

Terminology, Definitions and Glossary

Average Dry Weather Flow (ADWF) – ADWF consists of average daily sewage flows and groundwater infiltration (GWI). ADWF is the average flow that occurs on a daily basis with no evident reaction to rainfall.

C-factor – A measure of the interior roughness of a pipe.

Diurnal Demand or Flow – Fluctuation of water demands or wastewater flows over a 24-hour period.

Effective Storage – Effective storage for each storage facility is determined by establishing the level in each tank above which all points in the water system can be served at 20 psi or higher (based on peak hour or maximum day plus fire flow).

Equalization Storage – The storage of peaking flows to prevent overflows from the sewer collection and conveyance systems.

Groundwater Infiltration (GWI) – Groundwater that infiltrates pipeline and manhole defects located below the ground surface. Groundwater infiltration is separate and distinguished from inflow resulting from storm events. Infiltration is a steady 24-hour flow that usually varies during the year in relation to the groundwater levels above the sewers. Infiltration rates are normally estimated from wastewater flows measured in the sewers during the early morning hours when water use is at a minimum and the flow is essentially infiltration.

H2OMAP Water – H2OMAP Water is a computer model used for modeling the Department of Utilities' water system under various demand conditions.

H2OMAP Sewer – H2OMAP Sewer is a computer model used for modeling the Department of Utilities' sewer system under various flow conditions.

Inflow – Drainage that enters the collection system through illegal or permitted connections, such as catch basins, downspouts, area drains and manhole covers. Inflow is separate and distinguished from infiltration. The inflow rate can be determined from the flow hydrographs recorded with flow meters by subtracting the normal dry weather flow and the infiltration from the measured flowrate.

Infiltration/Inflow (I/I) – The wastewater component caused by rainfall-dependent infiltration/inflow (RDI/I) and groundwater infiltration (GWI).

Maximum Day Demand – The one day in the year when the consumption is the highest.

Maximum Hour Demand – The one hour in the year when water consumption is the highest.



Node – A junction of two or more pipes, commonly representing a point where pipe characteristics change.

Peak Dry Weather Flow (PDWF) – PDWF consists of peak sewage flows plus GWI. PDWF is the highest measured hourly flow that occurs on a dry weather day.

Peak Wet Weather Flow (PWWF) – PWWF consists of ADWF plus RDI/I. PWWF is the highest measured hourly flow that occurs during wet weather.

Peak Factor – Peak factor is PWWF/ADWF.

Pressure Reducing Valve (PRV) – A valve that will maintain a specified downstream pressure.

Pressure Zone – A network of water pipes having a common static hydraulic grade line. Pressure zones are separated by closed valves, pressure regulating valves, pumping stations, and reservoirs.

Rainfall-Dependent Infiltration/Inflow (RDI/I) – RDI/I consists of rainfall that enters the collection system through direct connections (roof leaders, manholes, etc.) and causes an almost immediate increase in wastewater flow.

Service Area – The area served by the water distribution or wastewater collection system.

Steady State Simulation – A network model solution for a single point in time.

Tributary Area – The tributary area of a sewage system consists of all areas that contribute flow to the sewer by gravity and/or force main discharges.

ADD	Average Day Demand
ADWF	Average Dry Weather Flow
AWWA	American Water Works Association
CIP	Capital Improvement Program
cfs	Cubic Feet per Second
CMOM	Capacity, Management, Operation and Maintenance
CWA	Clean Water Act
DOU	Stafford County Department of Utilities
D/DBP	Disinfectants/Disinfection Byproducts
EA	Environmental Assessment
EIS	Environmental Impact Statement
EPA	US Environmental Protection Agency
EPS	Extended Period Simulation
ft	Feet
FY	Fiscal Year
gpcpd	Gallons per Capita per Day
gpd	Gallons per Day



gpm	Gallons per Minute
gpdidm	Gallons per Day per Inch Diameter – Mile
GW	Groundwater Infiltration
HAAs	Haloacetic Acids
HGL	Hydraulic Grade Line
ICR	Information Collection Rule
I/I	Infiltration and Inflow
IESWTR	Interim Enhanced Surface Water Treatment Rule
ISO	Insurance Service Organization
L	Liter
MCL	Maximum Contaminant Level
MDD	Maximum Day Demand
MG	Million Gallons
MGD	Million Gallons Per Day
mg/l	Milligrams per Liter
mgd	Million Gallons per Day
MPN/100 ml	Most Probable Number per 100 Milliliters
NEPA	National Environmental Policy Act
O&M	Operations and Maintenance
PDWF	Peak Dry Weather Flow
PHD	Peak Hour Demand
PRV	Pressure Reducing Valve
psi	Pounds per Square Inch
PSV	Pressure Sustaining Valve
PWWF	Peak Wet Weather Flow
PWS	Public Water Supply
RDI/I	Rainfall-Dependent Infiltration/Inflow
SCADA	Supervisory Control and Data Acquisition
SDWA	Safe Drinking Water Act
SSO	Sanitary Sewer Overflows
SWTR	Surface Water Treatment Rule
TCR	Total Coliform Rule
THMs	Trihalomethanes
UFW	Unaccounted-for Water
ug/L	Micrograms per Liter
USACE	US Army Corps of Engineers
USEPA	US Environmental Protection Agency
USGS	US Geological Survey
VDEQ	Virginia Department of Environmental Quality
WTP	Water Treatment Plant
WWTP	Wastewater Treatment Plant



This Stafford County Water and Sewer Master Plan is the product of an effort to assess the Department of Utilities' many separate elements, and combine these elements into a single "road map" for the future. This Master Plan will serve as a guide to future system development and investment decisions. Based on the shared values of the County and the customers it serves, the Master Plan provides a holistic vision for the future of Stafford public water and sewer systems, as well as concrete strategies to carry out this vision.

1. OVERVIEW

The Stafford County Department of Utilities (DOU) which is under the direction of the County Board of Supervisors provides public water and sewer service in Stafford County. DOU was formed in 1982. Before 1982, the Aquia Sanitary District and the South Stafford Sanitary District provided public water and sewer services for Stafford County. In 1982, the Sanitary Districts were abolished and replaced with the Department of Utilities under the County Board of Supervisors. The service area population and the demand for water and sewer services have approximately quadrupled in the last 20 years and continue to grow. The demand for services is expected to quadruple again during the next 50 years. Today, DOU is a 132-employee utility serving more than 86,000 residential customers, over 1,000 businesses, and a portion of the Quantico Marine Corps Base.

To assist the growth and development of the County's utility systems, the Board of Supervisors has established the Utilities Commission. The Utilities Commission has the following functions, powers, and duties as established by the Stafford County Code:

- The Commission shall annually recommend to the Board a proposed rate and fee structure which shall be designed to ensure long-term self-

sufficiency of the utility system and the financial integrity of the utility enterprise fund.

- The Commission shall recommend ordinance amendments to the Board regarding the utilities system.
- The Commission shall make recommendations regarding neighborhood water and sewer projects.
- The Commission shall make recommendations regarding the expansion of utility facilities and services.

The Commission conducts public hearings on the following issues:

- Rate and fee structure.
- Ordinance amendments.
- Amendments to the master water and sewer element of the comprehensive plan.
- Other matters which have been specifically requested by the Board of Supervisors.

DOU operates as an enterprise fund separate from the County's General Fund. DOU is solely funded by the fees and charges that it assesses against its customers.

2. MASTER PLANNING PROCESS

In 1990 the Stafford County Board of Supervisors adopted the Stafford County Master Water and Sewer Plan. In October

2002, O'Brien & Gere Engineers, Inc. was engaged to update the chapters addressing the water demand and sewer load



projections, the water distribution system, and the wastewater collection system. As part of this master planning effort, the staff of the Stafford County Department of Utilities recognized the need to review all elements of the Master Plan. It was observed that planning for future development in a compartmentalized fashion would not allow DOU to directly address the linkages among operations – water supply, treatment and distribution; wastewater collection and treatment; and residuals management. DOU recognized the need to view these components holistically and to develop a vision for the long-range provision of water and sewer service to its customers.

The Master Plan effort has focused on the issues and challenges DOU will face over the next 50 years. The Master Plan highlights the implementation of specific

utility system improvements and provides action plans and decision points for each of the utility system elements.

The Master Plan has been completed through the sustained efforts of the DOU staff, the County's planning department staff, the Planning Commission, and the Utilities Commission. To improve the final Master Plan, staff developed the plan recommendations over the course of the study period from 2002 through 2004, with presentations to and input from the Utilities Commission and the Board of Supervisors.

The Master Plan is one of DOU's key policy instruments. The Master Plan will serve as a guide to annual investment decisions. In turn, implementation strategies in the Master Plan will be reviewed and updated periodically to reflect new information and changing community conditions.

3. ORGANIZATION OF THE MASTER PLAN

The Water and Sewer Master Plan has two components – the *Water and Sewer Master Plan* and the supporting *Technical Memoranda*.

This *Master Plan* provides a comprehensive assessment of the water and wastewater components and issues confronting DOU as it plans for the next 50 years. The Master Plan is prepared for DOU staff making strategic and facility planning decisions. The first two chapters, *Introduction and Guiding Principles*, summarize the foundation of the Master Plan. Chapter 3 (*Water Demands and Sewer Flows*) includes forecasts of future demands for water and sewer service as the DOU service area develops through 2050.

Chapters 4 (*Raw Water Supply*), 5 (*Water Treatment*), and 6 (*Water Distribution*) focus on the challenges of providing water service to meet future demand and adapting DOU's

facilities and infrastructure to anticipated regulatory programs affecting water supply, treatment, and distribution.

Chapter 7 (*Wastewater Collection*) and 8 (*Wastewater Treatment*) focus on the challenges to wastewater services.

Chapter 9 contains a bibliography of the documents used in support of the Master Plan.

The *Technical Memoranda* completed by O'Brien & Gere during the Master Plan process are included in Sections 1 through 12 of the Appendices in this volume. These memoranda contain detailed technical information about the individual components of DOU's utility system and are intended to be used by DOU technical staff and consultants to support planning and design decisions.



“The Stafford County Department of Utilities will provide water and wastewater services which satisfy the present and future needs and expectations of our customers. Our performance is directed at meeting or exceeding all regulatory requirements. We are committed to excellence in all that we do.”

The Water and Sewer Master Plan embodies the shared principles and values of Stafford County. Guiding principles serve as the framework for the objectives and solutions formulated for the Master Plan.

This chapter defines these five guiding principles:

DOU Mission Statement

1. Customer Service
2. Proactive Planning
3. Sustainability
4. Fiscal Responsibility
5. Adaptability

1. CUSTOMER SERVICE

Customer satisfaction is DOU’s number one priority. DOU provides water and wastewater services that meet or exceed the requirements of residential, commercial, and industrial customers. A high level of

customer satisfaction is maintained in terms of customer service, quality of water supplied, government and community relations, and environmental stewardship.

2. PROACTIVE PLANNING

Proactive planning and growth-neutral utility services are central tenets of the Master Plan and of DOU’s long-term strategy in general. Growth-neutral means that DOU’s policies and actions do not stimulate or inhibit growth, but merely respond to the rates of change embodied in Stafford County’s Comprehensive Plan and growth policies.

The Master Plan is based on the anticipated utility needs of the Stafford customer base within the service area as defined in this plan.

Faced with complex issues that involve competing goals and objectives, DOU supports an integrated resource planning approach to its full range of services and

facilities. Integrated resource planning involves coordination with different stakeholders, resolution of competing issues, and sensitivity to community needs. Integrated resource planning helps develop solutions that achieve level-of-service requirements while meeting financial, economic, environmental and other community constraints. Five key elements of integrated resource planning that are fundamental to the Master Plan include:

- Systems Evaluation - Rather than finding answers to individual system problems, DOU looks holistically at the systems of water, wastewater and the environment.



- Supply and Demand Management - DOU looks for both supply-side and demand-side solutions. Traditional supply-side solutions for meeting increased demand would include seeking a new water supply or building a new reservoir. Demand management conserves water by reducing its use and increasing the efficiency of the supply and delivery systems.
- Self-Sufficiency and Regional Cooperation - DOU's policy is to provide services to its customers through facilities and resources it owns and controls, wherever practical. It also maintains interconnections and relationships with utility service providers in other municipalities to enable cooperation during emergencies. Stafford

County is always open to regional approaches for water and wastewater services.

- Public Involvement - DOU works directly with other County departments and individuals to meet customer needs. Customers and citizens are provided with timely, clear and understandable information and opportunities for constructive participation in DOU's planning and decision-making process.
- Price of Being Wrong - In making decisions, DOU always asked: What is the price if we are wrong? What will the consequences be both financially and environmentally if the wrong option is selected?

3. SUSTAINABILITY

According to the United Nation's Brundtland Commission, sustainable development "meets the needs of the present without compromising the ability of future generations to meet their own needs."

Sustainability is a fundamental value shared by Stafford County and the community. Both Stafford County and the community strive to limit their impact on the environment so that it can continue to

provide the life-supportive resources that sustain the economic and social quality of lives for all. By systematically balancing short-term desires with nature's requirements, we can achieve sustainability. Obviously this task goes beyond the role of a single water and sewer utility. Still, DOU can make progress toward sustainability with an integrated and long-term approach to resource planning.

4. FISCAL RESPONSIBILITY

DOU recognizes the importance and implications of the costs of planning, constructing, upgrading, rehabilitating, operating, and properly maintaining water and sewer systems and customer services in today's regulatory, environmental, and economic climate. Through increased efficiency and cost management, DOU responds to the challenge of providing customers with high-quality water and sewer services in a sustainable and economic manner, despite rising costs. The long-range

financial planning and management objectives of DOU include the following:

SOUND FINANCIAL MANAGEMENT

- Sustain equity, fairness, and efficiency in all financial decisions
- Sustain reliable revenue
- Promote efficient use of water resources, reclaimed water, and demand management to defer capacity-related capital investments
- Maintain a favorable credit rating



- Create a favorable context for issuing County bonds

RISK MANAGEMENT

- Maintain an appropriate risk management program
- Minimize uncertainty in revenue, capital, and expense forecasts

RATE STABILITY

- Establish rates, fees, and charges that reflect the costs of supplying services
- Implement gradual, programmed rate adjustments
- Maintain rates, fees, and charges at levels competitive with similar water and sewer service providers

COOPERATION WITH OTHER ENTITIES

- Operate in compliance with legal requirements and interlocal agreements
- Foster cooperative provision of water and sewer services with other municipalities and authorities

CUSTOMER INVOLVEMENT

- Encourage input by customers, elected officials, and the general public in DOU's financial decisions
- Motivate staff to provide quality services to customers

Fiscal responsibility is one of the criteria used by DOU to evaluate strategic alternatives – for all aspects of a project and for capital improvements.

5. ADAPTABILITY

Because regulatory requirements, regional development, and customer demands will change over the next 50 years, DOU must be capable of adaptability as an organization. Future conditions may require modification, even reversal, of present approaches to facilities planning and operations.

The guiding principle of adaptability underscores the value of continuing to explore and develop multiple options for water supply, water treatment, wastewater treatment, and resource recovery since future development will affect the feasibility or effectiveness of the options in ways the present-day perspective cannot fully anticipate.

Some options have only windows of availability – land for future facility expansion may be developed for other

purposes if not obtained when it becomes available; a utility tunnel can be easily installed during a road construction project, but bore-and-jack construction while that busy road is in service will be more costly and, in some cases, no longer feasible.

An adaptable organization can respond to such unforeseen challenges with creative leadership. Without adaptability, an organization will rush to implement change with higher costs and uncertainty.

The Master Plan emphasizes active monitoring of trends in regulations, technology, and development, and encourages taking stock of DOU's current plans as new information becomes available. The long-term plan is viewed as a dynamic model that is adaptable to changes.



The Stafford County Department of Utilities provides water and sewer service to the central portion of the County generally extending east and west of the Interstate 95 corridor. The current and future water and sewer needs of its customers in the County are of central focus as DOU considers its long-range development options.

1. DOU SERVES ITS CUSTOMERS

The service area population and the demand for water and sewer services have approximately quadrupled in the last 20 years and continue to grow. The demand for services is expected to quadruple again during the next 50 years. Today, DOU serves more than 86,000 residential customers, over 1,000 businesses, and a portion of the Quantico Marine Corps Base.

Stafford County is located approximately 40 miles south of Washington, DC and 60 miles north of Richmond, VA. The County covers 277 square miles of which 51 square

miles in the northern portion of the County comprise the Quantico Marine Corps Base.

With its proximity to major industrial and commercial markets and its high percentage of undeveloped land, the County is experiencing rapid residential and commercial development. The number of water/sewer accounts has increased from 6,000 in 1982 to over 28,000 in 2004. Currently, the public utility customer base is increasing at an annual rate of approximately 5%. The Stafford County Board of Supervisors has adopted a goal of an annual population increase of 2%.

2. PLANNING HORIZON

DOU's Master Plan attempts to anticipate long-term utility needs through buildout (roughly 2050). This long "planning horizon" allows sustainability considerations to affect DOU's decision-making processes for maintaining adequate water and wastewater facilities. Decisions must not only make sense as short-term solutions, but as long-range investments in the community's future.

Although a 50-year planning horizon is a valuable tool for planning, long-term growth rates and scenarios for eventual buildout conditions are not well established and are subject to considerable uncertainty. While DOU's water demand projections assume a constant increase throughout the planning period, actual growth may occur differently, and full buildout may occur before 2050.

Near-term water and sewer projections were developed to identify the water and sewer improvements needed to satisfy near-term

water demands and sewer flows. The near-term water demand (2013) represents the potential for full utilization of the 14.5 mgd of safe yield of Abel Lake and Smith Lake and the 20 mgd of available water production capacity of the Smith Lake and Abel Lake WTP's prior to bringing Rocky Pen Run water supply facilities on-line.

To estimate near-term water demands, a global factor was uniformly applied to the entire system to reduce the maximum day water demands at buildout (46.3 mgd) to a maximum day demand of 20 mgd. The objective of this analysis was to identify what facilities may be needed and the size of those facilities to deliver water from the Smith Lake and Abel Lake WTP's to DOU's customers until the Rocky Pen Run Reservoir supply facilities are on-line. Bringing large quantities of water north from Rocky Pen Run WTP is a dramatic shift in the current operation which supplies water from Smith Lake in the north and Abel Lake



in the central portion of the County to the south. Reversing the direction of flow from the supplies requires careful planning to optimize use of existing facilities and properly size and locate proposed facilities so that they operate well under near-term and buildout conditions.

The near-term sewer flow (2010) represents the quantity of existing sewer flow plus the

projected flow from developments that are currently under consideration. While there is considerable uncertainty associated with the timing (and in some cases the future) of some of these future developments, it is prudent to plan the infrastructure needed to allow adequate time for planning, permitting, design and construction of the required facilities.

3. KEY ASSUMPTIONS AND UNCERTAINTIES

The overall planning approach outlined in this Master Plan gives reasonable projections of future water demands and sewer flows and allows DOU to build conservatism into the sizing of facilities and piping in the latter stages of the planning process, thereby minimizing the amount of rework required to update plans and proposed improvement projects.

The disaggregated water demand/sewer load method was used to separate (disaggregate) the water demands and sewer loads into more uniform groups of users as the basis for future projections. This method provides accuracy and flexibility in analyzing alternatives because of the ability to use different consumption and generation rates within each group and different growth rates among groups. This approach can be used with land use information and water/sewer duties (gallons per day per acre) to develop water demands and sewer flows.

Water and sewer utilities have traditionally adopted a conservative approach when planning and sizing facilities with high capital costs and long lead times required for planning, permitting, design and construction. This approach typically includes diligent efforts to avoid underestimating the level of future demands that those facilities will serve. Within this context, it is important to include allowances for the wide range of unknowns inherent in long-range forecasts.

A brief summary of the assumptions that underlie the projected water demands and sewer flows follows. Changes in these conditions could require modification of the Master Plan.

- Service area boundaries – The long-term service area for water encompasses the entire County whereas the sewer service area is limited to the Urban Service Area. For planning purposes, the water system facilities inside the growth area at buildout were sized in this Master Plan to deliver the flow needed to meet the buildout demands outside the growth area (i.e., eastern and western portions of the County). The sewer service area boundary for buildout conditions was based on the existing sewer service area, projected land use, sewer shed boundaries (i.e., drainage basins, roadway and water features, etc.) and discussions with DOU and Planning Department staff regarding future development and policies. The sewer service area boundary represents a “wall” and sewer flows for areas outside the Urban Service Area envelope were not included in this Master Plan.
- Future water demands remain internal (except for Quantico Marine Corps Base) – Future water demands will continue to be determined by retail water and sewer



sales within the service area (except for wholesale water delivery and sewer flows from Quantico Marine Corps Base). The demand forecasts do not anticipate retail or wholesale delivery of service outside of the service area (except for Quantico Marine Corps Base).

- Linear forecasts show moderate growth – Forecasts of water demand and sewer flows are essentially a linear extrapolation of current water demand and sewer flows through the buildout condition based on land use.
- Land Use and water/sewer duties - Land use information and water/sewer duties (gallons per day per acre) were used to define how water demands and sewer flows were allocated to the various land use categories throughout the County. Changes to the characteristics of a land use category over time could impact the water/sewer duties (i.e., quantity of water consumed or sewer flow generated). In addition, changing the land use for a specific geographic area could impact the water/sewer duties and alter the sizing of water or sewer facilities serving the area.
- Peaking factors – Peak water demands (maximum day or peak hour) and peak sewer flows (peak wet weather flows) are important because their magnitude drives the size and cost of future water and sewer facilities. Maximum day water demands were based on a global

peaking factor of 1.5 times the average day water demand. Diurnal water demand patterns for each pressure zone were used to characterize the change in water demand at each node in the system throughout the maximum day, including the peak hour. Of particular importance is the application of the same global peaking factor and diurnal curve to each land use category. It is understood that water demands and sewer flows vary by land use category and fluctuate differently throughout the day depending on the type of land use.

For the sewer flows, a peaking factor of 3.5 times the average dry weather flow was used to estimate the magnitude of the design wet weather storm event. The peaking factor was applied globally to the sewer loads at each manhole which were derived from the sewer duties and land use tributary to the manhole. The peaking factor for the sewer system is intended to reflect the sewer system's response to a design storm event. Additional flow monitoring of the system's response to significant storm events is needed to better define the design storm event used to assess the capabilities of the existing sewer system and to size the future sewer improvements outlined in this Master Plan. Throughout the planning period, DOU should continue to refine the water and sewer models and collect the data needed to characterize various land uses and storm events.

4. FOUNDATION FOR WATER DEMANDS AND SEWER LOADS

In terms of the total quantity of water required or sewer flow generated, water demands and sewer loads are usually estimated on the basis of per capita usage.

Variations in water use or sewer flow depend on size of community, geographic location, climate, season, day of week, time of day, and the extent of industrialization.



Because of these variations, the only reliable way to estimate future water demands and sewer loads is to study each community separately. To define how the total water use is distributed within a

community throughout the day, the best indicator is land use. Table 1 compares the per capita and duties (gpd/acre) for water demand and sewer loads.

Table 1. Per capita and duties for water demands/sewer loads

Reference	Per Capita Water Demands and Water Duties	Per Capita Sewer Loads and Sewer Duties
Per Capita Factor (GPD)	80	64
Suburban Residential (GPD/Ac)	500	400
Urban Residential (GPD/Ac)	1300	1040
Rural Residential (GPD/Ac)	80	64
Agricultural (GPD/Ac)	40	32
Commercial (GPD/Ac)	750	600
Office (GPD/Ac)	500	400
Light Industrial (GPD/Ac)	500	400
Heavy Industrial (GPD/Ac)	2000	1600
Institutional (GPD/Ac)	500	400

Many utilities apply a global reduction factor after the total water demand or sewer flow is computed (total typically reduced to 70-90%) to reflect the projected reduction in the level of development of the land use category (i.e., the gross area that includes the area required for existing and future

road corridors, on-site stormwater facilities, on-site open space, etc.). Rather than apply a global reduction factor after computing the total water demand and sewer load, the water/sewer duties were reduced for each land use category prior to compiling the water demands and sewer loads.

5. PROJECTED WATER DEMANDS

Computation of Average Day Demands

A detailed water demand forecast was recently developed in support of DOU's proposed Rocky Pen Run Reservoir permitting project and the buildout water demands in this Master Plan are based on the Rocky Pen Run Reservoir water demand forecast. The objective of the demand analysis for this Master Plan was to determine how and where the water demands should be allocated throughout the County. This was accomplished by

developing an independent water demand projection based on the most recent Land Use information and revising the computed water demands as needed to match the projections generated for the Rocky Pen Run Reservoir project.

Using pressure zone and land use information provided by DOU, disaggregated water demand forecasts were developed. The following steps summarize the general methodology that



was used to estimate the future water demands shown in Table 2:

- Compute the acreage for each land use category in the County.
- Apply water duties (gpd/acre) for each land use type.
- Add the projected Federal or Military (FED) demand (1.5 mgd).
- Add the unaccounted-for water (UAW) portion of the total demand (15%).

- Subtract the conservation component of the total demand (8%).

Note that the area for RRE was not included in the Rocky Pen Run Reservoir study and essentially accounts for the differences shown for the “Residential” and “Total Demand” values in Table 2

Table 2. Water demands for buildout conditions

Land Use	Proposed Water Duty (gpd/acre)	Computed Area from April 2003 Land Use (acres)	Computed Master Plan Demand (mgd)	Computed Master Plan Demand (mgd)	Table 2-17 Rocky Pen Run Water Demand (mgd)	Table 2-17 Rocky Pen Run Water Use Category
Residential				16.8	14.0	Residential
Suburban Residential (SRE)	500	19,427	9.71			
Urban Residential (URE)	1,300	1,887	2.45			
Rural Residential (RRE)	80	35,424	2.83			
Agricultural (AGR)	40	45,768	1.83			
Commercial/Institutional/Light Industrial				10.2	10.2	- Commercial - Institutional - Light Industrial - Heavy Industrial
Commercial (UCM, SCM, RCM)/Neighborhood Center (NCT)	750	4,915	3.69			
Office (OFF)	500	201	0.10			
Light Industrial (LIN)/Business (BUS)	500	10,529	5.26			
Institutional (INS)	500	1,710	0.86			
Heavy Industrial (HIN)	2,000	127	0.25			
Federal or Military (FED)				1.5	1.5	Military
Subtotal Demand ¹				28.5	25.6	
Unaccounted-for Water (15% of Total Demand)				5.0	4.5	
Total Demand (without Additional Conservation)				33.5	30.1	
Additional Conservation (8% of Total Demand)				2.7	2.4	
Total Demand (with Additional Conservation)				30.8	27.7	

¹ Rounding-off error for subtotal demand from Table 2-17. Commercial/Institutional/Light Industrial demand of 10.15 mgd was developed in the Rocky Pen Run Reservoir study and rounded off to 10.2 mgd in Table 2-17 of Rocky Pen Run study.



Peaking Factors and Diurnal Curves

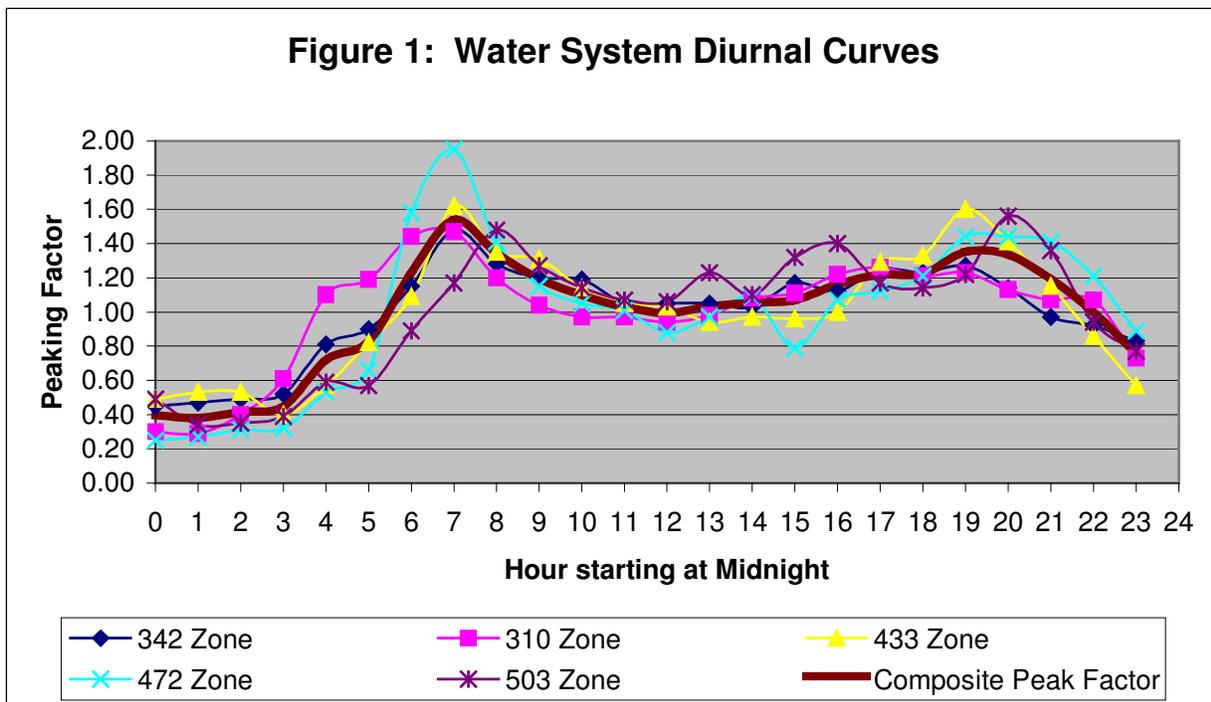
Water systems are required to supply flow at rates that fluctuate over a wide range from day-to-day and hour-to-hour. Rates most important to planning, design and operation of a water system are average day, maximum (peak) day, maximum (peak) hour, and maximum hour plus fire flow.

- Average day demand is the total volume of water delivered to the system in a given year divided by the number of days in the year.
- Maximum (peak) day demand is the largest quantity of water supplied to the system on any given day of the year.
- Maximum (peak) hour demand is the highest rate of flow for any hour in a year.
- Maximum day plus fire flow considers the possibility of a fire event under maximum day demand conditions.

Diurnal curves are frequently used to represent how water is used over time of

day. Diurnal curves are different for each house, each industry and each water user. However, for the purpose of creating a model to represent a water distribution system, simplifications are generally made such that residential, commercial, industrial, and other water use classifications are each assumed to have consistent water demand (diurnal) curves.

Different demand patterns can be applied to individual water nodes or groups of nodes to accurately represent water use categories (e.g., residential, commercial, etc.). For this Master Plan, the diurnal data provided by DOU was used to calibrate the water model and conduct the modeling analyses. The diurnal demand patterns are shown in Figure 1 and were used for each pressure zone. Consequently, the average day demand at each water node was multiplied by the diurnal demand pattern for the pressure zone to predict the water use at the node throughout the day.



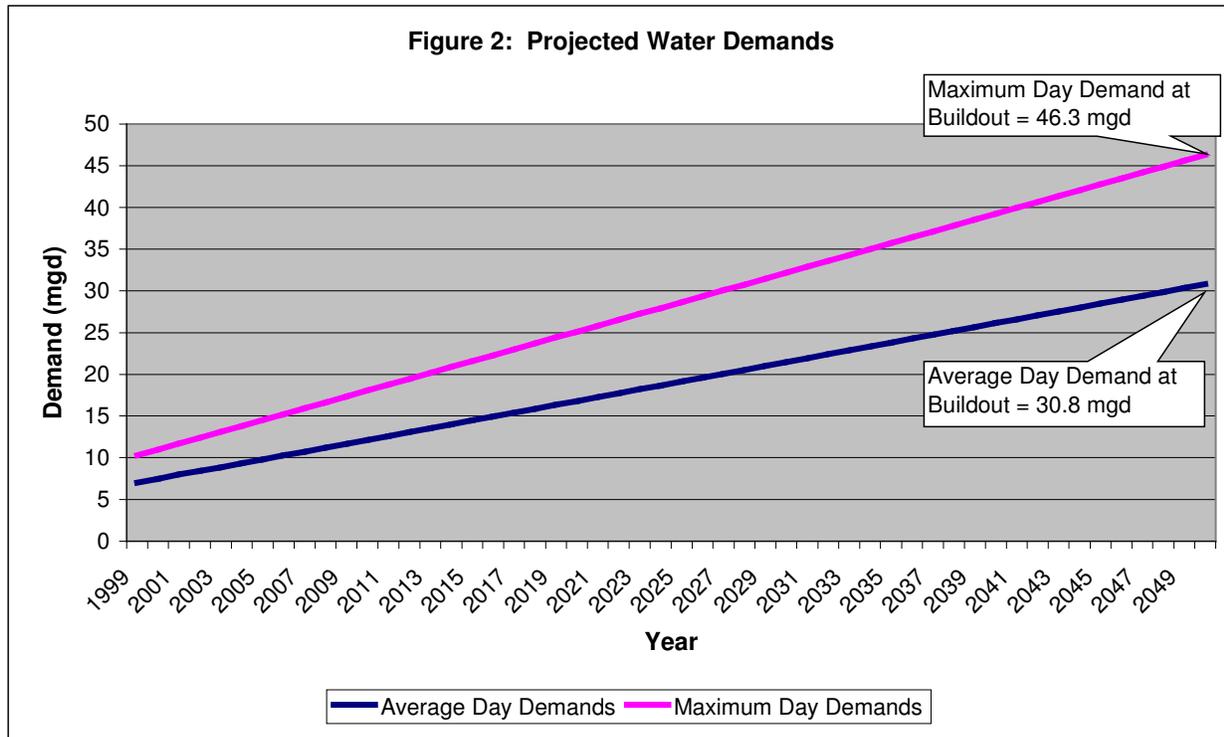
The peak day factor (maximum day demand / average day demand) for 2002 was 1.67.

Peaking factors will typically drop as the water system continues to expand through



the planning period. Average day water demands are expected to increase from approximately 8.4 mgd (2003) to 30.8 mgd under buildout (2050) conditions. During the same period, the maximum day

demands are expected to increase from approximately 13 mgd (2003) to 46 mgd at buildout (2050) based on a peaking factor of 1.5 times the average day demand (Figure 2).



6. PROJECTED SEWER FLOWS

Methodology for Projecting Sewer Flows

Wet weather flows are used to assess the hydraulic capacity of sewer systems and are composed of three components:

- Sanitary base flow generated by homes, businesses, etc.,

- Infiltration due to normal groundwater levels (dry weather infiltration), and
- I/I due to rainfall and high groundwater levels (rainfall-dependent I/I)

The formula for calculating the sewer loads for wet weather conditions is as follows:

$$\text{Peak Wet Weather Flow (PWWF)} = \text{Average Dry Weather Flow (ADWF)} + \text{Rainfall-Dependent I/I (RDI/I)}$$

Where:

Peak Wet Weather Flow (PWWF) equals the peak hourly flow during wet weather conditions.

Average Dry Weather Flow (ADWF) is the average flow that occurs in sanitary sewers on a daily basis with no evident reaction to rainfall. The ADWF is composed of sanitary base flow and groundwater infiltration. Sanitary base



flows are roughly equal to 80% of the water demand which approximates the customers' water demand that is returned to the sanitary sewer. Groundwater infiltration (GWI) is an allowance that is added to the sanitary base flow (derived from sewage flow factors) to obtain the dry weather flow. GWI represents flow that is separate and distinguished from inflow resulting from storm events during wet weather conditions. The allowance used in this Master Plan for GWI is estimated to be 500 gpd/inch diameter-mile (gpdidm).

Rainfall-Dependent I/I consists of rainfall that enters the collection system through direct connections (roof leaders, manholes, etc.) and causes an almost immediate increase in wastewater flows. RDI/I data from an August 2002 storm event (2-year return interval) was used for sewer model calibration. For the August 28, 2002 storm event, peaking factors at various pumping stations ranged from 2.6 to 3.7 (i.e., peak hourly flows were 2.6 to 3.7 times greater than the average dry weather flow for that period). The weighted peaking factor for the overall sewer system was approximately 2.8 for the August 28, 2002 storm event.

Additional flow monitoring information is needed to accurately predict the response of the sewer system to larger storm events with varying characteristics (i.e., intensity,

duration, and volume). To define the design flow conditions for the sewer system, the equation presented above was modified as follows:

Peak Wet Weather Flow (PWWF) = Average Dry Weather Flow (ADWF) x Peak Factor

The peak factor is equal to the PWWF/ADWF. In the sewer model, a global peak factor is multiplied by the sanitary base flow at each manhole in the sewer system and the GWI component (500 gpdidm) is subsequently added to the computed manhole flow as the flow is routed through the downstream sewer piping.

Sanitary Base Flows for Near-term Conditions

Near-term flows were developed using water demands from customer billing data for 2001 (reduced to 80% to obtain sewer flow) and estimated sewer flows from proposed developments. Average sewer flows were applied to the nearest manholes.

This approach results in an accurate allocation of current water demands to the nearest sewer manhole. Sewer loads for developments which could occur prior to 2010 were provided by DOU and applied to the existing H2OMAP Sewer model to test the capabilities of the existing infrastructure to handle the proposed near-term flows.

Sanitary Base Flows for Buildout Conditions

Land use, customer class flow values, and flow ratios (peaking factors) were used to determine peak flow conditions. The general process for estimating the sanitary base flow at each manhole included:

- Establishing the base map of the service area. It should be noted that sewer service area boundary was established and served as a "wall" for calculating sewer loads.
- Obtaining the land use areas and customer class assignments based on the Land Use Plan.
- Calculating the sanitary base loads defined by land use for customer classes.
- Overlaying the map of land use for customer classes and the manholes in the sewer model.
- Establishing the area of influence for each manhole and summing up the loads within each manhole's area of influence.
- Estimating the peaking factor to be applied to the loads at each



manhole.

This technique for assigning sewer loads to manholes in the model can easily accommodate changes in loading for land use and reconfiguration of the model network.

Determination of Total Peak Design Flow

Design flow for a sewer is defined as the maximum flow rate that occurs under selected weather and growth conditions. Because a significant portion of the peak flow results from rainfall, the design storm flow that the sewer must convey is related to the probability of occurrence of a design storm event. Design flow for a selected rainfall event is the sum of the peak sanitary base flow, infiltration and inflow.

The design storm or storm recurrence interval is also the basis for prescribing a level of protection to the pipe capacity to carry the design flow. Selection of the design storm determines the threshold flows at which the sewer will be expected to surcharge and potentially overflow.

To establish the design storm for the sewer system, data from storm events that occurred during the flow monitoring period were analyzed to compute an R-value. The R-value is defined as the ratio of calculated RDI/I volume to the rainfall volume over the sewershed area, expressed as a percent. For example, an R-value of 0.10 indicates that 10% of the total monitored rainfall volume that fell over the sewershed area made its way into the sewer system as monitored RDI/I.

Rainfall data were reviewed for storm events that occurred during the period when flow monitoring data were collected:

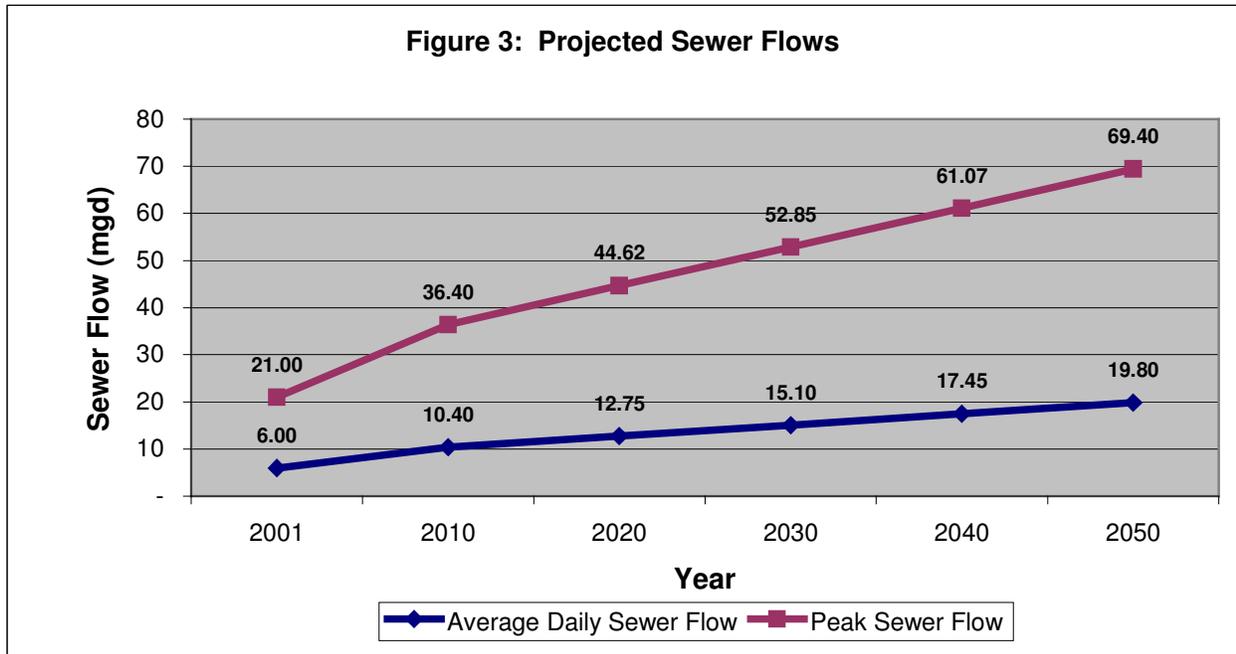
- August 28 – 30, 2002
- April 7 – 12, 2003
- April 18 – 19, 2003

Using the inflow data from flow monitoring for the storm events in combination with the volume of rainfall that occurred during the period, the average R-values based on the Quantico, Garrisonville, K4HR/Goldvien rainfall gages were estimated to be 1%, 1.3%, and 0.91%, respectively.

The system-wide RDI/I was computed for various storm events using the 24-hour rainfall totals from precipitation curves for Stafford County and average R-values. Combining the system-wide RDI/I with the dry weather flow yielded an estimated peak wet weather flow for the overall future sewer system for various storm events. In addition, the system-wide sewer flows associated with various peaking factors were computed by multiplying the average dry weather flow at buildout times the peaking factors. Comparing the peak wet weather flow computed from use of R-values with those computed using average dry weather flows times peaking factors, it appears that a peak factor of 3.5 represents a peak wet weather flow for a 24-hour storm event with an estimated 25-year recurrence interval. The total rainfall from a 25-year 24-hour storm event is 5.9 inches. A detailed discussion of the peak design flow is presented in Technical Memorandum 8 (*Wastewater Collection, Pumping and Conveyance Facilities*).

The peak factor is used to convert projected average sewer flows through the planning period to peak wet weather flows. Average daily sewer flows are expected to increase from approximately 6.0 mgd (2001) to roughly 19.8 mgd under buildout (2050) conditions. During the same period, the maximum day demands are expected to increase from approximately 21 mgd (2001) to 69.4 mgd at buildout (2050) based on a peaking factor of 3.5 times the average dry weather flow. The sewer flow projections are shown in Figure 3.





7. KEY FINDINGS

- ◆ Bringing the Rocky Pen Run Reservoir water facilities on-line and reversing the direction of water flow from the supply sources through a major portion of the transmission system requires careful planning to optimize use of existing facilities and properly size and locate proposed facilities so that they operate well under near-term and buildout conditions.
- ◆ Water system facilities in the growth area were sized to deliver the quantity of water needed to meet the buildout demands in the areas outside the growth area. However, the sewer service area boundary which generally follows drainage basins, roadways, and water features represents a “wall” and sewer flows for areas outside the Urban Service Area envelope were not included in this Master Plan.
- ◆ Water/sewer duties (gpd/acre) were held at low levels for each land use category prior to compiling the water demands and sewer loads. This approach eliminates the need to apply a global reduction factor to the total water demand and total sewer load in latter stages of the computation.
- ◆ Average daily water demands are expected to increase from approximately 8.4 mgd (2003) to 30.8 mgd under buildout (2050) conditions. During the same period, the maximum day water demands are expected to increase from approximately 13 mgd (2003) to 46 mgd at buildout (2050) based on a peaking factor of 1.5 times the average day demand.
- ◆ Based on the results of the August 2002 storm event, industry guidelines, and anticipated regulatory requirements, a peak factor of 3.5 is used to derive the peak wet weather flow for the sewer system for a 24-hour storm event with an estimated 25-year recurrence interval. The total rainfall from a 25-year 24-hour storm event in Stafford County is approximately 5.9 inches.



- ◆ Average daily sewer flows are expected to increase from approximately 6.0 mgd (2001) to roughly 19.8 mgd under buildout (2050) conditions. During the same period, the peak flows are

expected to increase from approximately 21 mgd (2001) to 69.4 mgd at buildout (2050) based on a peaking factor of 3.5 times the average dry weather flow.

8. PLAN OF ACTION

- ◆ DOU will continue to monitor growth in water and sewer accounts and update water demands and sewer flows.
- ◆ DOU will continue to refine techniques used to develop water demand and sewer load forecasts and update projections provided in the Master Plan. Changes in the characteristics of land use categories (i.e., number of housing units per acre, persons per household, etc.) and patterns for water use and sewer flow generation will be routinely reviewed.
- ◆ If water demand or sewer load forecasts are revised, DOU will review the timing for capital projects identified in the Master Plan and possibly revise the sizing or timing of projects.
- ◆ DOU will continue to monitor the sewer system's response to storm events with varying characteristics (i.e., intensity, duration, etc.) and, if necessary, modify the peaking factor used to represent the design storm event.



Chapter 4

RAW WATER SUPPLY

(Draft text being reviewed by DOU for inclusion at a later date)



(Draft text being reviewed by DOU for inclusion at a later date)



Drinking water from Smith Lake and Abel Lake Water Treatment Plants (WTPs) is provided to DOU's customers through a network of pipes (including more than 462 miles of pipes four inches and larger in diameter). Storage tanks throughout the water distribution system provide equalization storage and reserve capacity for fire and emergencies. The water distribution system must respond to increasing water demands, water pressure distribution, and the challenges of aging infrastructure.

1. DELIVERING DRINKING WATER FROM THE WATER TREATMENT PLANTS TO THE CUSTOMERS

The DOU water supply system includes two raw water supply reservoirs (Abel Lake and Smith Lake), two water treatment plants, two large ground-level water storage tanks, six major water pumping stations, 12 elevated water storage tanks, and approximately 462 miles of pipes ranging in size from 4 to 30 inches in diameter. Most of the pipe material in the DOU distribution system is ductile iron pipe (DIP), cast iron pipe (CIP), asbestos-cement (A-C) pipe, and polyvinyl chloride (PVC) pipe.

DOU's current water distribution system is divided into five pressure zones essentially extending east and west from the Interstate

95 corridor:

- 310 Zone in the northeast portion of the County.
- 433 Zone in the northern portion of the County.
- 472 Zone in the northwest portion of the County.
- 342 Zone in the southeast portion of the County.
- 503 Zone in the southwest portion of the County.

A map showing the current and future water system is included in the back pocket at the end of this Master Plan (Stafford County Water System Proposed Improvements).

2. LEVEL OF SERVICE REQUIREMENTS FOR WATER DISTRIBUTION

The performance of a finished water distribution system is judged by its ability to deliver the required flows while maintaining desirable pressure and water quality. Customer water demands and fire flow requirements must be met. Meeting these requirements depends upon the proper design and performance of distribution and transmission piping, elevated and ground storage tanks, and high service and booster pumping stations.

Planning and design guidelines vary from state to state and from utility to utility. While national organizations, such as the American Water Works Association (AWWA), provide some guidelines and many states regulate certain performance criteria, planning and design criteria are

often left to the discretion of the water utility. The planning and design criteria proposed for use in the DOU's Water and Sewer Master Plan project were compared with the criteria used by similar utilities in the region (e.g., location, estimated population served, growth rate, customer demographic, etc.). It is important to recognize that the planning and design criteria should be applied on a case-by-case basis and may change over time.

DOU's planning and design criteria for waterworks facilities are summarized below.

Water Treatment Facilities

Water treatment facilities shall be adequate to provide the maximum day water demand.



Pumping Stations

Water booster pumping stations shall be adequate to pump the maximum day water demand. While pumping stations are typically sized for maximum day demands, it may be desirable to size pumping facilities for peak hour demand (or a portion of peak hour demand) if the pumping station serves a pressure zone with a single storage tank that must be taken out-of-service for maintenance. It is generally desirable to provide at least two storage tanks per pressure zone to simplify operation of the pumping facilities when a tank is taken out-of-service.

Pipelines

Pipelines are sized for the following:

- The largest of maximum hour flow, maximum day flow plus fire flow, or replenishment flow. Fire flow requirements are a primary factor affecting the sizing of piping in the water distribution system (6-inch and 8-inch mains).
- An allowable velocity of 5 ft/sec.
- An allowable headloss of 2-5 feet/1,000 feet of pipeline.

Maximum Pressure

Maximum pressure refers to the maximum pressure that the customer will experience. It is often in the range of 90-110 psi. The maximum pressure is based on common household appliance limitations (water heaters can withstand 120-130 psi). Maximum water pressures at the service connections were set at 120 psi for this Master Plan.

Minimum Pressure

Minimum pressure is the minimum pressure at a customer's tap. The most common minimum pressure among utilities is 40 psi.

If pressures are less than 40 psi, there could be a noticeable pressure decrease when more than one device (e.g., faucet, toilet, shower, etc.) is used. The Virginia Department of Health's Waterworks Regulations require that the water system shall provide a minimum pressure of 20 psi

at the service connection based on the greater of maximum hour or maximum day plus fire flow demand condition.

Pressure Fluctuation

Pressure fluctuation is the difference between maximum hour and minimum hour conditions at any one location in the system.

An acceptable pressure fluctuation is 20-30 psi. Customers come to rely on steady pressure; thus in the interest of providing good service, large pressure fluctuations should be avoided in design. The maximum pressure fluctuation criteria used for this Master Plan was 30 psi.

Pressure Zone Layout

Pressure zone layout refers to the design and layout of pressure zones across the system. Because pressure is related to ground elevation, a system covering hilly or mountainous terrain will have more pressure zones than one covering relatively flat terrain. The minimum pressure establishes the highest ground elevation that can be supplied, and the maximum pressure establishes the lowest ground elevation. Pressure zone boundaries can be moved to increase or decrease pressures and resolve pressure complaints from customers in the vicinity of the boundaries.

Pipeline Looping

Looping refers to providing supply to a single point or an area through two or more pipelines. This practice provides a higher level of reliability (i.e., if one source is out-of-service to the area, supply can be provided from a second source).

Pipe Materials

Pipe materials generally accepted include ductile iron, steel, concrete, and polyvinyl chloride (plastic or PVC). PVC is usually used for smaller diameter piping.

Drinking Water Storage

DOU's water storage facilities are located



throughout the distribution system – providing flexibility to meet highly variable customer demands throughout each day. Storage facilities are sized to provide for:

- Equalization Storage – to meet fluctuating water demands that exceed the WTP pumping capacity.
- Fire Flow Storage – to meet the demands for fire fighting.
- Emergency Storage – to provide water reserves for contingencies such as system failures, power outages, main breaks, and other emergencies.

According to the Virginia Department of Health (VDH), water utilities must have combined storage equal to or greater than one-half of the average day demand.

Water Quality

The quality of the water in the distribution system can be affected by design and operation of the system, such as:

- Oversized pipelines and storage facilities.
- Operating practices for storage facilities that result in long detention times for the water stored.
- Corrosion of pipeline materials or increased growth potential of microorganisms.
- Backflow and cross-connection prevention.

There is a need to balance storage requirements with water quality. A utility cannot discount the need for adequate storage for fire flow and flow equalization. However, excess storage in storage tanks increases water residence times in the system, which can cause low disinfectant residuals, higher disinfection byproducts, and bacterial regrowth. Water quality in the distribution system can be improved by:

- Optimizing the operation of existing storage facilities by matching tank levels and turnover rate to water demands.
- Optimizing the operation of the distribution system and pressure

zones.

- Designing emergency and reserve storage in new storage facilities.
 - Providing an effective backflow prevention program.

Monitoring of some water quality issues in the distribution system is regulated (e.g., lead, copper, etc.) while others are identified by customer complaints (e.g., taste, odor, etc.). DOU has placed increased emphasis on understanding its water system, including data collection for the GIS and hydraulic computer models.

Regulatory Requirements

Water distribution systems are regulated under Safe Drinking Water Act rules, as described below.

- Lead and Copper Rule – The Lead and Copper Rule sets action levels for lead and copper. DOU monitors sites throughout its distribution system for lead and copper.
- Total Coliform Rule – The Total Coliform Rule sets the Maximum Contaminant Level goal of zero for total coliforms. Water systems must monitor for the presence of total coliforms and for chlorine to ensure that adequate chlorine residuals are maintained throughout the distribution system.
- Backflow Prevention/Cross-Connection Control Program – The Safe Drinking Water Act Amendments of 1986 and the Uniform Building Code require that DOU protect its potable water supply from contamination by unapproved sources or any other substances by cross-connecting or back-siphoning. DOU administers a cross-connection program to eliminate existing cross-connections. Approved backflow-prevention devices are installed and maintained at any water service connections with a potential hazard.

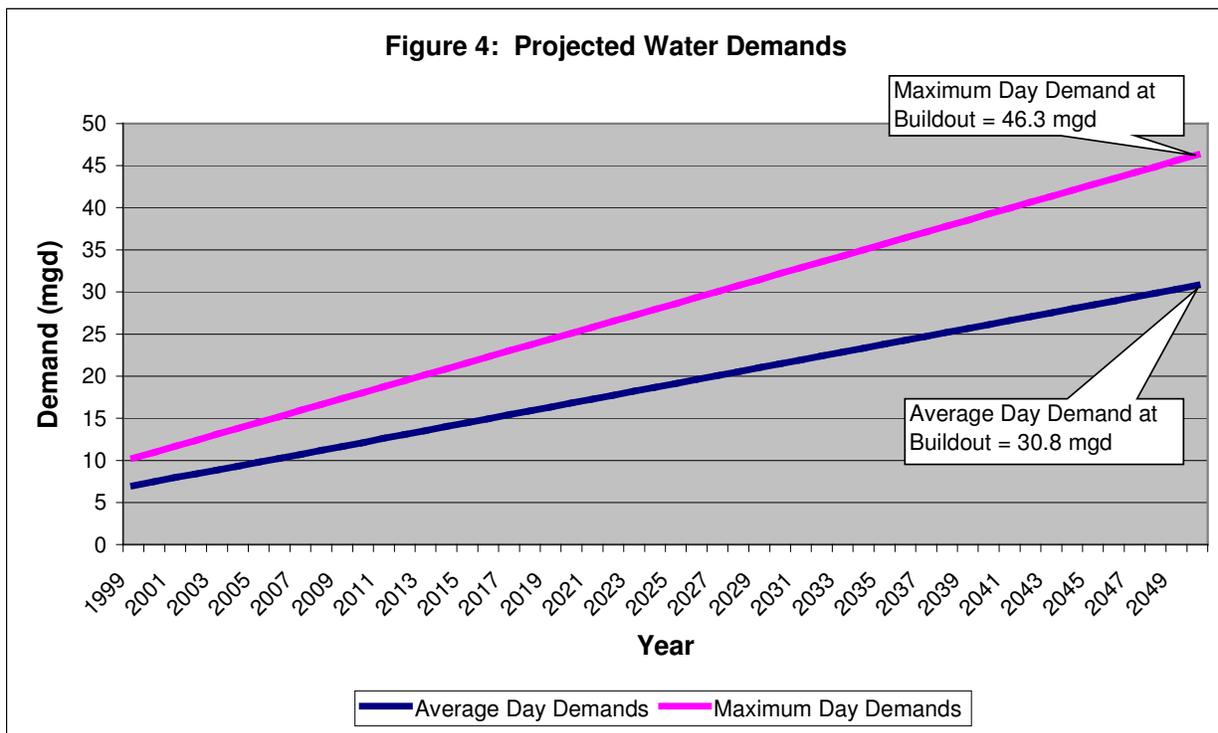


3. REVIEW OF PROJECTED WATER DEMANDS

Water demands represent the average flows that are applied to the water system network from the contributing area. These demands are defined as the amount of water that must be carried by the distribution system to satisfy the need. Nodes represent points in the water system where water demands are taken from the system. For the model of the existing system which was used for calibration, DOU provided the water demands based on customer billing data for 2001. The demands were applied to the nearest water node which results in

an accurate allocation of water demands for model calibration.

Future water demands were projected using the estimated consumption method described in Technical Memorandum 2 (*Water Demands*). This method uses land use, customer class consumption values, and consumption ratios (diurnal demand curves) to determine the maximum day and peak hour demand conditions. The average and maximum day demands through the planning period are shown in Figure 4.



4. EXISTING WATER SYSTEM LIMITATIONS AND PROPOSED IMPROVEMENTS

The condition and performance of the components of DOU's water distribution system is influenced by hydraulic capacity, age, material and service conditions (i.e., line pressures, soils, and installation). DOU reviews the characteristics of the water

system piping and facilities during day-to-day operations and maintenance activities as well as specific condition and modeling studies. Although this Master Plan does not directly evaluate system integrity (i.e., condition assessments), hydraulic modeling



was performed using H2OMAP Water to assess the capabilities of the existing and future water system under near-term (2013) and buildout (2050) demand conditions. The near-term and buildout maximum day demands used for hydraulic modeling were 20 mgd and 46.3 mgd, respectively. Schematics showing the delivery of flow through the system under near-term and buildout conditions are presented in Appendix C of Technical Memorandum 5 (*Finished Water Pumping, Storage and Distribution Facilities*).

The proposed water system improvements are shown on the figure in the pocket at the end of this Master Plan (*Stafford County Water System Proposed Improvements*) and the timing for implementation of the improvements is included in the pocket at the end of this Master Plan (*Summary of Costs and Schedule for Recommended CIP Improvements (inside Urban Service Area)*). In addition, a detailed description of each project is presented in Technical Memorandum 5 (*Finished Water Pumping, Storage and Distribution Facilities*).

Hydraulic Modeling

A functional, calibrated model was used to assess the performance of DOU's water distribution and transmission system. The hydraulic model can be used to better understand and assess the capabilities of DOU's system by simulating and identifying hydraulic limitations – low pressures and fire flow limitations – within the system under specified demand conditions. It is important to note that the model was calibrated using conditions that occurred during field testing in April 2003. Calibration is best over a range of demand conditions. By using a variety of demand conditions, the response of the system under critical demand conditions can be tested and the level of confidence in the model results can be assessed. A detailed discussion of model calibration is presented in Technical Memorandum 4 (*Development and*

Calibration of H2OMAP Water Hydraulic Model).

The hydraulic model will be a very valuable tool for DOU provided that the input files are maintained and updated as the distribution and transmission system expands and changes. This includes collecting additional data on demand conditions with varying characteristics. When used in conjunction with the other tools, such as GIS and SCADA, the model will serve as an integral part to the successful management and operation of the DOU water distribution and transmission system.

Cost Estimates

The unit cost basis and assumptions used for estimating construction costs for water treatment, pumping, storage, transmission and distribution system piping are presented in Technical Memorandum 12 (*Cost Estimates*). Project costs to be incorporated into the County's capital improvements program were generated by adding allowances to the estimated construction costs.

The cost estimates generated for this study are termed "budget" estimates and are appropriate for the level of detail associated with concept level planning. Budget level estimates are made without detailed engineering data or information on site-specific conditions (e.g., final pipeline alignments, aesthetics, etc.). The intended use of these estimates is for developing budgets for inclusion in the County's capital program. Budget level estimates are considered accurate within +30% and -15%.

Construction cost estimates were converted to total project costs by adding an allowance of 20% for engineering, legal and administrative fees. Project cost estimates are intended for use in budget development, wherever site-specific costs are not utilized. They represent typical experience and should be adjusted, where appropriate, to



meet special needs.

The overall cost for the proposed water system improvements presented in this Master Plan through the buildout condition is approximately \$51.4 million. Approximately \$11.8 million is proposed through the near-term planning period (2013).

Timing of Proposed Improvements

The timing of each proposed water improvement identified in this Master Plan is shown in the pocket at the end of this Master Plan (*Summary of Costs and Schedule for Recommended CIP Improvements (inside Urban Service Area)*).

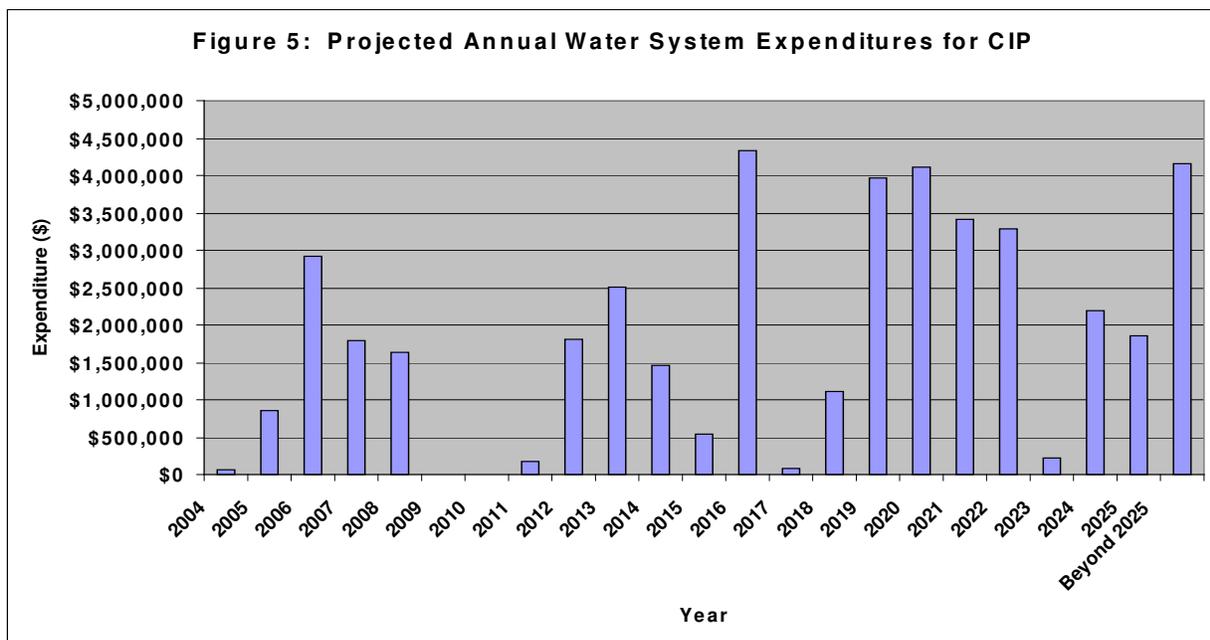
Projects were grouped into one of four categories:

- Priority 1 - Critical to the current and future operation of the system or supplies areas not previously served.
- Priority 2 - Necessary to meet basic hydraulic performance requirements and improve system operation and reliability.
- Prior Appropriation – Funds for these projects have been appropriated by DOU.
- Developer Projects – These projects

serve the proposed developments and provide little (if any) benefit to the overall water system.

The timing for implementation of the proposed improvements is based on projected demands and hydraulic modeling of the capabilities of the existing water system facilities. A number of factors may dictate that projects be accelerated or deferred (e.g., timing of water demands or developments, groundwater well failures, physical condition of facilities or piping, upcoming maintenance expenditures, etc.). While the timing of the proposed projects shown in the implementation schedule was developed to allow for a smooth transition through the planning period, it should be noted that the projects were deferred to the extent possible to allow as much time as possible for assessment of these factors prior to implementation. Figure 5 shows the proposed expenditure schedule for the improvements identified in this Master Plan.

It is recommended that DOU conduct an annual review of the proposed projects and revise the project costs and implementation schedule as necessary.



5. KEY FINDINGS

- ◆ Planning and design criteria used in this Master Plan are consistent with the criteria adopted by national organizations, local utilities, and state regulatory agencies. In addition, planning and design criteria should be applied on a case-by-case basis and may change over time.
- ◆ Hydraulic modeling was performed using H2OMAP Water to assess the capabilities of the existing and future water system under near-term (2013) and buildout (2050) demand conditions. The near-term and buildout maximum day demands used for hydraulic modeling were 20 mgd and 46.3 mgd, respectively.
- ◆ The cost estimates generated for this study are termed “budget” estimates and are appropriate for the level of detail associated with concept level planning. Budget level estimates are made without detailed engineering data or information on site-specific conditions (e.g., final pipeline alignments, aesthetics, etc.). The intended use of these estimates is for developing budgets for inclusion in the County’s capital program.
- ◆ The overall cost for the proposed water system improvements presented in this Master Plan through the buildout condition is approximately \$51.4 million. Approximately \$11.8 million is proposed through the near-term planning period (2013).

6. PLAN OF ACTION

- ◆ DOU will continue to assess water distribution system conditions by conducting field investigations and periodically reviewing physical attributes (pipe diameter and material), incidence of water quality complaints, results of hydraulic modeling (high pressure and high headloss), and locations of water main breaks and other maintenance history (work orders).
- ◆ DOU will continue to review water system planning and design criteria and make changes to the proposed improvement projects, as needed.
- ◆ DOU will continue to collect data for various design demand conditions and refine the hydraulic model of the water system.
- ◆ DOU will collect site-specific cost information on proposed projects, if available, and refine the budget-level costs presented in this Master Plan.
- ◆ DOU will routinely review the timing of water projects proposed in this Master Plan and coordinate these water projects with sewer projects, roadway projects and other related activities.



Wastewater from DOU's customers is conveyed through a network of pipes (including over 400 miles of sewer piping) and pumping stations to the Aquia and Little Falls Wastewater Treatment Plants (WWTP) for treatment and discharge. Focus by DOU and regulatory agencies on wastewater collection systems has been increasing, and new regulations to protect public health and water quality will include stricter standards that prevent sanitary sewer spills and overflows. DOU will continue to upgrade, replace, and rehabilitate wastewater collection system components to improve performance, reduce WWTP impacts, and prepare for regulatory changes.

1. COLLECTION AND TRANSPORT OF WASTEWATER TO TREATMENT PLANTS

DOU's wastewater collection and conveyance system is served by two wastewater treatment plants:

- Aquia WWTP in the northern portion of the service area along Austin Run and adjacent to Jefferson Davis Highway.
- Little Falls Run WWTP in the southeastern portion of the County along Kings Highway and near the confluence of Little Falls Run and the Rappahannock River.

The DOU wastewater collection system consists of approximately 400 miles of pipe, 47 miles of sewer force mains, 8,673 manholes, and 83 pumping stations. Pipe

sizes in the collection system range from 2 to 48 inches in diameter. The most common pipe materials in the collection and conveyance system are reinforced concrete pipe (RCP), cast iron pipe (CIP), ductile iron pipe (DIP), polyvinyl chloride (PVC), and asbestos cement pipe (ACP). Prior to 1978, ACP was primarily used. In more recent construction, PVC pipe has been used extensively. The first conventional wastewater collection facilities in Stafford County were constructed in 1930.

A map showing the current and future sewer system is presented in the back pocket at the end of this Master Plan (*Stafford County Wastewater Improvements*).

2. LEVEL OF SERVICE REQUIREMENTS FOR SANITARY SEWER SYSTEM

In general, the regulatory requirements for collection systems are becoming more stringent and there appears to be a trend toward a "zero tolerance" policy for sanitary sewer overflows. A sanitary sewer overflow (SSO) is the discharge of raw sewage from a municipal sanitary sewer system into basements, or out of manholes and pumping stations and onto city streets, playgrounds, and streams without any form of treatment. The USEPA and the Virginia Department of Environmental Quality (VDEQ) believe that inadequate management, operation and maintenance for sewage collection and conveyance systems pose a significant threat to receiving water quality and public health through the discharge of SSOs.

Capacity, Management, Operations and Maintenance

The USEPA is considering regulations and enforcement policies that will affect all municipal wastewater utilities by requiring all collection systems to be permitted through the National Pollutant Discharge Elimination System (NPDES) process. As part of this permitting process, utilities will be required to implement a Capacity, Management, Operations and Maintenance (CMOM) program.

In anticipation of the USEPA SSO policy, which may include a prohibition against sanitary sewer discharges, public utilities across the nation are working to ensure that their wastewater collection and conveyance



systems can accommodate current and projected dry and wet weather flows without experiencing sanitary sewer overflows. The USEPA premise for the CMOM program is that when the permittee incorporates good business principles into its organization, the wastewater collection system will meet the intended performance standards and will ultimately have fewer SSOs. The CMOM program would place the burden of proof on the permittee to demonstrate that SSOs are being prevented through (1) use of pipes and pumping stations with adequate capacity, and (2) proper management, operations, and maintenance of the system.

If the permittee cannot demonstrate that good business practices are being developed or in place when SSOs occur, the permittee could be deemed to be in violation of its NPDES permit.

The proposed CMOM program was developed, in part, to encourage all utilities to implement a proactive, rather than reactive, approach to wastewater collection system management, operations, and maintenance. According to both the USEPA and VDEQ, utilities with proper management, operation, and maintenance programs reduce the likelihood of SSOs, extend the life of their infrastructure, and provide better customer service through relatively steady sewer rates and greater efficiency.

Performance Criteria

USEPA and VDEQ recognize that SSOs cannot be completely eliminated, and that sanitary sewer systems that are designed to not overflow when a given design storm occurs, may nonetheless experience wet weather induced overflows as the result of conditions other than the design storm.

Therefore, as part of the NPDES permitting process, it is anticipated that USEPA and VDEQ will require local governments to certify that their sanitary sewer systems will not produce SSO events as a result of storm events equal to, or less than, a design storm of specified intensity and duration. The USEPA and VDEQ have yet to define the

design storm criteria; however, the DOU collection and conveyance system has been analyzed for impacts associated with the 25-year, 24-hour peak inflow event.

Ideally, storm event data over at least 20 to 30 years are collected and the storms are ranked based on their effect on the sewer system (i.e., the amount of I/I caused in the system by the storm), rather than on individual storm characteristics (i.e., peak intensity, volume, and duration). The storms are commonly referred to as “peak inflow events” because the assigned return intervals more accurately refer to the ranking of the amount of I/I generated by the storm, rather than the actual size or characteristics of the storm. However, an analysis of the impacts of historical storm events on the wastewater collection and conveyance system is a significant effort and was not conducted in this study. Rather, inflow hydrographs were developed for storm events that occurred during the 2002 and 2003 flow monitoring period using hourly historical rainfall records. As described in Technical Memorandum 6 (*Rainfall/Flow Monitoring Program*), a 2-year storm event occurred on August 28, 2002 and was used for wet weather calibration of the hydraulic model and identification of the peak flow characteristics for a 2-year storm event.

An important aspect of RDI/I is its correlation to rainfall events and duration. Even within the same system, identical rainfall events may produce different wastewater flow reactions. It is difficult to predict a flow reaction from a large storm event based on data from a small event, as wastewater flows and rainfall intensity do not have a linear relationship.

Planning and Design Criteria

A sanitary sewer collection system has basically two main functions: (1) to convey the design peak discharge, and (2) to transport solids so that deposits are kept to a minimum. It is imperative, therefore, that the sanitary sewer has adequate capacity of the peak flow and that it functions at



minimum flows without excessive maintenance and generation of odors.

A comparative review of DOU's planning and design criteria for sewer systems was performed to identify whether the sewer system criteria proposed for use in the Water and Sewer Master Plan project are reasonable. The planning and design criteria were used to evaluate the sewer system and to plan future improvements, upgrades, and expansions of facilities.

While national organizations provide some guidelines and many states regulate certain performance criteria, design criteria are often left to the discretion of the utility. The planning and design criteria proposed for use in DOU's Water and Sewer Master Plan project are comparable to the criteria used by similar utilities in the region (e.g., location, estimated population served, growth rate, customer demographic, etc.).

Planning and design criteria were reviewed with DOU to identify any modifications needed to reflect recent or anticipated future changes and to document policy decisions regarding application of the criteria. Understanding the potential impacts that revising the planning and design criteria may have on the existing and proposed capital improvements is essential. Additional studies (e.g., flow monitoring, historic flow data, etc.) may be needed in the future to more clearly define modifications needed to the planning and design criteria.

The sewer planning and design criteria used in this Master Plan include the following:

- "n" value = 0.013 for all pipe materials
- Minimum Velocity = 2.25 ft/sec
- Maximum Velocity = 15 ft/sec
- Minimum Depth of Cover = 3 feet
- Maximum Depth of Cover = 20 feet

An analysis criteria curve was developed for this study to define the "threshold" values at which point capacity enhancement

measures for pipelines within the sanitary sewer system should be evaluated. There are no established requirements or guidelines for partial-to-full flow (q/Q) ratios used for the analysis criteria curve. Selection of the q/Q ratios and the associated range of pipeline sizes are based on best professional judgement taking into consideration the following:

- Potential delays associated with implementation of future improvements (e.g., planning, siting, design, and construction).
- Risk of sanitary sewer system overflows.
- Excess capacity in sanitary sewer pipelines resulting in higher maintenance and possible odors.
- Rate of development (i.e., timing for additional future improvements).
- Potential for additional future development.

Based on these considerations, the values shown in Table 3 are proposed for the analysis criteria curve used in this study.

Table 3. Analysis criteria curve

Pipeline Diameter	q/Q Ratio
8-inch through 12-inch	0.50
15-inch and up	0.85

The q/Q ratio of 0.85 (d/D ratio of 0.75) for the large diameter pipelines reflects the desire to maximize flow in the existing interceptor sewers while maintaining some reserve capacity. The q/Q ratio of 0.50 for smaller diameter pipelines reflects the uncertainty in the spatial distribution of sewer loads served by the smaller piping in the sewer system. By applying relatively conservative q/Q ratios for the analysis curve, pipelines will be identified prior to reaching full capacity and thus reduce the likelihood of surcharge and/or overflow



conditions. It should be noted that existing pipelines that exceeded the design criteria and were less than full through buildout conditions (q/Q less than 1.0) were not recommended for replacement. Rather, these pipelines were flagged for future investigation and possible flow monitoring during the planning period.

The design criteria curve is used for designing the relief or replacement pipelines when the capacity of the existing pipelines has been exceeded as defined by the analysis criteria curve. In general, the design criteria curve generally reflects the desire to limit the possibility of requiring additional improvements in the near-term

planning period. The initial design criteria curve values proposed for use in this study are shown in Table 4.

Table 4. Design criteria curve

Pipeline Diameter	q/Q Ratio
8-inch through 12-inch	0.50
15-inch and up	0.85

A more detailed discussion of the sewer design criteria is presented in Technical Memorandum 11 (*Summary of Sewer Planning and Design Criteria*).

3. REVIEW OF PROJECTED SEWER FLOWS

Methodology for Projecting Sewer Flows

Wet weather flows are used to assess the hydraulic capacity of sewer systems and are composed of three components:

- Sanitary base flow generated by homes, businesses, etc.,

- Infiltration due to normal groundwater levels (dry weather infiltration), and
- I/I due to rainfall and high groundwater levels (rainfall-dependent I/I)

The formula for calculating the sewer loads for wet weather conditions is as follows:

$$\text{Peak Wet Weather Flow (PWWF)} = \text{Average Dry Weather Flow (ADWF)} + \text{Rainfall-Dependent I/I (RDI/I)}$$

Where:

Peak Wet Weather Flow (PWWF) equals the peak hourly flow during wet weather conditions.

Average Dry Weather Flow (ADWF) is the average flow that occurs in sanitary sewers on a daily basis with no evident reaction to rainfall. The ADWF is composed of sanitary base flow and groundwater infiltration. Sanitary base flows are roughly equal to 80% of the water demand which approximates the customers' water demand that is returned to the sanitary sewer. Groundwater infiltration (GWI) is an allowance that is added to the sanitary base flow (derived from sewage flow factors) to obtain the dry weather flow. GWI represents flow that is separate and distinguished from inflow resulting from storm events during wet weather conditions. The allowance used in this Master Plan for GWI is estimated to be 500 gpd/inch diameter-mile (gpdidm).

Rainfall-Dependent I/I consists of rainfall that enters the collection system through direct connections (roof leaders, manholes, etc.) and causes an almost immediate increase in wastewater flows. RDI/I data from an August 2002 storm event (2-year return interval) was used for sewer model calibration. For the



August 28, 2002 storm event, peaking factors at various pumping stations ranged from 2.6 to 3.7 (i.e., peak hourly flows were 2.6 to 3.7 times greater than the average dry weather flow for that period). The weighted peaking factor for the overall sewer system was approximately 2.8 for the August 28, 2002 storm event.

Additional flow monitoring information is needed to accurately predict the response of the sewer system to larger storm events with varying characteristics (i.e., intensity,

duration, and volume). To define the design flow conditions for the sewer system, the equation presented above was modified as follows:

Peak Wet Weather Flow (PWWF) = Average Dry Weather Flow (ADWF) x Peak Factor

The peak factor is equal to the PWWF/ADWF. In the sewer model, a global peak factor is multiplied by the sanitary base flow at each manhole in the sewer system and the GWI component (500 gpd/ft) is subsequently added to the computed manhole flow as the flow is routed through the downstream sewer piping.

Sanitary Base Flows for Near-term Conditions

Near-term flows were developed using water demands from customer billing data for 2001 (reduced to 80% to obtain sewer flow) and estimated sewer flows from proposed developments. Average sewer flows were applied to the nearest manholes.

Sanitary Base Flows for Buildout Conditions

Land use, customer class flow values, and flow ratios (peaking factors) were used to determine peak flow conditions which were applied to the nearest manholes.

Determination of Total Peak Design Flow

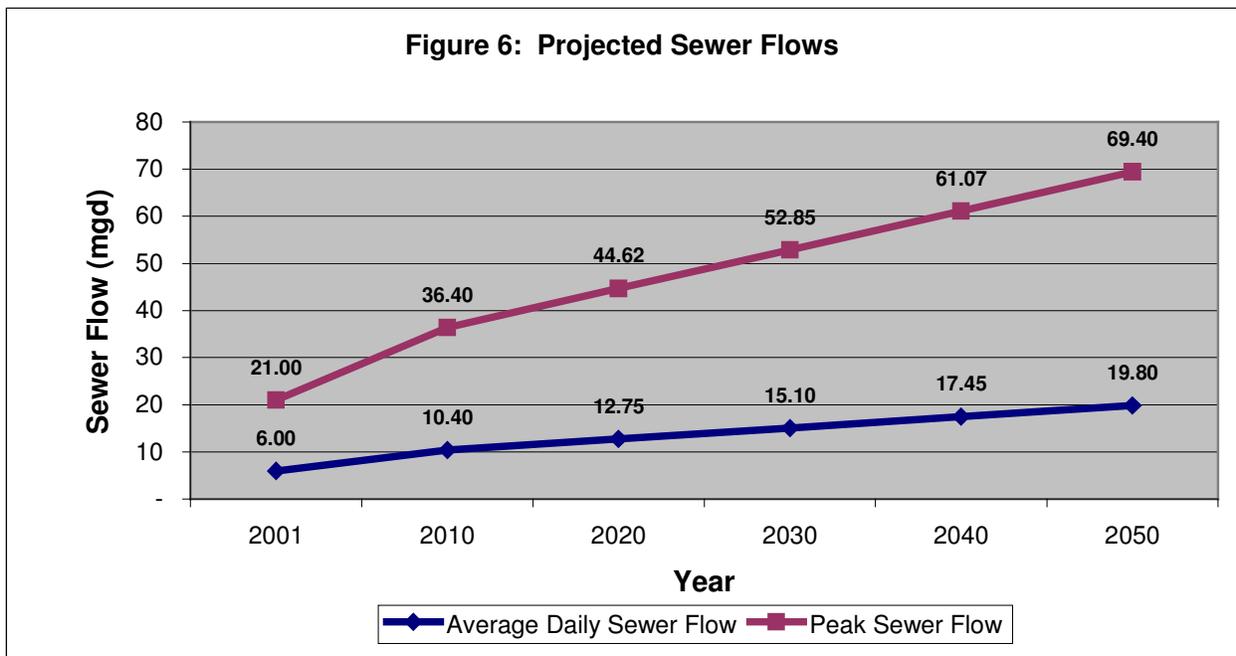
Design flow for a sewer is defined as the maximum flow rate that occurs under selected weather and growth conditions. Because a significant portion of the peak flow results from rainfall, the design storm

flow that the sewer must convey is related to the probability of occurrence of a design storm event. Design flow for a selected rainfall event is the sum of the peak sanitary base flow, infiltration and inflow.

The design storm or storm recurrence interval is also the basis for prescribing a level of protection to the pipe capacity to carry the design flow. Selection of design storm determines the threshold flows at which the sewer will be expected to surcharge and potentially overflow. Based on the results of the August 2002 storm event, industry guidelines, and anticipated regulatory requirements, a peak factor of 3.5 is used to derive the peak wet weather flow for a 24-hour storm event with an estimated 25-year recurrence interval. The total rainfall from a 25-year, 24-hour storm event is 5.9 inches.

Average daily sewer flows are expected to increase from approximately 6.0 mgd (2001) to roughly 19.8 mgd under buildout (2050) conditions. During the same period, the maximum day flows are expected to increase from approximately 21 mgd (2001) to 69.4 mgd at buildout (2050) based on a peaking factor of 3.5 times the average dry weather flow. The sewer flow projections are shown in Figure 6.





4. EXISTING WASTEWATER SYSTEM LIMITATIONS AND PROPOSED IMPROVEMENTS

Hydraulic modeling was performed using H2OMAP Sewer to assess the capabilities of the existing and future sewer system under near-term (2010) and buildout (2050) flow conditions. The near-term and buildout peak flows used for hydraulic modeling were approximately 36.4 mgd and 69.4 mgd, respectively.

The sewer system improvements presented in this Master Plan are shown on the figure in the pocket at the end of this Master Plan (*Stafford County Wastewater Improvements*) and the timing for implementation of the improvements is included in the pocket at the end of this Master Plan (*Summary of Costs and Schedule for Recommended CIP Improvements*). In addition, a detailed description of each project is presented in Technical Memorandum 8 (*Wastewater Collection, Pumping and Conveyance Facilities*).

Hydraulic Modeling

A functional, calibrated model was used to assess the performance of DOU’s sewer system. A detailed discussion of model calibration is presented in Technical Memorandum 7 (*Development and Calibration of H2OMAP Sewer Hydraulic Model*).

The hydraulic model will be a very valuable tool for DOU provided that the input files are maintained and updated as the collection and conveyance system expands and changes. This includes collecting additional data on the system’s response to storm events with varying intensity and duration.

Cost Estimates

The unit cost basis and assumptions used for estimating construction costs for sewer facilities are presented in Technical Memorandum 12 (*Cost Estimates*). Project



costs to be incorporated into the County's capital improvements program were generated by adding allowances to the estimated construction costs.

Similar to the water projects, the cost estimates generated for sewer improvements in this study are termed "budget" estimates and are appropriate for the level of detail associated with concept level planning.

Construction cost estimates were converted to total project costs by adding an allowance of 20% for engineering, legal and administrative fees. Project cost estimates are intended for use in budget development, wherever site-specific costs are not utilized. They represent typical experience and should be adjusted, where appropriate, to meet special needs.

The overall cost for the proposed sewer system improvements presented in this Master Plan through the buildout condition is approximately \$94 million. Approximately \$23.4 million is proposed through the near-term planning period (2010).

Timing of Proposed Improvements

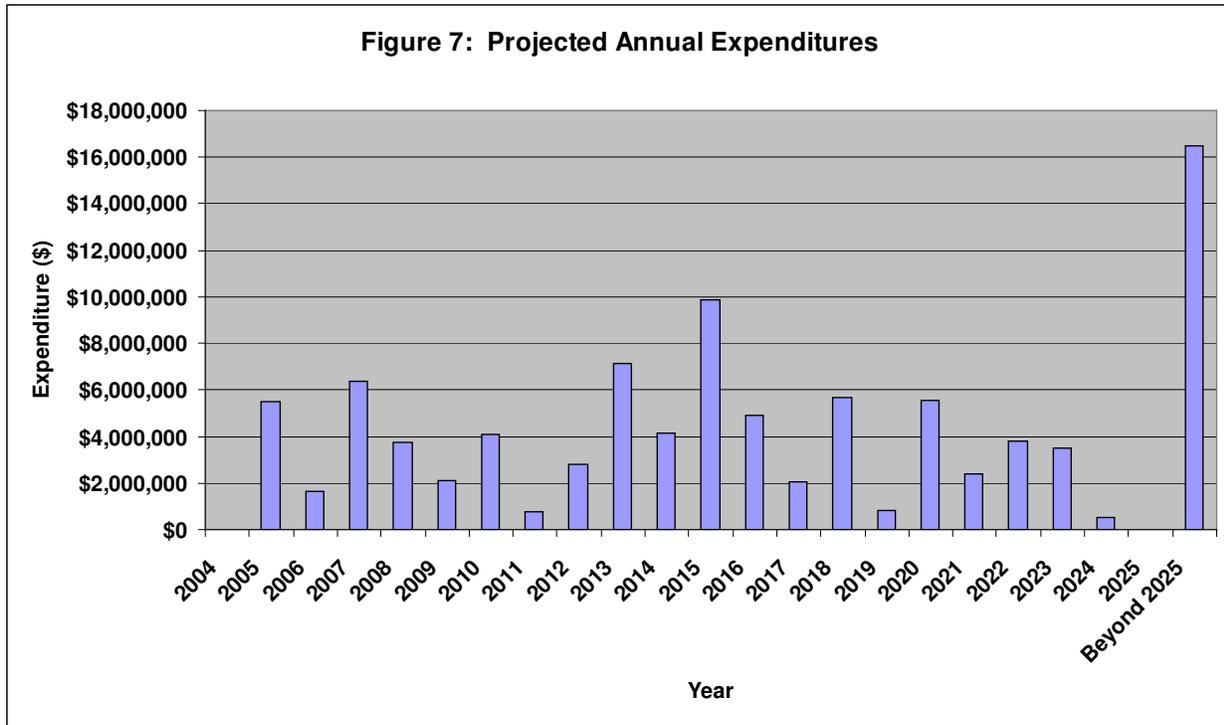
The timing of proposed sewer improvements identified in this Master Plan is shown in the pocket at the end of this Master Plan (*Summary of Costs and Schedule for Recommended CIP Improvements*). Projects were first grouped into either the "Developer Pro Rata" or "Developer Non-Pro Rata" category.

Proposed projects were then grouped into one of the following categories:

- Priority 1 - Operations: Essential to the current operation of the system or serves areas not previously served.
- Priority 2 - Near-term: Essential to the near-term operation of the system or serves areas not previously served.
- Priority 3 - Buildout: Essential to the buildout condition of the system or serves areas not previously served.
- Prior Appropriation – Funds for these projects have been appropriated by DOU.
- Candidate Projects for Flow Monitoring Prior to Recommendation for Implementation.

The timing for implementation of the proposed improvements is based on projected demands and hydraulic modeling of the capabilities of the existing system facilities. A number of factors may dictate that projects be accelerated or deferred (e.g., timing of sewer flows or developments, physical condition of facilities or piping, upcoming maintenance expenditures, etc.). Figure 7 shows the proposed expenditure schedule for the improvements identified in this Master Plan. It is recommended that DOU conduct an annual review of the proposed projects and revise the project costs and implementation schedule as necessary.





5. KEY FINDINGS

- ◆ Planning and design criteria used in this Master Plan are consistent with the criteria adopted by national organizations, local utilities, and state regulatory agencies. In addition, planning and design criteria should be applied on a case-by-case basis and may change over time.
- ◆ Proposed regulations will have more stringent requirements for planning, operating and maintaining the wastewater collection system to prevent SSOs.
- ◆ Hydraulic modeling was performed using H2OMAP Sewer to assess the capabilities of the existing and future water system under near-term (2010) and buildout (2050) flow conditions. The near-term and buildout maximum day flows used for hydraulic modeling were 36 mgd and 69.4 mgd, respectively.
- ◆ The cost estimates generated for this study are termed “budget” estimates and are appropriate for the level of detail associated with concept level planning. Budget level estimates are made without detailed engineering data or information on site-specific conditions (e.g., final pipeline alignments, aesthetics, etc.). The intended use of these estimates is for developing budgets for inclusion in the County’s capital program.
- ◆ The overall cost for the proposed sewer system improvements presented in this Master Plan through the buildout condition is approximately \$94 million. Approximately \$23.4 million is proposed through the near-term planning period (2010).



6. PLAN OF ACTION

- ◆ DOU will continue to maintain the GIS database on the wastewater collection system and sewer hydraulic model with complete and up-to-date information.
- ◆ DOU will continue to assess sewer system conditions by conducting field investigations and periodically reviewing physical attributes (pipe diameter and material), results of hydraulic modeling, and locations of sewer main breaks and other maintenance history (work orders).
- ◆ DOU will continue to review sewer system planning and design criteria and make changes to the proposed improvement projects, as needed.
- ◆ DOU will continue to collect data for various design storm events and refine the hydraulic model of the sewer system.
- ◆ DOU will collect site-specific cost information on proposed projects, if available, and refine the budget-level costs presented in this Master Plan.
- ◆ DOU will routinely review the timing of sewer projects proposed in this Master Plan and coordinate these sewer projects with water projects, roadway projects and other related activities.



Chapter 8

WASTEWATER TREATMENT

(Text to be prepared by DOU)



Chapter 9

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