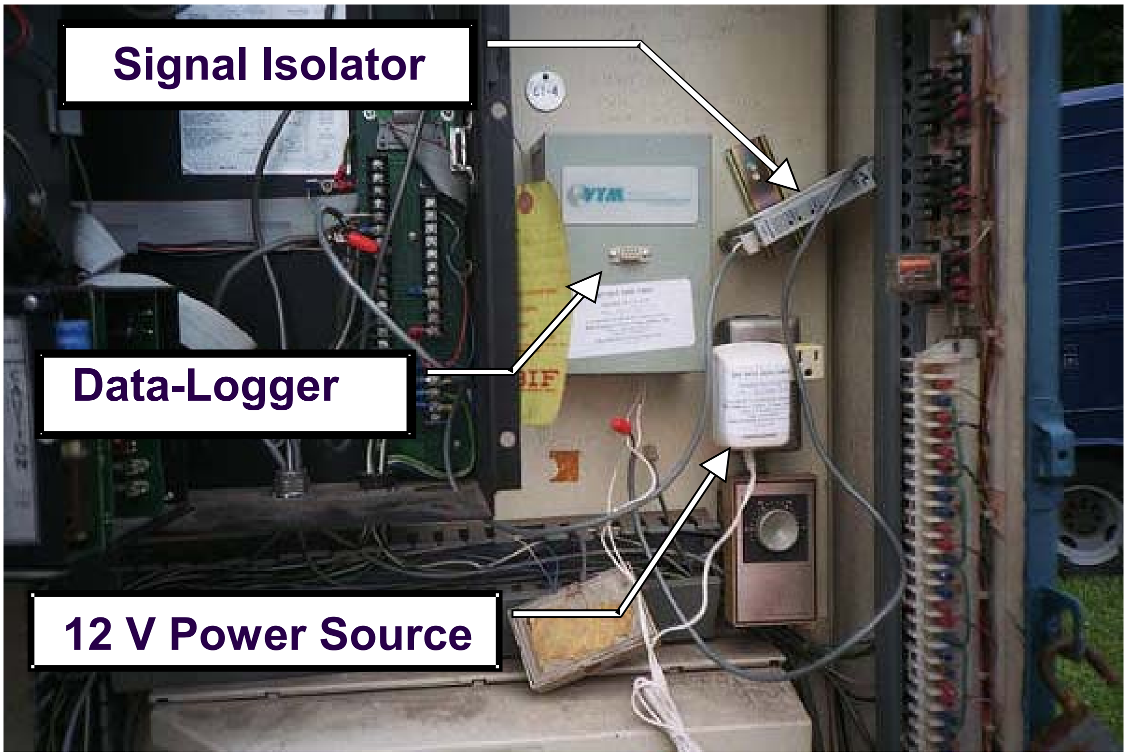

Figure 2 Close-up of Data Logger Setup

Each data-logger was capable of monitoring the four to twenty milliamp signals on three different channels. Each channel used required the input of the lowest value expected (value for four milliamps), the highest value expected (value for twenty milliamps) and an offset value (used to calibrate the data logger). The low value was usually zero while the high value was equal to the expected high range of the meter device in MGD times 100. Thus a two MGD venturi would have a high value of 200. This was used because the data-loggers cannot use decimal points. The offset correction value was determined during calibration.

Signal Isolators

Model Q-501 signal isolators manufactured by Action I/Q were used in this study. The isolators can isolate a two-wire input for up to two channels and are primarily used to prevent ground loops from occurring. The installed isolators were used to keep the data-loggers from creating a ground loop and thus reducing the four to twenty milliamp signal sent from the meter DP (Differential Pressure) cells. Product information is included in Appendix E.

Signal Converter

Act-Pak Model 1000 series signal converters manufactured by Sensus were used in this study. They were required at the mechanical meter locations because the newly installed

Sensus mechanical meter heads only provide a pulse signal output. The signal converters convert a pulse signal to a four to twenty milliamp signal that the data loggers can read. These signal converters are meter size specific due to the signal conversion methods. A separate signal converter was required for every flow-measuring device monitored. Thus locations with a low and a high side meter required two signal converters. Product information is included in the Appendix E.

Twelve Volt Power Supply

A standard wall outlet 120 Volt AC to 12 Volt DC power source was required to power the data-loggers. The meter cabinets have an outlet located in the cabinet available for use. This outlet was used to power the data-logger equipment. In case of power loss to the cabinet outlet, the data-logger would be without power and would not log flow data. This proved to be a minor problem during the monitoring period for meter pits with flooding problems because the cabinet outlet is usually on the same circuit as the meter pit outlets. The flooded pit would trip the circuit breaker of the cabinet outlet, rendering the data-logger without power.

Data-logger Field Calibration

Each data-logger was calibrated in the field. A twelve-point calibration curve was developed for each channel monitored. The calibration curve measured twelve data-logger signal count response values between four to twenty milliamps. The calibration curve enabled the project team to greatly reduce the measurement error of the data-logger. The twelve-point calibration curve reduced the error of the data logger from 5% to approximately less than one percent of actual flow. A detailed description of the calibration curve process as well as a discussion regarding the calculations used for data correction can be found in Appendix F.

Data Retrieval Procedures

Data at each of the 34 data-loggers used were collected by a roving two-person crew with a laptop computer and a cell phone for communicating with the office. Each data logger was visited weekly to minimize potential data loss from data logger or meter problems. A data logger download route was developed for each day of the week. Monday through Thursday were utilized for data-retrieval, while Friday was reserved for addressing any data logger problems observed during the week. Download routes typically included eight to ten data loggers per day. A copy of the download route can be found in Appendix B.

Download forms were developed to streamline and standardize data collection. The download forms recorded the time of arrival and departure of the project team and the totalizer readings at the start and end of downloading. This information was useful in the QA/QC process. Example forms are presented in Appendix C.

The download crew was asked to record the last data logged by the data logger on the download form. The time and data of the last data logged was checked to see if it was within fifteen minutes of arrival date and time. The data values were also checked for unusual readings during the data download. Any unusual findings were documented on the form. These simple field QA/QC checks helped ensure the quality of the gathered data.

The data file was checked for completeness and copied to floppy disk to ensure that all data was captured to the file before the data logger memory was cleared. Several other checks were included to ensure that the data logger memory was properly cleared and that the cabinet lock was securely fasted before the download crew left the meter site.

At the end of the day, the download crew completed a brief one to two page summary of work. The form included a record of meters visited for the day, any problems or unusual circumstances encountered, and the time and last data recorded at each meter. The form and data text files sent to the project QA/QC team via email for review.

Daily Data QA/QC Review

Quality Assurance and Quality Control (QA/QC) procedures were developed by the project team to minimize data loss and to enhance the confidence in the data collected. QA/QC procedures also included methods for addressing meter or data-logger problems once identified.

The procedures included a daily conference call with the download crew that allowed the project team to briefly review the previous days data with the field crew. The meeting would address obvious data-logger and meter problems found by the download crew such as data-logger wiring problems and power outages at the meter cabinets. Clarifications of data transfer protocols were also addressed to ensure procedures were clearly followed.

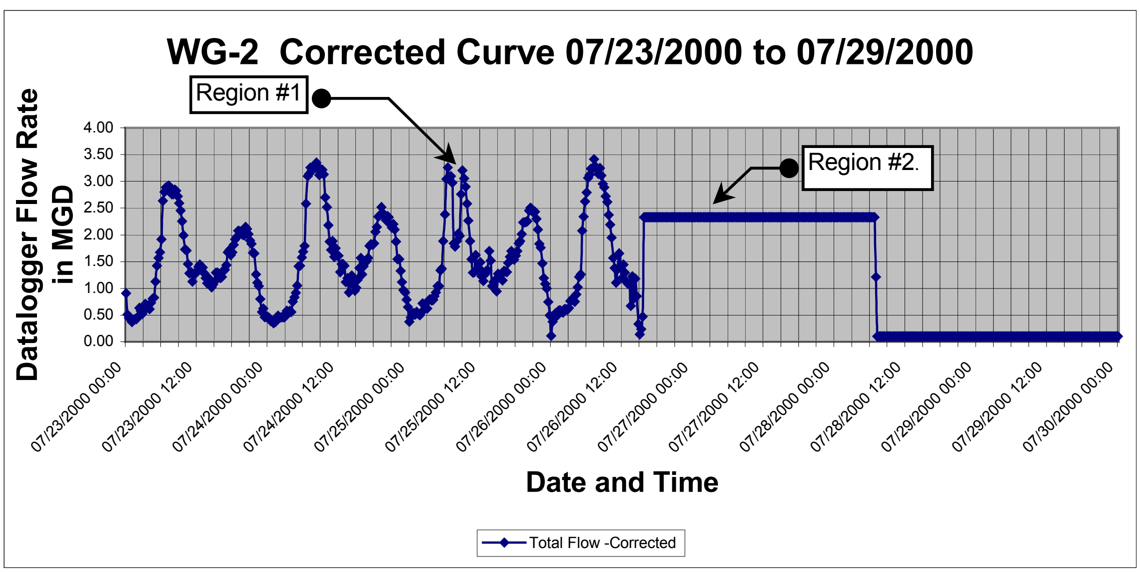

Figure 3 Example QA/QC Data Graph

A graphical review of the data was found to be the simplest and fastest way to check the incoming data with questionable results. An Excel spreadsheet template was developed to aid in the graphical review. A separate Excel spreadsheet for each data logger monitored was developed from this template to simplify and standardize the data review. The data text files containing the data were manually copied into the spreadsheet for the associated meter. The templates produced a standardized graph of the collected data for review. A sample graph can be seen in Figure 3.

Figure 3 illustrates the advantages of the graphical data review. A review of the figure depicts the ability to quickly identify unusual results. Region #1 in the figure reveals an unusual dip in demand during the period of highest water use. Because this data drop was only experienced on this day and no others, it was flagged as "suspect data".

Region #2 in the figure illustrates a typical wiring problem. While the data was downloaded around 3 PM on the 27th, the wiring problem resulted in a flat line in the data. This meter was subsequently visited shortly after this download to fix the wiring problem.

A data flag classification was employed to identify questionable data. Good data was given a flag of zero. This data had no reason to be questioned and was assumed good. Data loss due resulting from meter problems (Flag 2) or data logger problems (Flag 1) was flagged as lost data. Suspect or unusual data (i.e. region 2 in Figure 3) was flagged with data Flag 4 as suspect data. When a reasonable engineering estimate could be made for any lost or suspect data a correction was made to the original value to estimate the actual flow result. This data was flagged as corrected data (data flag 3).

Table 2 QA/QC Data Flags

Data Flag	Explanation
0	Good data – no known problems
1	Lost data due to problem with data logger
2	Lost data due to problem with DWSD meter
3	Corrected data (estimate of true value)
4	Suspect data (atypical pattern or unrealistic values)

Any potential meter problem identified in the QA/QC process was brought to the attention of the DWSD Instrument shop. Meter problems typically involved a loss of power to the cabinet plug or calibration of the DP cells for venturi type meters. Observed data logger problems were typically related to loose wiring or a loss of setup data due to power surges. The desired goal in this process was to address identified problems as soon as possible to minimize data loss. All Excel data files used for QA/QC are included in Appendix G.

A data record documenting all data downloads for each meter was kept during the monitoring period. These records describe any identified meter problems found during the QA/QC process. Copies of this information can be found in Appendix B.

Data Analysis Procedures

Additional Data Collected

Daily system pumpage data was obtained from DWSD SCC for the entire flow-monitoring period. Climate data for the summer of 2000 was obtained from the web site of the National Weather Service for Detroit and Pontiac. Climate information included the total daily rainfall, as well as the daily high, average and low temperature in the region.

Comparison Methods

Water use patterns were developed using the Hourly Demand Factor (HDF) method. The HDF normalizes the water demand to the 24-hour daily average flow and is calculated for each hour of the day. It is calculated using the following formula:

$$HDF_i = \frac{\text{Recorded hourly flow rate at hour i (at meter X)}}{\text{24 hour average flow rate (at meter X)}}$$

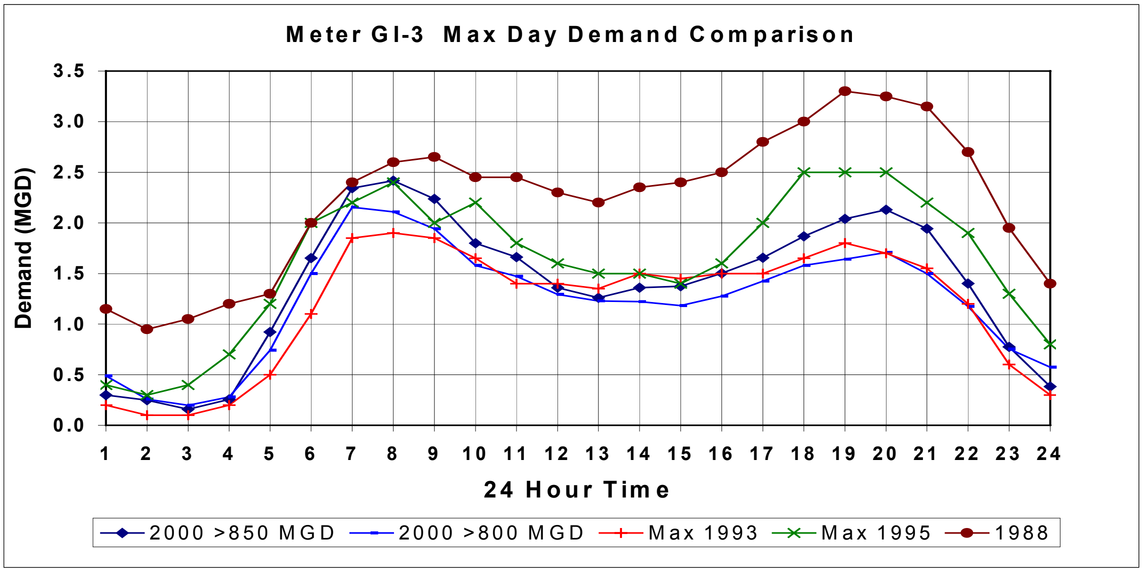

Figure 4 Maximum Day Demand Comparison for Meter GI-3

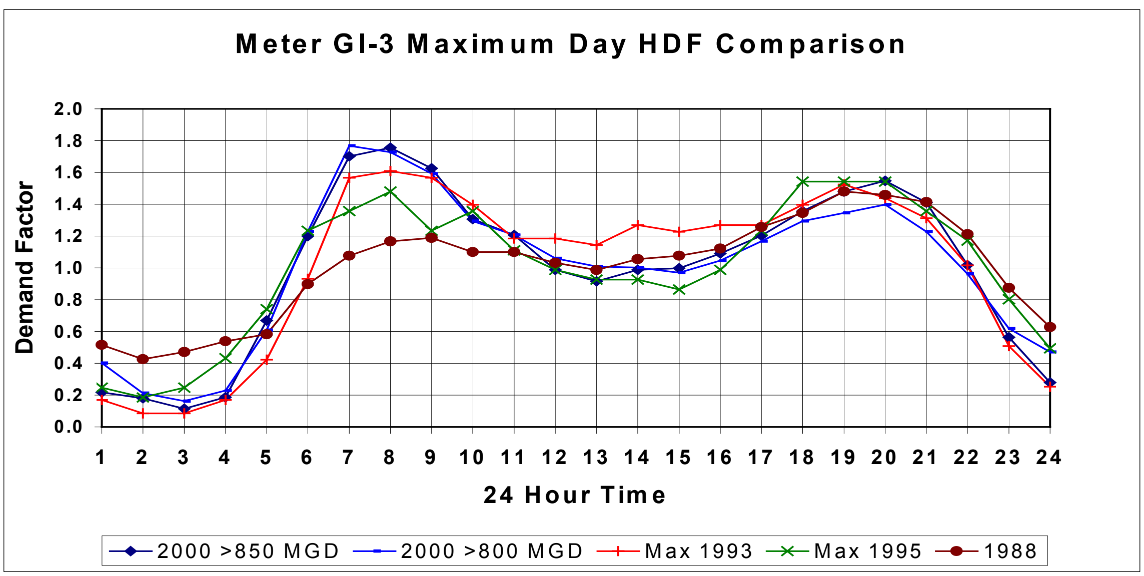

Figure 5 Maximum Day HDF Comparison for Meter GI-3

The HDF allows water use patterns developed for different demand conditions to be compared to other years and other days during the monitoring period. Examples of this can be seen in Figure 4 and Figure 5. Figure 4 shows the water use patterns based on actual demand while Figure 5 shows the water use patterns based on HDFs. Because the water use greatly fluctuated between 1988 and 2000, it is difficult to compare the water use patterns based on actual demand (Figure 4). However, Figure 5 illustrates how similar the patterns are when HDFs are used.

Data Sets Analyzed for Each Meter

The primary goal of Task G was to collect hourly flow rate data to use in developing the models for the master plan. Therefore, the data sets were grouped based on the system demands that will be represented in the models (i.e., maximum day, average day, and minimum day). To best achieve this meters were analyzed over a 24-hour period and the days were grouped based on that day's system demand. Furthermore, weekend and weekdays were also grouped to see if the demand patterns varied. The following data sets were selected for analysis:

Table 3 Data Sets Selected for Analysis

Data Set	Description
1	All data (weekdays and weekends)
2	All weekday data
3	All weekend data
4	Weekdays with system pumpage > 850 MGD
5	Weekdays with system pumpage > 800 MGD
6	Weekdays with system pumpage > 650 & < 750 MGD
7	Weekdays with system pumpage < 650 MGD
8	Weekends with system pumpage < 650 MGD

Maximum day water use pattern comparisons were made by comparing Data Set 4 patterns (> 850 MGD) and Data Set 5 patterns (>800 MGD) with previously developed patterns developed for the maximum days of 1988, 1993, 1995, and 1999.

Average day water use pattern comparisons were made by comparing Data Set 6 patterns (weekdays between 650 to 750 MGD) and Data Set 7 patterns (< 650 MGD) with the previously developed patterns for the 1995 average day.

Minimum day water use pattern comparisons were made by comparing Data Set 8 (weekends < 650 MGD) and Data Set 3 (all weekend data) with the previously developed 1993 minimum day patterns. Weekend data was used in this comparison because the 1993 minimum day used was a Sunday.

Finally, a comparison of how the water use patterns vary with changes in system pumpage was made by analyzing Data Sets 4, 5, 6, and 7. These data sets provided a range of system pumpage for this analysis. This comparison identified the similarities and differences in water use patterns over the range of system pumpage values. This information assisted in QA/QC of historical water use patterns.

Comparisons of HDF patterns using only good data (Data Flag 0) as well as good and corrected data (Data Flags 0 and 3) were completed for each data set. The water use patterns using corrected and non-corrected data for all cases except for a few involving Data Set 4 and 5 were identical. Corrected data was used for only a couple of meters due to a lack of data for Data Sets 4 and 5.

In addition all data set patterns did not contain any climate criteria such as daily rainfall or high temperature.

Developed MS Access Interface Program

A Microsoft Access visual basic interface program was developed to assist data analysis efforts. The vast amount of data collected as well as the difficulty in selecting data meeting the selection criteria provided the impetus for developing this program. The interface allowed individual meter data to be queried by the following criteria:

1. Day of week
2. System pumpage
3. Data flag
4. High temperature
5. Rainfall

Selection parameters used by the program were allowed to be either a single value or a range of values. The program also allowed either a single meter data set or multiple meter data sets to be analyzed. However, multiple meter selections always resulted in a unique HDF pattern for each meter selected. Data from multiple meters was never combined into one pattern. An example form utilized by the interface is shown in Figure 6.

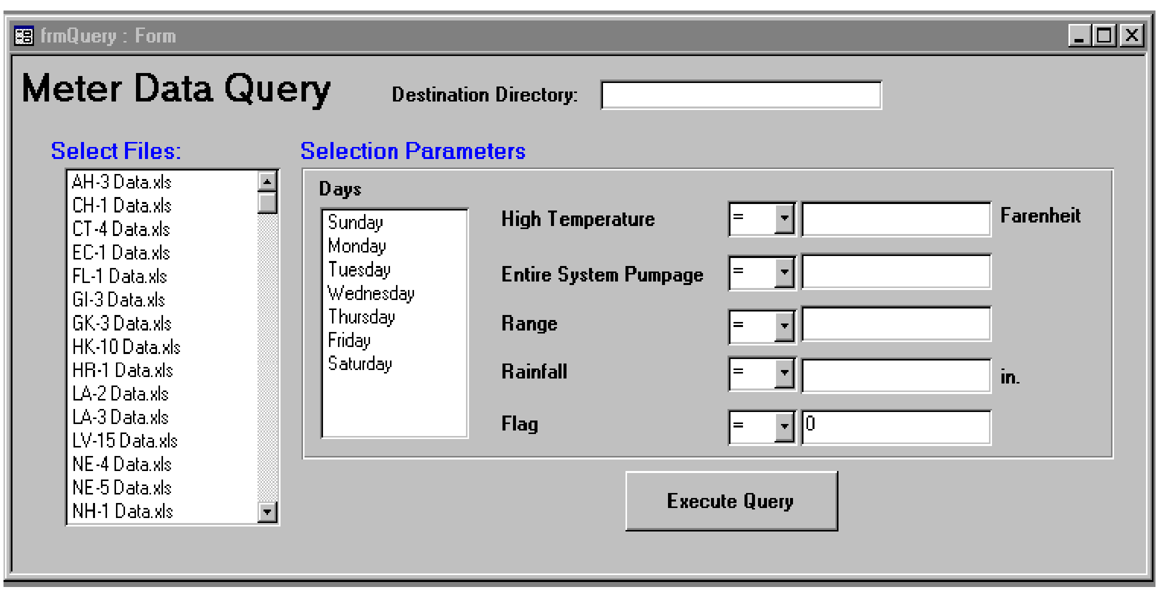

Figure 6 Example MS Access Interface Program Screen

The user the interface program would provide the following output each meter selected for all twenty-four hours of the day given the specified selection criteria:

1. Average of selected data
2. Standard Deviation
3. Number of data points selected
4. Hourly Demand Factor (HDF)

3. RESULTS

This section will provide a review of the Task G results. Only representative data will be presented in the report due to the large number of data graphs produced. All graphs are presented in detail in Appendix H.

The section includes a discussion of the typical observed effect of system pumpage on the water use patterns as well as the differences between weekday and weekend water use. Water use patterns for maximum, minimum and average day conditions for a typical venturi meter and a typical mechanical (totalizer) meter will also be discussed.

Historical System Pumpage Values

Available historical system pumpage data used in this comparison is presented as reference in Table 4. The limited data for Table 4 corresponds with the available diurnal water use data used in the analysis. From the data, July 1988 is the maximum day of record while 1995 and 1999 are more recent maximum day demands. A difference of 430 MGD separates the maximum day values. Chart data from 1988, 1993, 1995, and 1999 were available for analysis. The historical average day data was gathered using 1995 chart data and represents the average system pumpage. The minimum day was developed from 1993 chart data and is representative of weekend use. The average and minimum day data was based upon the data collected for the DWSD Water Quality Models.

Table 4 DWSD Available Historical System Pumpage Data from 1988 to 2000

Maximum Day	Average Day	Minimum Day
1988 – 1342 MGD (July 7)	1995 – 628 MGD	1993 – 509 MGD
1993 – 912 MGD (July 23)	(average of May 24 and 25)	(Sunday, October 17)
1995 – 1159 MGD (June 19)		
1999 – 1115 MGD (June 8)		
2000 – 994 MGD (June 10)		

Summer 2000 System Pumpage

The DWSD daily system pumpage was obtained from the DWSD SCC and is shown in Figure 7. Unfortunately the highest system pumpage of the summer occurred a few days before installation commenced. However, a reasonably hot and dry period during the end of July provided a reasonable maximum day period for analysis. The range of recorded system pumpage from a high of 935 MGD to a low of 565 MGD can be seen in the figure.

A histogram of the distribution of system pumpage is seen in Figure 8. This figure reveals that nearly half of the 128 days monitored (48% of all data) were between 650 and 750 MGD. Surprisingly the 29 data values, ranging from 550 to 650 MGD, comprised the next largest group (22% of all data). Approximately 5% of the days had system pumpage greater than 850 MGD. The roughly 25% of days left fell evenly in the 750 to 850 MGD range.

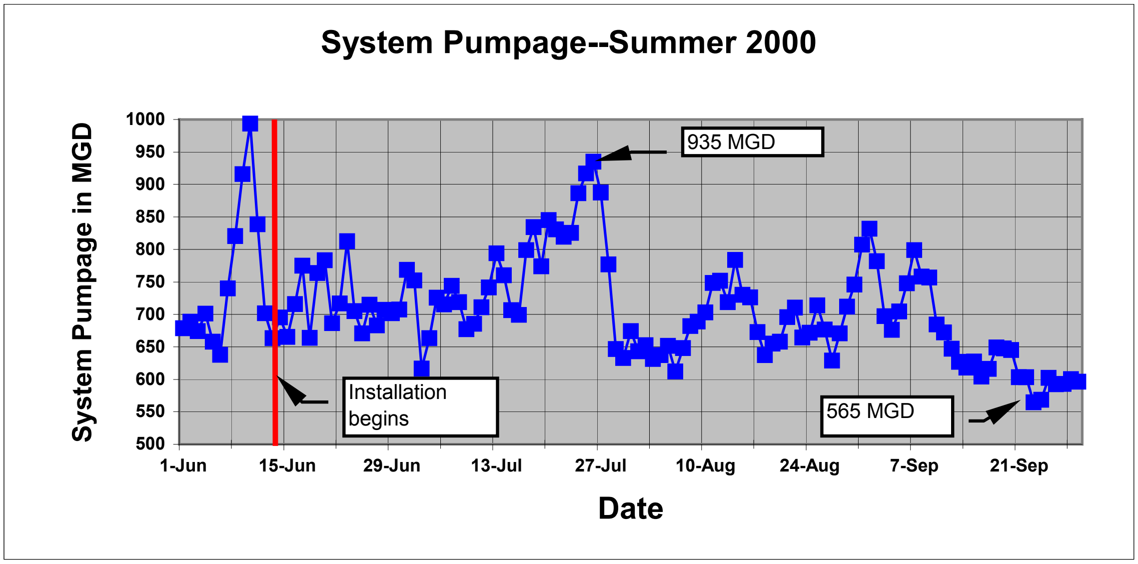

Figure 7 Summer 2000 DWSD System Pumpage

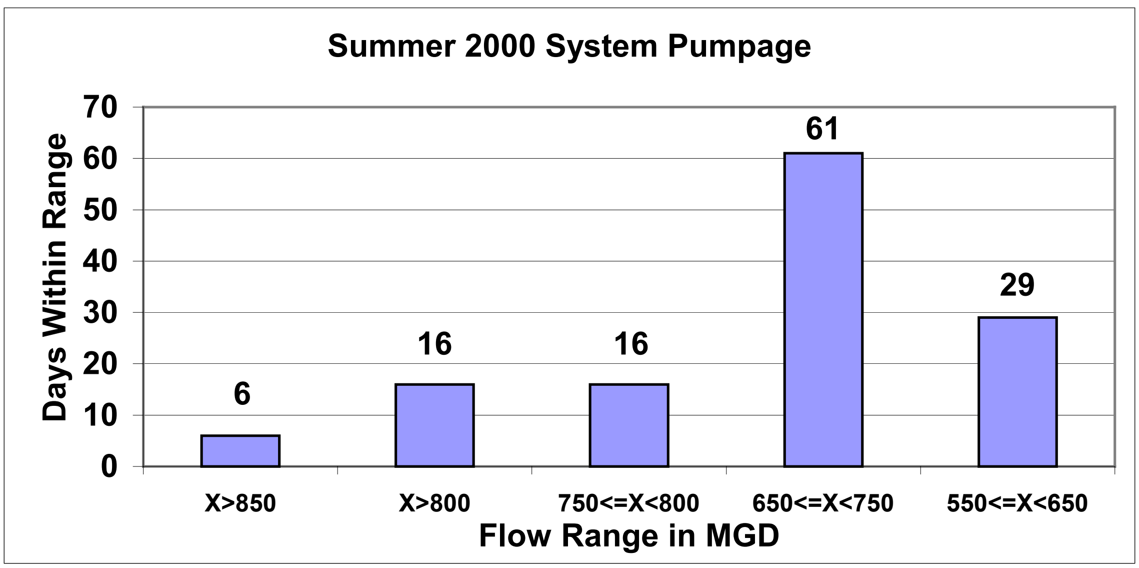

Figure 8 Histogram of Summer 2000 System Pumpage

The system pumpage and climate information gathered is included in Appendix I. The following sections are provided to discuss the analysis followed as well as to identify the typical results of the analysis. Much of the analysis described was actually used to improve the existing CGDFs developed for use in previous model analyses.

System Pumpage and Water Use Patterns

As example, data from meter GI-3 is presented as a typical comparison graph in Figure 9. This graph represents the average HDF water use pattern of four of the weekday data sets analyzed. These data sets span the range of the observed system pumpage during the monitoring period.

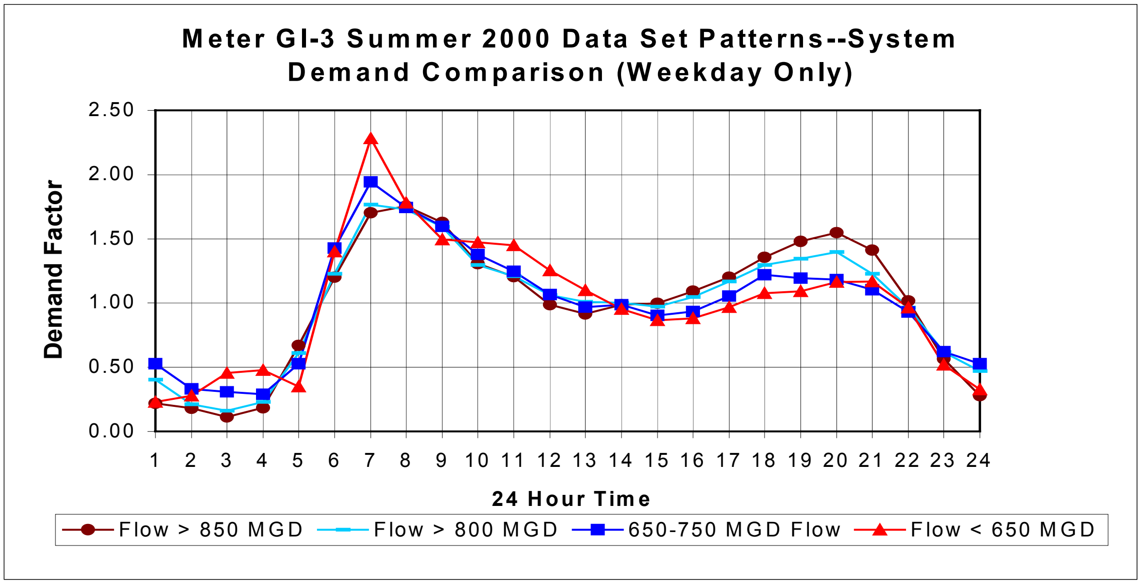

Figure 9 Effect of System Pumpage on Water Use Pattern at Meter GI-3

Upon analyzing the graph an important trend was observed. The HDF for the morning peak hour was higher when the system demand was small, while the HDF for the evening peak was higher for the larger system demands. This makes sense intuitively because the HDF normalizes water use to the daily average flow. While the actual morning peak demand during high system pumpage is slightly higher than during low system pumpage, the daily average flow is greater during periods of high system pumpage. This is the primary cause of the observed trend.

However, one of the most important observations regarding this comparison is the similar trends and shape observed for all patterns. The hour of peak demand occurs at roughly the same time regardless of the system demand. This trend was observed for nearly all master meters observed (29 out of 34 meters monitored).

The stability in the hour of peak use and general shape of the curve was a critical finding in this analysis. Previously developed patterns developed from chart meters or from CGDF analysis that did not exhibit a similar shape and peak hour water use as the current data were set aside for investigation. Most of the investigations resulted in either a modification of the historical pattern or the identification of a unique water use pattern.

Four of the five meters that did not display this trend (NH-1, SN-1, WB-2, and WL-8) experienced significant problems during the monitoring period. Meter NH-1 was only able to use the high side meter to measure flow. The high side meter is not very accurate in the low flowrate region experienced during the summer. As a result water use measured at this meter was quite erratic.

The low side flows for meter WL-8 could not be measured during the monitoring period due to problems with the meter head. The meter head was cracked and was not able to be replaced during the monitoring period.

Meters SN-1 and WB-2 both experienced significant data loss due to power outages. The meter cabinet at WB-2 was without power for all but three weeks of the summer. Only one or two days of data were available in the high and low flow region at meter SN-1. Because meter SN-1 only feeds a Detroit Edison power plant, reasonable water use pattern are difficult to develop without many data points.

The additional meter not revealing this trend (PO-1) was due to the fact that this meter registers the filling of the reservoir at the pump station for the city of Pontiac. Reservoir filling is not as regular and systematic as the overall water use from a community.

QA/QC Observations

Peak Hour Water Use

The resulting consistency in peak water use is an important tool in developing water use patterns from analog chart recordings. The major time divisions labeled on a typical chart are in three-hour intervals. The distance on the chart between these intervals varies form ¼ inch to ¾ inch depending on the actual flow rate. This small distance makes it difficult to ascertain the time of peak flow on a chart any better than plus or minus 1.5 hours. The Task G results demonstrated a consistent hour of peak water use with times accurate to the nearest fifteen minutes. To further complicate matters, the actual start time for the chart meter is rarely recorded and often plus or minus 3 hrs of the actual time. This is exacerbated when the chart start time and end time is not recorded on the chart.

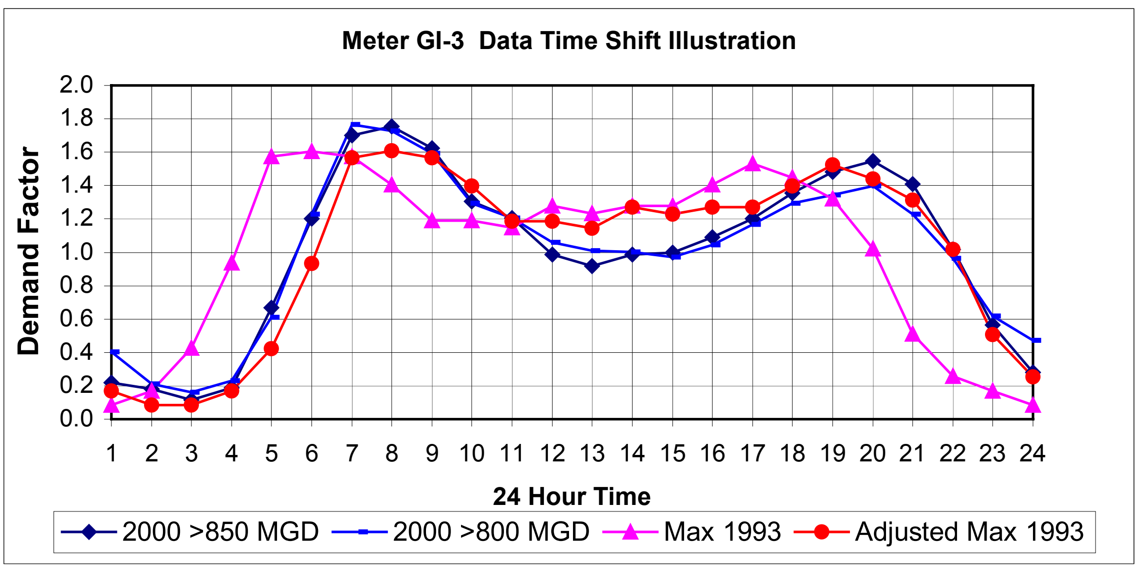

Figure 10 Example of QA/QC of Historical Pattern Data

The consistency of Task G observed peak hour use was used for QA/QC analysis of previously developed data. During the Task G comparisons, some previously developed patterns appeared to exhibit a very different water use pattern than observed for Task G as seen in Figure 10 for the 1993 Maximum Day Demand pattern. However, when this pattern was shifted forward two hours (Adjusted Max 1993) the patterns were nearly identical. This type of adjustment was used to improve one or more of patterns contained in 42 of the 102 comparison graphs developed for maximum, average, and minimum day analysis.

Consistent Shape of Diurnal Curve

Identifying Potential Meter Inaccuracies

The fairly consistent shape and trend of the water use patterns with increasing system demand was found to be a useful tool for identifying potential meter inaccuracies. Any unusual patterns observed for a meter or during community group analysis are indicative of potential problems and should be investigated. This analysis found that many of the unusual patterns observed were the result of limitations of a large venturi in capturing low flow readings (readings that are outside of the venturi's range). Figure 11 shows the summer 2000 data for EC-1 and the 1993 Minimum Day Demand CG 3 pattern. The unusual shape of the CG pattern prompted a closer look at the data used to develop it (CG-3 1993 Min Est.).

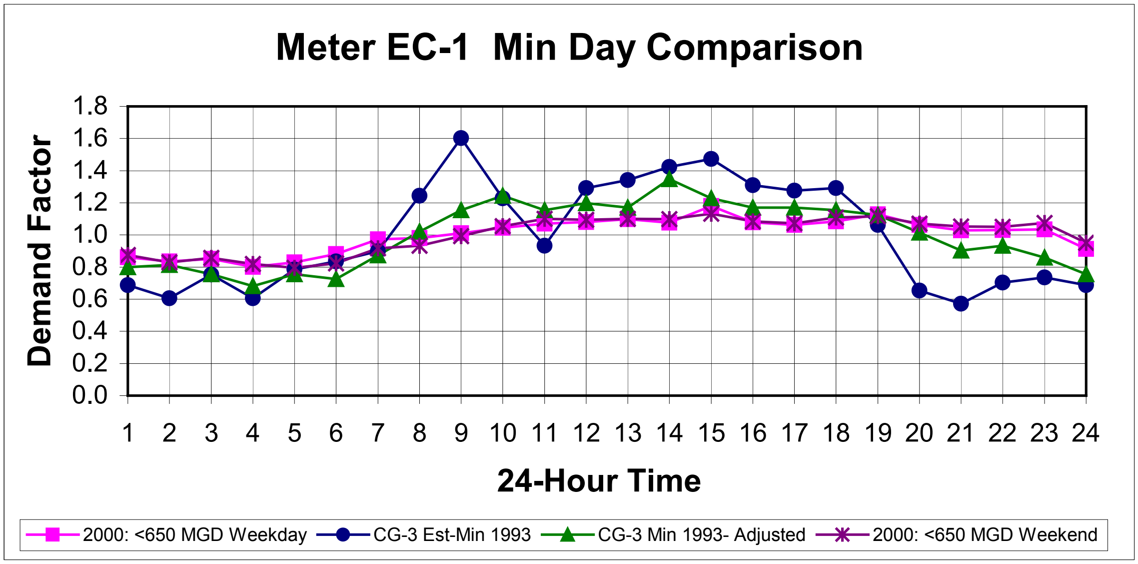

Figure 11 Example of QA/QC Investigation of Unusual CG Patterns

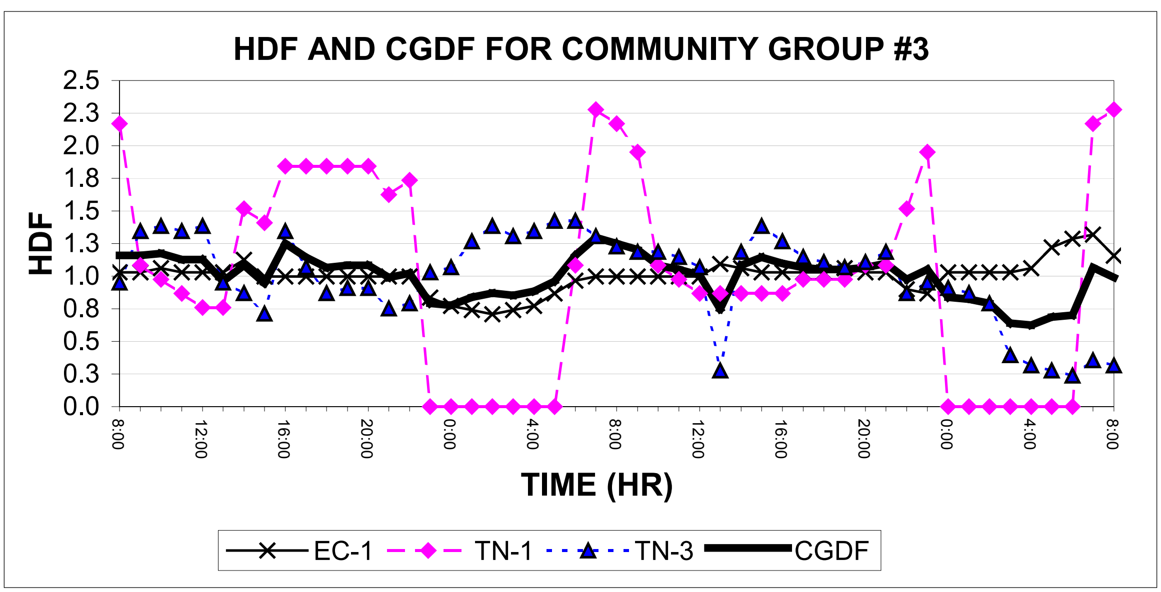

Figure 12 Example: Original Pattern Data before QA/QC (CG-3 Average Day)

This investigation revealed that the CG pattern was developed using the data from meters EC-1, TN-1, and TN-3. Both TN-1 and TN-3 patterns had several hours with no recorded flow (See Figure 12). Further investigation of these two locations revealed that they are both associated with large venturi meters operating near the low end of their range. Both meters would have difficulty in correctly recording low flows resulting in zero flow values. Estimates of the flow were made for the low flow regions and the CG pattern was recalculated. The revised pattern (CG-3 Min 1993 - Adjusted) was found to more closely match the summer 2000 data.

Inaccuracies in flow measurement due to the limited accuracy range for a venturi can produce unusual diurnal curves. Flows exceeding the high flow limit of the meter will result in "flat" water use patterns during peak water use such as observed in the 1995 curve for meter GI-3 in Figure 4. Conversely, flows below the low flow limits of the meter are characterized by sharp drops in flow or zero flow observed during off-peak periods (typically during the night) as seen in the data from TN-1 in Figure 12. Figure 11 appears to show that interpolated water use values can reasonably estimate water use during periods of meter inaccuracy. The corrected data could subsequently be included in a CG analysis.

Weekday vs. Weekend Water Use

The HDF patterns for weekend and weekday data were compared for all meters. This analysis revealed a consistent data trend (see Figure 13). The analysis revealed that morning peak water use on weekdays is approximately 2 to 4 hours earlier than for weekends. This time shift is community specific and can have an effect on the CG analysis. This data shift is one of the primary reasons that the model representing the minimum day water demand is different than the average and maximum day demands. The minimum day model was based on a Sunday demand, while the average and maximum days all used weekday data.

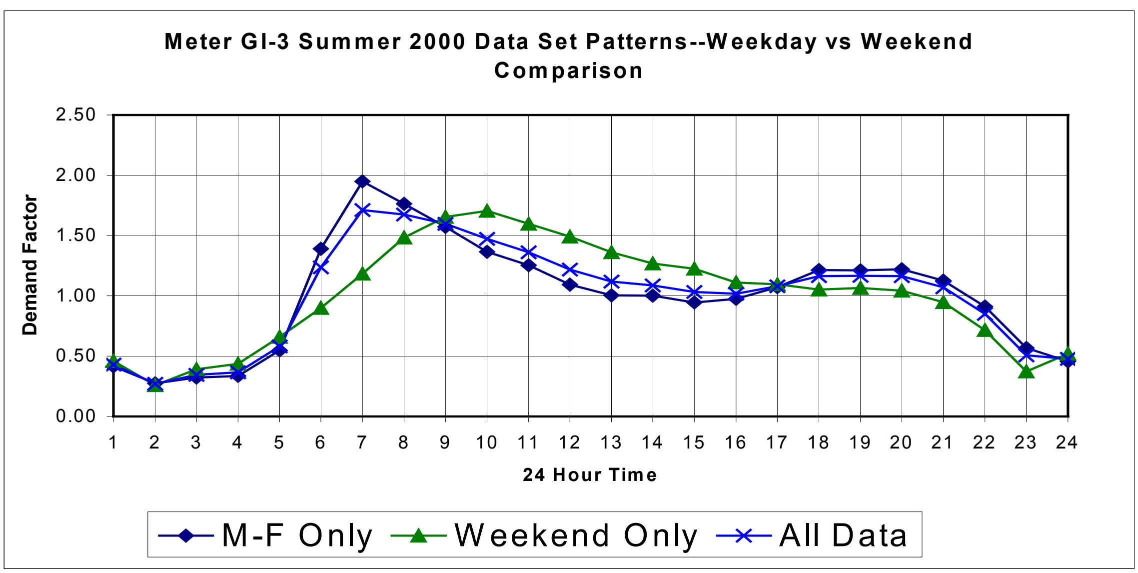

Figure 13 Example Comparison of Weekday vs. Weekend Water Use

The inclusion of all weekend and weekday data in the HDF pattern development produces a statistically significant general use pattern for the meter. The additional data used in the analysis provides a smoother pattern by minimizing data anomalies. However while the combined pattern appears to reasonably estimate the weekday water use, it does not appear to provide a reasonable estimation of weekend water use. The smoothed curve may be acceptable for an average day condition, but will likely minimize the extreme water use seen on maximum days. Care should be taken when analyzing data sets that include weekend and weekday use.

Community Group Verification

The HDF water use patterns developed from the Task G data were compared with previously developed HDF patterns to verify the CG approach. The data sets gathered could be classified into two major classes of information. The first class contained meters with historical chart information. This class contained only meters that contained a chart recorder at some period since 1988. The second class contained meters with no prior water use information. These meters include all mechanical meters as well as those meters with malfunctioning charts.

Meters with previously developed HDF patterns provided a means of analyzing the water use in a community over a decade in time under a variety of system pumpage values (see Table 4). Consistency in the HDF water use pattern over time would provide credibility to the CG approach for planning purposes. Any significant changes observed would necessitate further examination to ascertain why a difference was observed. Possible explanations might include community growth, a miscalculation in one or more of the patterns, or a change in community water use.

Meters with no previously developed HDF patterns provide a good verification of the CG approach for predicting diurnal water use. The Task G patterns are the only available diurnal water use data for these meters. Comparisons of the current HDF patterns to the CG estimates for these meters will provide a reasonable indication of the accuracy of the CGDF approach.

Comparison results are presented by demand condition (i.e. maximum day, average day, and minimum day). Discussions of both classes of meter data discussed above are presented separately. Example meter data is presented as representative samples of the observed data. Complete data results by meter are presented in Appendix H.

Maximum Day Pattern Comparisons

Meters with Historical Chart Information

Meter GI-3 data is presented as an example of the maximum day results in Figure 14. This figure shows the maximum day water use in 1988 and 1995. As expected, the water use for 1993 and 2000 are quite similar.

The normalized water use using the HDF procedure is shown in Figure 15. This figure shows that even though there is a difference in actual demands, the HDF patterns are similar. The curves all have a similar shape and follow the same trend in spite of the difference in system pumpage for these days. Most of the meters observed for Task G exhibited similar behavior.

The patterns for GI-3 are nearly identical from 11 a.m. on. This was also observed for most other meters as well. Even though the 1988 evening demand was significantly greater than the other years, the evening HDF patterns for all years were similar.

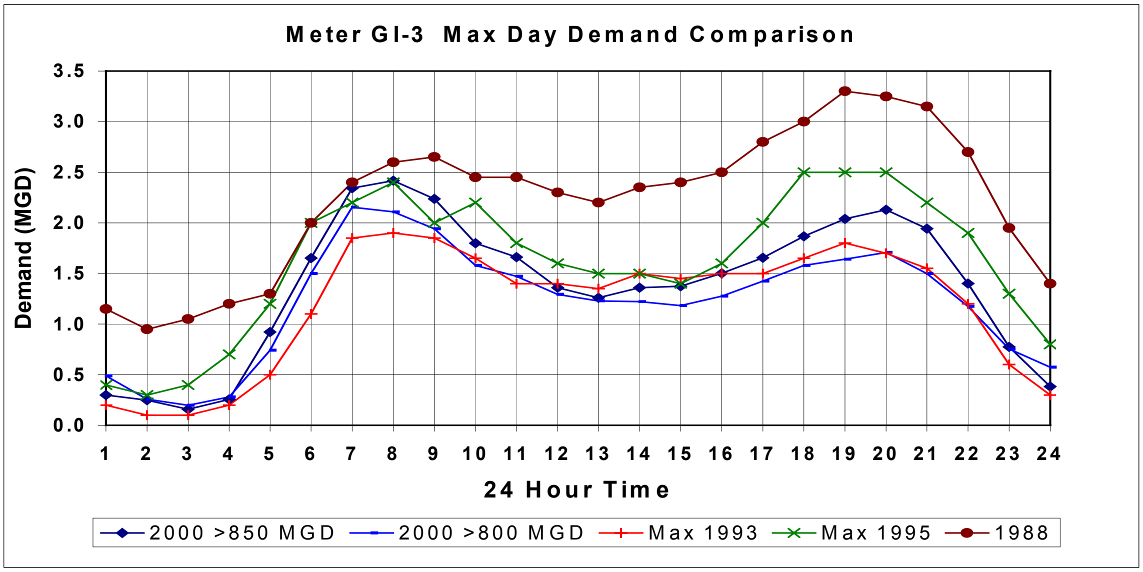

Figure 14 Maximum Day Demand Comparisons for Chart Meter GI-3

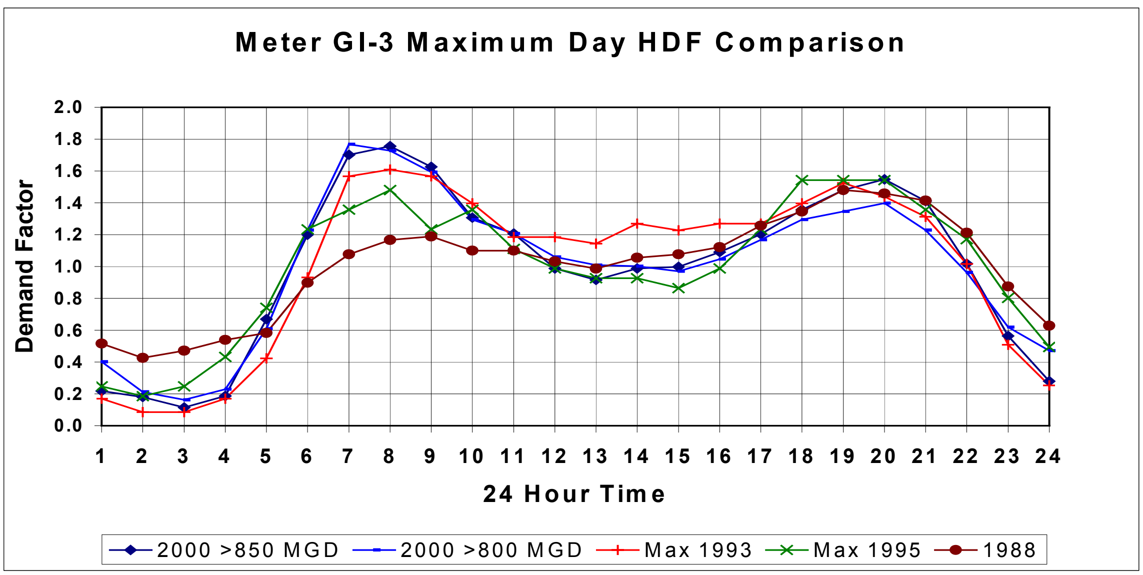

Figure 15 Maximum Day Pattern Comparisons for Chart Meter GI-3

The one consistent difference observed for the maximum day patterns dealt with the morning peak. While the GI-3 patterns are overall quite similar, the 1988 and 1995 HDF patterns were typically slightly lower in value during the morning peak period.

Meters with CG Only Estimates

Meter WO-2 data is presented as a representative of the eight mechanical meters monitored for Task G. Figure 16 reveals that the overall shape of the previously developed CGDF estimates for WO-2 differed slightly from the 2000 HDF patterns for both data sets analyzed.

Water use in the morning and evening is either slightly under or overestimated. However, the basic trend in water use predicted by the CGDF estimate is fairly reasonable. Maximum day comparison graphs for all other meters can be found in Appendix H.

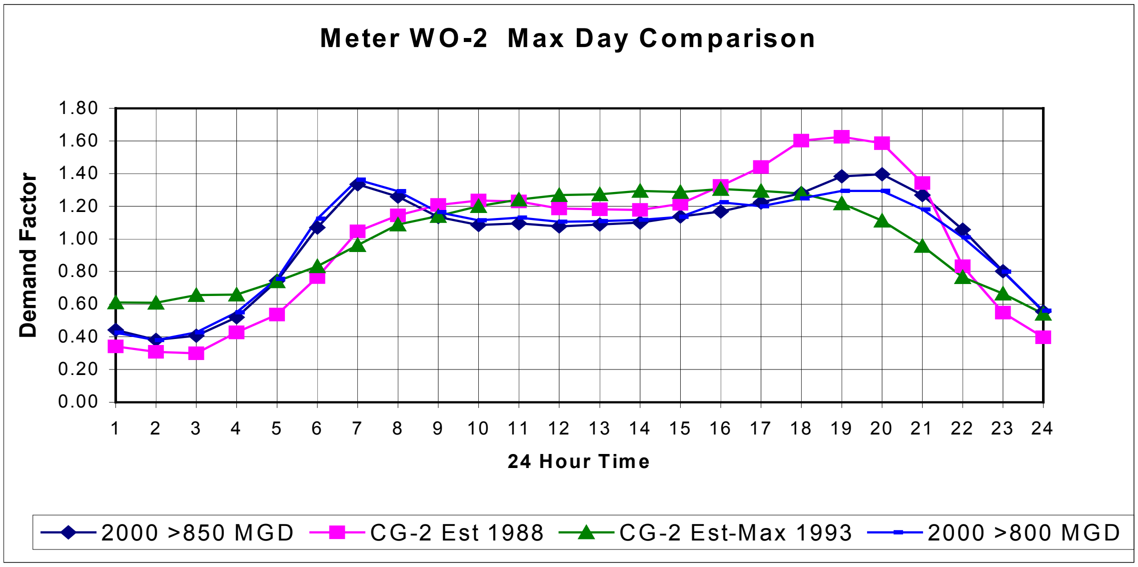

Figure 16 Maximum Day Pattern Comparisons for Totalizer Meter WO-2

Average Day Pattern Comparisons

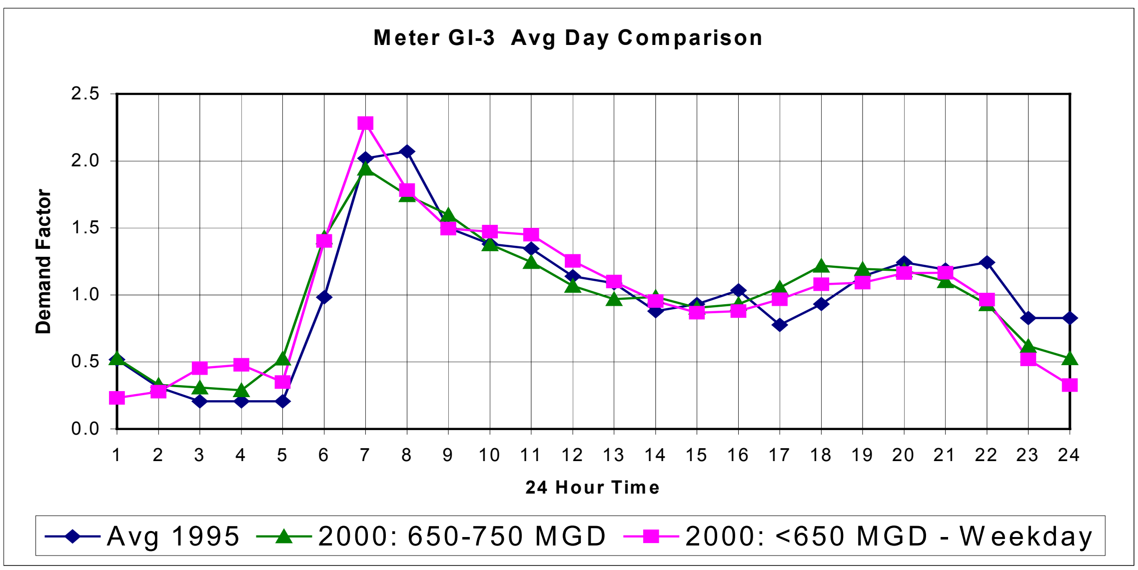

Figure 17 Average Day Pattern Comparisons for Chart Meter GI-3

Meters with Historical Chart Information

The average day water use comparison revealed that in general the historical average day patterns matched the observed data very closely. Figure 17 is the HDF comparison for meter GI-3. This figure shows essentially no difference between the patterns. The overall water use trend, hour of peak water use, as well as the peak hour consumption are similar. These similarities were observed for nearly all meters investigated. All other average day comparison graphs for all other meters with chart data can be found in Appendix H.

Meters with Only CG Estimates

The average day comparisons for mechanical meters also revealed that the CGDF estimates closely matched the observed data. Figure 18 shows the comparison for meter WO-2. The figure shows the close similarity between the previously developed CGDF estimate and the measured HDF pattern for meter WO-2. The CGDF pattern had been modified via the QA/QC procedures discussed previously. The overall water use trend, hour of peak water use, as well as the peak hour consumption are essentially identical for the two patterns.

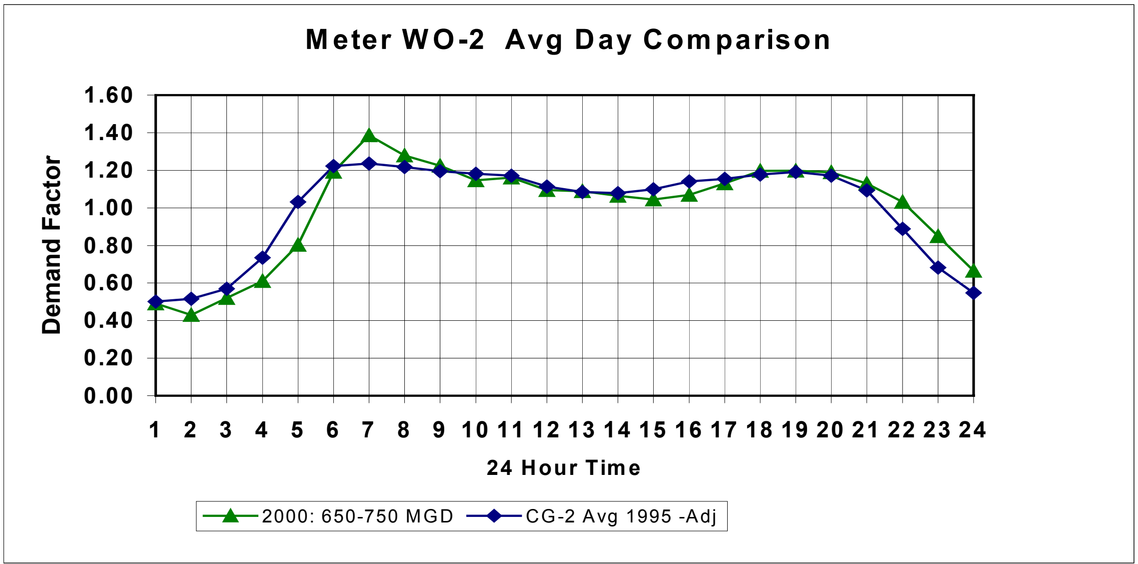

Figure 18 Average Day Pattern Comparisons for Totalizer Meter WO-2

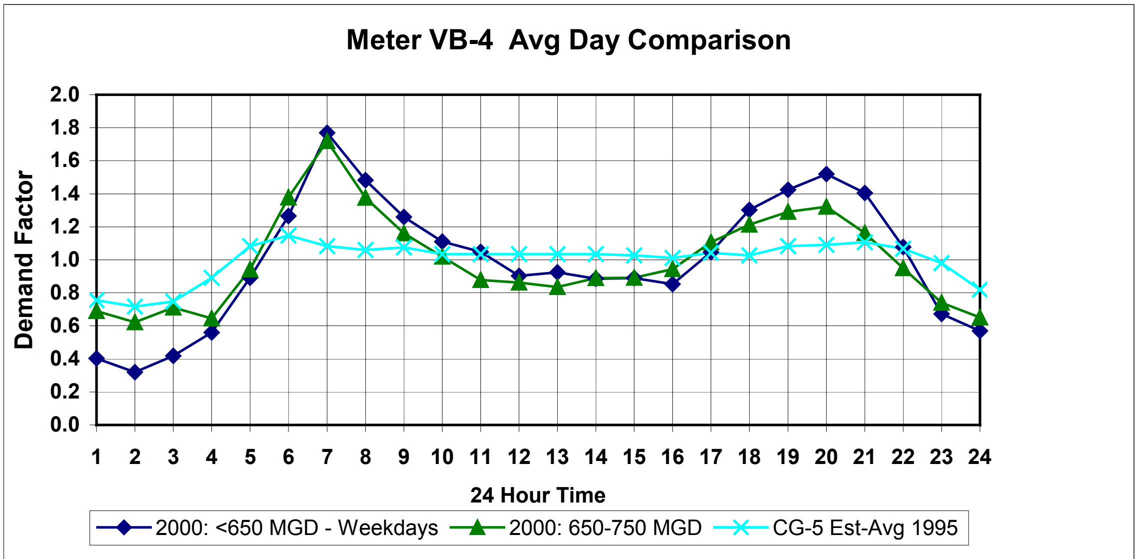

Figure 19 Average Day Pattern Comparisons for Totalizer Meter VB-4

Some of the Average Day Demand CGDF estimates for totalizer meters appear to be less accurate than the CGDF estimate for meter WO-2. For example, Figure 19 compares the Average Day Demand CGDF estimate for meter VB-4 to the 2000 patterns. The CGDF estimate for VB-4 is different than the observed water use. The observed discrepancy may be attributed to the lower average demand (less than a quarter of the average demand at VB-3) and limited Industrial, commercial, Institutional (ICI) use at meter VB-4 (based on land use maps). These types of meters typically have a higher HDF at peak hour than meters with higher average demand and significant ICI water use. However, because the demand is small, these nodes should result in little if any error introduced into the models.

Any observed pattern discrepancies will be investigated further as part of the planning model pattern development process. While some discrepancies may be due to an actual significant difference in water use, many appear to be resolved by using the QA/QC procedures outlined previously.

Minimum Day Pattern Comparisons

Meters with Historical Chart Information

The minimum day water use comparisons revealed similar trends. Figure 20 is the minimum day pattern comparison for meter GI-3. Two of the summer 2000 patterns have a similar shape and trend when compared to the 1993 HDF pattern. The slight differences between the HDF values of all three patterns are likely the result of the low overall flow rates. Small inaccuracies in flow rate measurement are magnified under low flow conditions. This results in greater variability in the minimum day HDF patterns. In general, the summer 2000 minimum day patterns were quite similar to those developed from 1993 data.

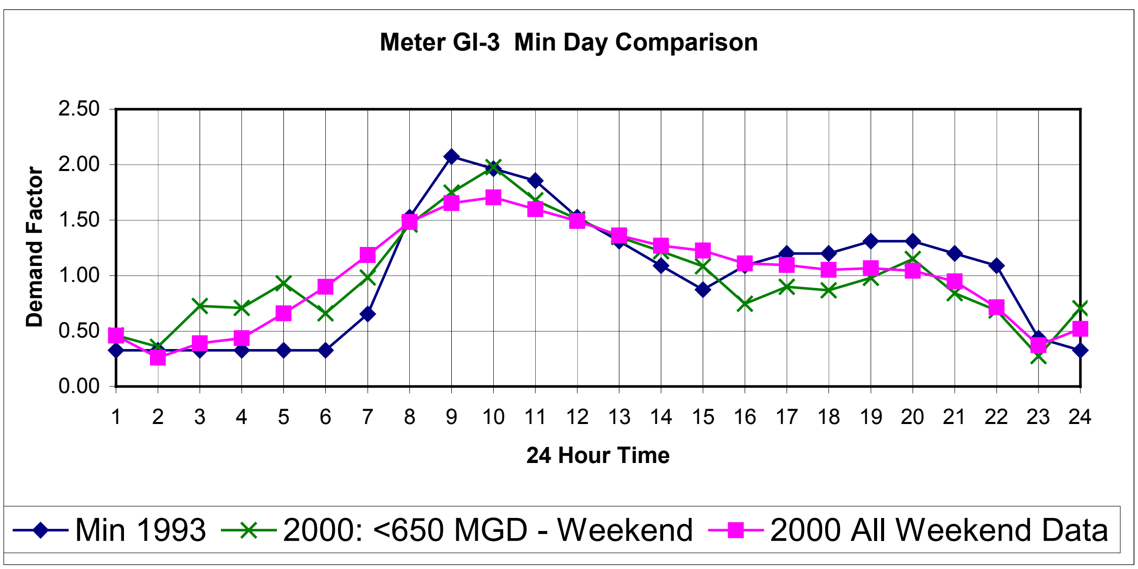

Figure 20 Minimum Day Pattern Comparisons for Chart Meter GI-3

Meters with Only CG Estimates

The Minimum Day Demand pattern comparisons for the mechanical meters showed similar results to the other demand conditions. Figure 21 presents the comparison for Meter WO-2.

The Minimum Day Demand CG-2 pattern appears to provide a reasonable estimate of water use. The CGDF estimate is quite similar to the Task G patterns in the peak value as well as the overall trend. Once again, the rest of the figures are included in Appendix H.

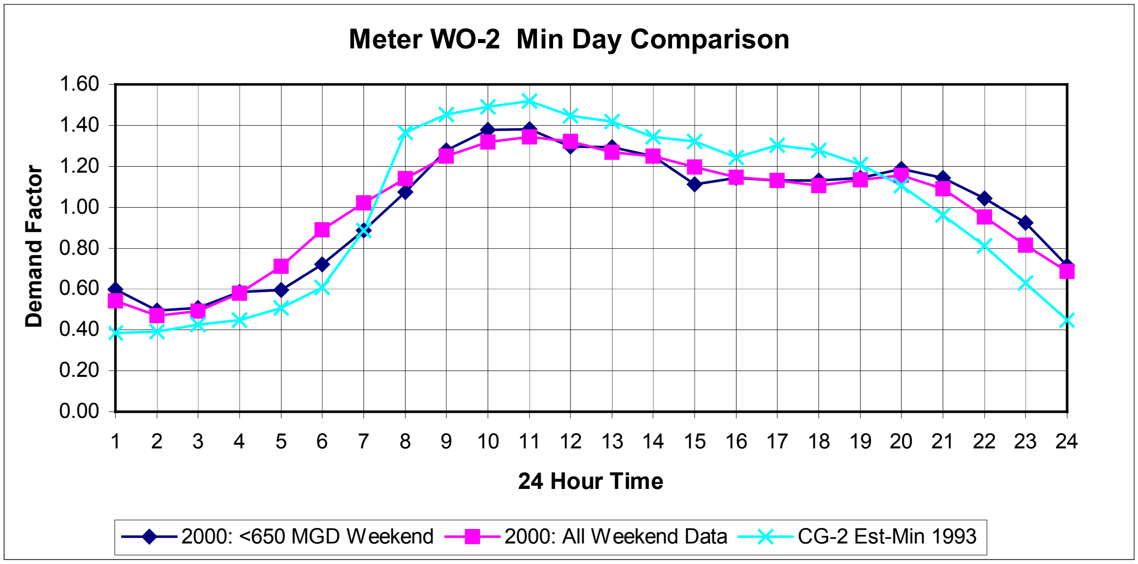

Figure 21 Minimum Day Pattern Comparisons for Totalizer Meter WO-2

Special Case Meters

While most of the CGDF estimates appeared to provide a reasonable estimate of the water use for totalizer meters, several meter situations were identified which appear to be distinctly different. Special case meters were found to include meters serving communities with water storage facilities, meters serving only an industrial complex, and meters connected to DWSD booster pumping facilities.

Meters Serving Communities with Storage

Figure 22 is an illustration of the how a special case meter incorrectly influenced the CG-7 pattern. CG-7 contains Auburn Hills, Keego Harbor, Lake Orion, Orion Twp., Pontiac, Rochester, Rochester Hills, Romeo, Shelby Twp., Sylvan Lake, Utica, and Washington Twp. This community group has also typically contained very few chart recorders with data useable for CG analysis. The city of Pontiac has a large water storage facility fed by meter PO-1 (chart recorder) with a 40-MGD capacity. Chart meter PO-1 is usually available because the staff at the Pontiac station uses the chart reading for reference during station operations.

Because PO-1 has a large capacity, it has a significant effect on the overall CG pattern. However, this meter truly records the filling of the Pontiac station reservoir rather than typical water use for the community. Thus the chart reading for PO-1 should be separated from the information used to develop the CGDF's.

CGDF estimates also appear to provide a poor estimate of water use for communities with storage facilities. The city of Oak Park has two DWSD meters, OP-1 and OP-2, but only utilizes meter OP-2 for service. The city of Oak Park contains a 6 MG pumping and storage facility downstream of OP-2. Meter OP-2 was monitored for Task G and is part of CG-8. Since no previous chart information was available for OP-2, only CG estimated patterns were available for comparison. Figure 23 illustrates how the communities using a storage facility can create an HDF pattern that is very different from the CG estimate.

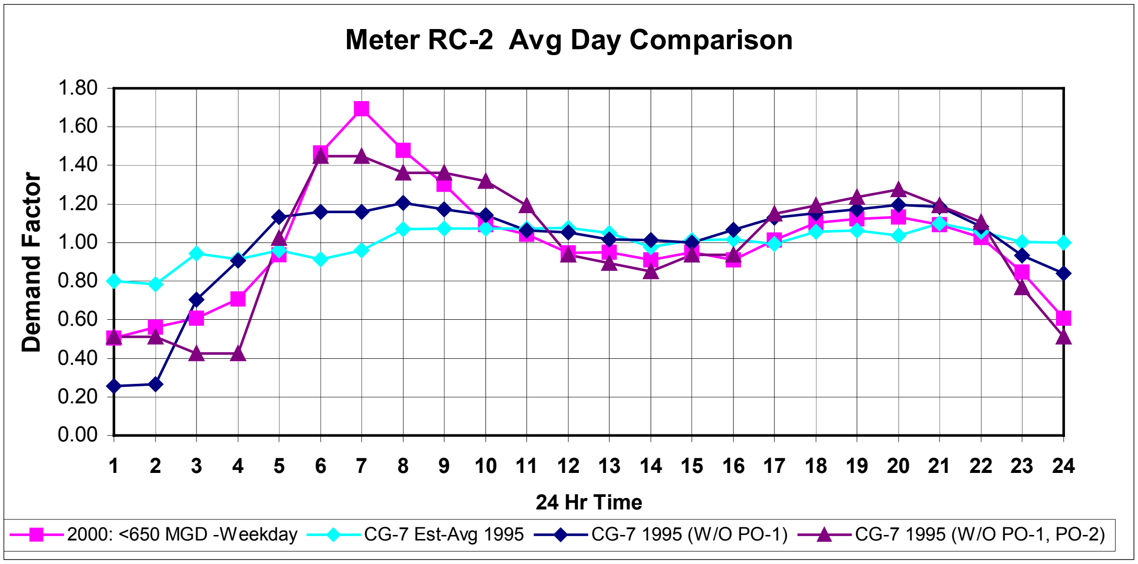

Figure 22 Effect of Including Special Case Meter in CGDF

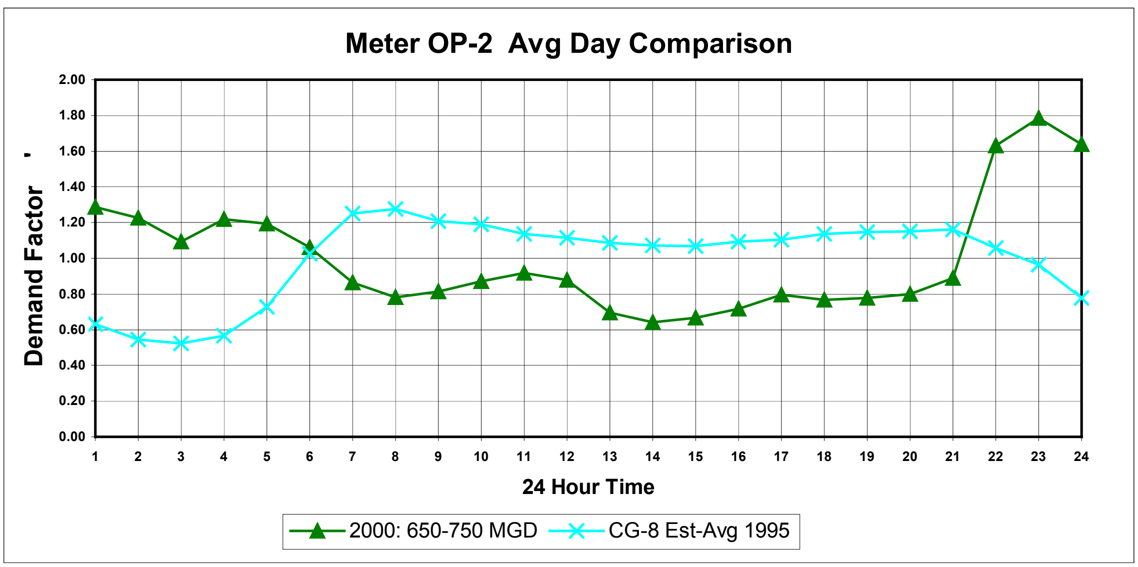

Figure 23 CGDF Estimate for Community with Storage (Meter OP-2)

Figure 22 reveals that the CG estimate improves when meter data for PO-1 and PO-2 is removed from the CG pattern. The original 1995 CG-7 pattern is transformed from nearly a straight line into a diurnal curve quite similar in shape to the summer 2000 HDF pattern for RC-2. This figure again demonstrates why caution should be used when including special case meters in CG analysis.

CGDF estimates also appear to provide a poor estimate of water use for communities with storage facilities. The city of Oak Park has two DWSD meters, OP-1 and OP-2, but only utilizes meter OP-2 for service. The city of Oak Park contains a 6 MG pumping and storage facility downstream of OP-2. Meter OP-2 was monitored for Task G and is part of CG-8. Since no previous chart information was available for OP-2, only CG estimated patterns were available for comparison. Figure 23 illustrates how the communities using a storage facility can create an HDF pattern that is very different from the CG estimate.

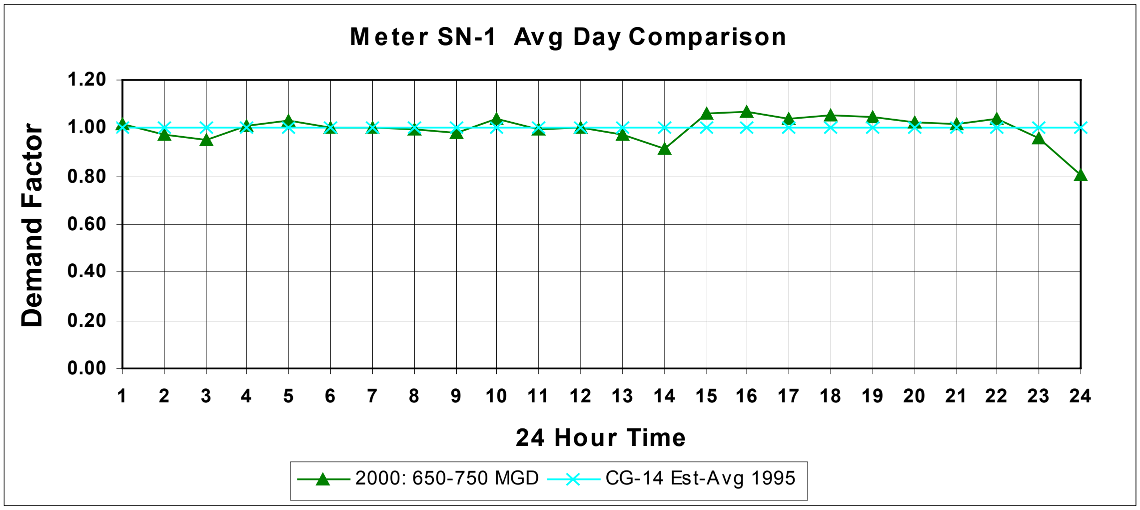

Figure 24 Example Special Case Meter: Service to an Industrial Complex (SN-1)

Meters Serving An Industrial Complex

One meter monitored for task G provides water to an industrial complex. Meter SN-1 is the only feed for CG-14 and provides water for the Detroit Edison Greenwood Energy Center in St. Clair County. While only one or two days of data were available during high and low flow conditions for meter SN-1, a reasonable amount of data was available for Average Day Conditions and is shown in Figure 24. This data reveals that the water use at SN-1 is essentially flat over the course of the day. This pattern is not characteristic of residential water use and is why meters serving industrial complexes are classified as special case meters.

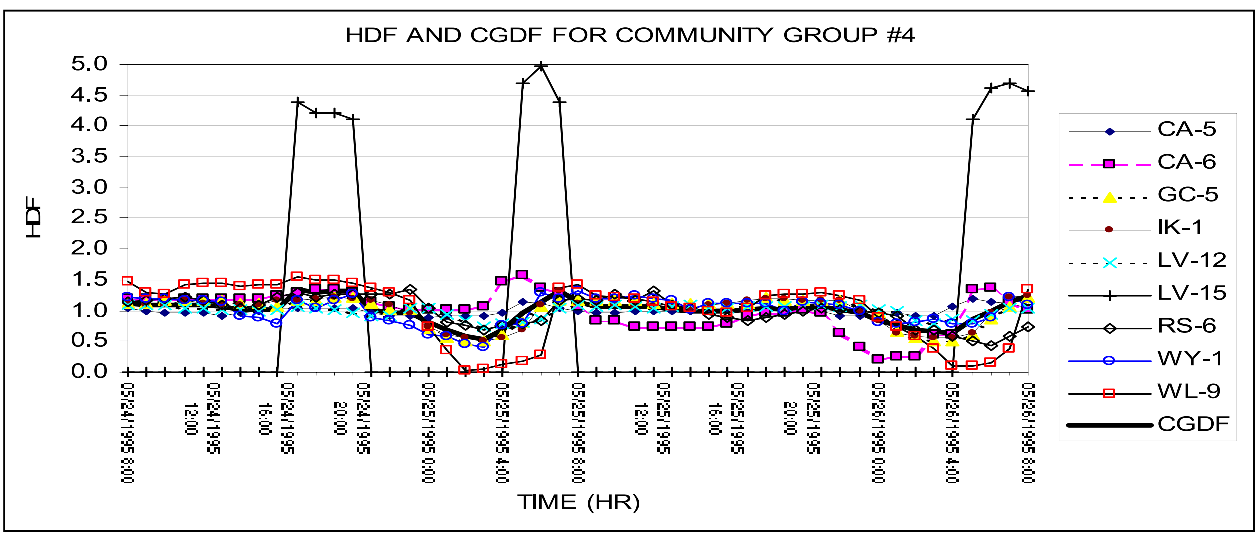

Figure 25 Example Special Case Meter: Meter LV-15 At West Chicago Station.

Meters Connected To DWSD Booster Pumping Facilities

Meter LV-15 is located at the discharge of the DWSD West Chicago Pump Station and is part of CG-4. This meter is unusual because water use only occurs when the station pumps are on. Since a considerable number of hours have zero water use, very high HDF values occur when the pumps are on (see Figure 25). Because all meters in the CG are not restricted by pump station activity, it was determined that LV-15 should be separated from the CG-4 CGDF analysis.

4. CONCLUSIONS

Hour of Peak Water Use

Several conclusions can be made based on observations of the Task G results in regard to the hour of peak water use for a particular meter. First, the hour of peak water use at a particular meter appears to be fairly independent of system demand. The peak water use for an individual meter occurs at essentially the same time regardless of the system demand. Thus previously developed demand patterns should be reviewed and possibly shifted in time to match the observed peak hour use for meters that were monitored for Task G.

Second, the hour of peak water use was found to remain fairly consistent over the periods evaluated from 1988 to 2000. This consistency is especially valid for communities that are 100 percent served by DWSD.

Third, for many communities the hour of peak water use during weekdays appears to be different that for weekends. This is the primary reason that the Minimum Day Demand patterns are different from those developed for the Average and Maximum Day models. Caution should be exercised for communities that do not experience a change in peak hour use on weekends. Their diurnal water use may be significantly different that the others in the CG.

The consistency in the hour of peak water use for a community was found to be an invaluable QA/QC tool during analysis. Many of the initial discrepancies observed during the pattern comparisons were resolved by simply shifting the historical patterns one, two, or three hours so that the peak hour of use matched. The accurate time information gathered for Task G makes this procedure possible.

Community Group Analysis

The verification of the CG approach involved the investigation of how well the CGDF estimates for a community match the recorded water use. This was accomplished in several ways.

First, the CGDF pattern estimates developed from 1993 and 1988 data were compared with the patterns from the meters observed during the summer of 2000. The overall similarity between the current and previously developed patterns appears to demonstrate that the CGDF approach can reasonably predict the water use of meters included in the CG analysis.

Second, the Task G analysis demonstrates that the CGDF approach can produce reasonable estimates of the diurnal water use for totalizer meters. Several meters with no prior diurnal water use information were monitored as part of this Task. While some discrepancies were found between the CGDF and observed water use, most of the discrepancies were found to have reasonable explanations when investigated. The CGDF estimates appeared to provide a reasonable estimate of the trend in water use and the hour of peak water use.

Third, the investigation of diurnal water use patterns for individual meters revealed a consistent shape and hour of peak water use for the three demand conditions analyzed. The similarity in shape and hour of peak use of individual meters within a community group was reflected in the close correlation between CGDF estimates and the diurnal water use patterns developed for Task G. Since meters that serve a particular community are usually hydraulically connected, it is theoretically reasonable to assume that the meters within a community will experience similar peak hour flows. This assumption appears to be valid for meters serving communities with primarily residential use, no large storage facilities, or unusual restrictions. Meters that did not meet these conditions are special cases and are expected to have fairly unique diurnal water patterns, while those that do should be amenable to CG analysis.

Fourth, the QA/QC procedures developed from observations of the Task G results increases the confidence in the accuracy of the individual HDF patterns used in the CGDF approach. Many of the discrepancies in the diurnal water use patterns found in this analysis were attributed to special case meters, meter inaccuracies, or misreading the chart information. Thus, there is good potential that previous discrepancies observed in the CGDF analysis can be eliminated.

Climate Effects

The effect of climate on the diurnal water use pattern was not examined as part of this analysis. However, examination of the system pumpage vs. temperature and rainfall appear to imply that they are related. The extent of the relationship was not part of the scope of this project. However, the MS Access interface was designed to analyze the effect of climate on the diurnal water use. This may be of use in future studies of the data collected as part of Task G.

Additional analyses of DWSD system data can be accomplished using the MS Access interface as long as the data is stored as 15-minute averages. Current DWSD projects are modifying DWSD master meters to allow meter flows to be electronically recorded in this format. Analysis of future data using the interface program could potentially provide a means of predicting water demand based on the predicted weather and time of year.

5. IMPORTANCE TO THE CWMP

Pattern Development

Task G data will be used to develop the diurnal water use patterns for the CWMP planning models. This will be accomplished using the CGDF approach and incorporating the demand data from the summer 2000 flow-monitoring program with previously collected flow rate data. The available diurnal water use data to be used in the CWMP model pattern development is as follows:

a. Maximum Day: 1988, 1993, 1995, 1999, 2000

b. Average Day: 1995, 2000

c. Minimum Day: 1993, 2000

The QA/QC approach described will be performed on all available data sets to develop new CGDF's for the planning models. The QA/QC measures will include identification of potential special case meters, a check for time shifts in peak hour use, examination of unusual patterns for inaccuracies in reading the chart data, and meter flow measuring limitations.

All special case meters identified will also be separated from their associated CG to improve the CG patterns. Hourly demand patterns for the meter classified in this manner will be uniquely applied in the models.

6. REFERENCES

1) *Water Quality Model of the DWSD Transmission System* (CS 1171). 1993, TYJT/CH2M Hill Detroit, Michigan
2) National Weather Service Climate Records http://www.crh.noaa.gov/dtx/climate.htm.