TECHNICAL MEMORANDUM 4

Raw Water Supply

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This technical memorandum is one of a series being prepared for the Stafford County Water and Sewer Master Plan project. The purpose of this technical memorandum is to summarize the ability of DPW's existing raw water supplies to reliably meet the water demands associated with future growth and development.

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4.1 DPW'S EXISTING RAW WATER SUPPLIES

The County's water supply comes from Lake Mooney and Smith Lake Reservoirs. The reservoirs store water that DPW treats to supply customer demands. The reservoirs must be large enough to meet the County's current and future water demands in drought years. In addition, the reservoirs must be kept safe from sources of health-related water quality constituents, and other constituents that could affect the water's aesthetics (e.g., taste and odor). To protect its water supplies, DPW has several programs to minimize the potential for contamination of the reservoirs.

In 1992, the Stafford Board of Supervisors selected Lake Mooney (formerly named Rocky Pen Run Reservoir) as the new source of water supply to meet the County's needs well into the future. The reservoir is located in the southern portion of the County and is filled from the Rappahannock River using a 40 mgd river pumping station. The reservoir holds approximately 5.5 billion gallons of water. Smith Lake is located on Aquia Creek in the northern portion of the County. The reservoir holds approximately 1.8 billion gallons of water.

4.2 SAFE YIELD OF EXISTING RAW WATER SUPPLIES

The safe yield for Lake Mooney (11.9 mgd) was computed during the planning and permitting phases of the work on the reservoir according to the County. The safe yield for Smith Lake was calculated in this study based on its characteristics (i.e., storage volume, surface area, streamflow, etc.). In Virginia, safe yield for a water supply source is defined as the maximum sustainable withdrawal rate available to withstand the worst drought of record in Virginia since 1930 with 60 days of reserve water storage. For this evaluation, hydrologic data from 1930 through 2016 were used to simulate daily operation of the reservoir during the historical droughts of known severity.

4.2.1 Reservoir Yield Model Theory

A PC-based reservoir model developed by O'Brien & Gere in 2003 was updated to simulate operation of the reservoir had it been in place over the period of historical streamflow records. The hydrologic model developed to analyze Smith Lake calculates the average annual yield for the reservoir for a given set of operating characteristics. Yield is determined by solution of a water balance equation using an iterative approach, based on constraints on the input data. Solution of the water balance equation occurs when the difference in reservoir inflow and outflow equals the change in reservoir storage volume. Model inflows include daily streamflows. Outflows include factored user demands and reservoir releases. Bank storage and seepage are assumed to be negligible, and therefore no adjustments were made. The water balance equation used in the reservoir yield model is:

$$END = [BEG + INFLOW] - [(YIELD \times FCTR) + REL)]$$

The variables in the equation are defined as:

END = reservoir volume at end of the day

BEG = reservoir volume at the beginning of the day

INFLOW = volume of inflow during the day

YIELD = volume of yield during the day

FCTR = daily demand factor for seasonal adjustment

REL = daily release from the reservoir to the downstream channel

4.2.2 Reservoir Inputs

Reservoir inflows

For the safe yield analyses performed in this study, the US Geological Survey stream gage station at Goose Creek near Leesburg was used.

Table 4.2.1 – Streamflow Gage

Stream Gage	Drainage Area (square miles)	Period of Record Used in Analysis
Goose Creek near Leesburg, VA (01644000)	332	1/1/30 - 12/27/16

To identify representative streamflow gages for Aquia Creek inflows, the daily streamflow data at several stream gages were compared in the 2003 work for the period of October 1, 1962 through December 31, 1986. It was determined in 2003 that the Goose Creek gage was representative. The period of record used in this study for the Goose Creek gage was from January 1930 through December 2016. The gage data at the Goose Creek gage was transferred to the reservoir intake location using the following equation:

$$Q_{intake} = Q_{gage} \times (\text{intake drainage area/gage drainage area})$$

The drainage area for the Aquia Creek stream gage (01660400) upstream of Smith Lake is approximately 35 square miles which includes the drainage area for Lunga Reservoir (12 square miles). A 1991 study identifies that releases (constant 0.75 mgd) from storage in Lunga Reservoir during dry periods could increase the safe yield of Smith Lake. It is assumed that Lunga Reservoir would remain full during a critical drought event and consequently, its drainage area is included in the Smith Lake drainage area. For this study, a drainage area of 47 square miles was used for Smith Lake.

Reservoir elevation-surface area-storage relationship

The reservoir elevation-surface area-storage characteristics were based on limited data obtained from previous studies (*Comprehensive Water Supply Study, O'Brien & Gere, 1991*). For Smith Lake, the 1991 study identified that increasing the height of Smith Lake Dam by 20 feet would increase the usable storage volume by 1,100 MG. Dead storage requirements (sediment storage and poor water quality in lower strata) of 25% of existing total storage (900 MG) plus 10% of expanded storage capacity (1,100 MG). The dead storage volume identified in the 1991 study for the increased Aquia Dam elevation was 350 MG.

Yield and demand factors

The hydrologic model used to compute the safe yield accounts for daily fluctuations in demand. The daily demand factors used in the 2003 study were used in the 2018 work. The daily demand factors were based on actual daily production data compiled for the Rivanna Water & Sewer Authority's water system, and are considered to be representative of Stafford County's demand factors for this planning study. A demand factor was computed for each day of the year by dividing the actual production for that day by the average annual production. These demand factors were multiplied by the County's projected average day demand to obtain daily water demands.

Reservoir Release

The amount of water released from Smith Lake is based on the available storage capacity. The reservoir release requirements are established by regulatory agencies and represent the flow that is required to remain in the stream for protection of aquatic habitat, wasteload assimilation and other

uses. In this study, the reservoir releases or flowby used to calculate the safe yield for Smith Lake are shown in Table 4.2.2.

Table 4.2.2 – Smith Lake Release Requirements

Date	Water Supply Storage in Smith Lake	Release Requirement from Smith Lake
March 1st to May 31st	Greater than or equal to 80% full	At least equal to 40% of the mean annual flow or natural inflow whichever is less
March 1st to May 31st	Less than 80% full	At least equal to 20% of the mean annual flow or natural inflow whichever is less
June 1st to February 29th	Greater than or equal to 80% full	At least equal to 20% of the mean annual flow or natural inflow whichever is less
June 1st to February 29th	Less than 80% full, but greater than 60% full	At least equal to 15% of the mean annual flow or natural inflow whichever is less
June 1st to February 29th	Less than 60% full, but greater than 40% full	At least equal to 7.5% of the mean annual flow or natural inflow whichever is less
June 1st to February 29th	Less than 40% full, but greater than 60% full	At least 0.7 mgd or natural inflow whichever is less

4.2.3 Modeling Results

As part to this Water and Sewer Master Plan, hydrologic modeling was performed to estimate the existing safe yield for Smith Lake. The safe yield for Smith Lake (1,775 MG) is approximately 5.1 mgd based on the period of record from 1930 through 2016. For this study, 5.1 mgd is used as the safe yield of Smith Lake based on the 1930's critical drought. The combined safe yield of Smith Lake and Lake Mooney is approximately 17 mgd based on the period of record which includes the 1930's drought.

4.3 SUSTAINABLE YIELD OF EXISTING RAW WATER SUPPLY SYSTEM

The adequacy of drinking water supply sources to reliably meet water demands is based on safe yield which is the amount of water that the supply can safely provide, even during a critical drought. In Virginia, the adequacy of surface water supplies with storage reservoirs is based upon the most severe drought since 1930. The safe yield of Lake Mooney and Smith Lake Reservoirs are shown in Table 4.3.1.

Table 4.3.1 – Safe Yield

Source	Safe Yield (mgd)

Lake Mooney	11.9
Smith Lake	5.1
Total	17.0

OBG obtained the safe yield for Lake Mooney Reservoir (11.9 mgd) from the County. The safe yield for Smith Lake Reservoir (5.1 mgd) was computed by OBG based on the following:

- Useable water storage volume in Smith Lake is 1,775 MG with 60 days of storage held in reserve (DEQ requirement).
- Minimum release requirements from Smith Lake were obtained from DEQ permit for Smith Lake WTP.
- Assumes a continuous release of 0.75 mgd from Lunga Reservoir (Quantico Marine Corps Base) upstream of Smith Lake. Stafford's current contract with the Quantico Marine Corps Base requires that they provide water for treatment by releasing water from the Lunga Reservoir. The Lunga Reservoir has the potential to provide the additional water that Quantico may request in the future. A contract amendment to provide the Marine Corps Base with water above the current 0.75 mgd allocation should include a requirement that the Marine Corps Base release additional water from the Lunga Reservoir to provide the water supply.
- Assumes unrestricted average day water demands (i.e., no customer water use restrictions in effect).
- A daily mass balance model was used to compute yield based on daily streamflow data from January 1, 1930 through December 27, 2016.
- The critical drought of record for Smith Lake occurred in the 1930's.

The centerpieces of DPW's raw water supply system are its reservoirs – Lake Mooney and Smith Lake. In order to use these reservoirs, DPW must maintain reservoir intakes and raw water pipelines to deliver raw water from the reservoirs to the WTPs. Each of these components is critical to the operation of the raw water supply system, and the limitations of each are factors in planning for future needs.

In 2010 through 2011, an emergency water interconnection between Stafford County and Spotsylvania County was investigated in the vicinity of the Lake Mooney WTP and the Motts Run WTP. This interconnection was further evaluated during this Master Plan and would enable the transfer of treated water from one locality to the other at up to 5 to 10 mgd. This project would greatly increase Stafford County's capability to transfer treated water to or from Spotsylvania County on an emergency basis and will enhance reliability to each locality's water system. The localities are currently limited to a transfer capacity of approximately 1.5 mgd through the existing Chatham and Falmouth interconnection with the City of Fredericksburg. At the time the project was developed in 2011, Stafford and Spotsylvania were each expected to cover 40% of the project cost and Fredericksburg was expected to cover the remaining 20% of the cost. Stafford County portion (40%) of the overall cost of the regional interconnection is approximately $6 million. The cost sharing arrangement may be revisited if the interconnection project is implemented.

4.4 RAW WATER SUPPLY IMPROVEMENTS

4.4.1 Need for Additional Water Supply

The sustainable yield of the existing raw water system is primarily limited by the available storage in the Lake Mooney and Smith Lake Reservoirs. Under anticipated growth rates, the existing raw water supply is expected to meet Stafford's raw water needs until roughly 2045, when the anticipated average day demand of 17 mgd will exceed the safe yield of the existing reservoirs. The community will then become increasingly vulnerable to drought-related water shortages, but the timing and degree of that risk will depend on the rate of growth in demand. Managing those demands and providing additional water supply capacity will reduce risks.

Existing supplies are expected to meet the County's needs through 2045, but numerous factors could cause DPW's water supply to fall short of what is required. These factors may include, but are not limited to, the following:

- Further revisions to the safe yield calculations.
- A drought more severe than the critical drought could occur.
- Residential population or employment increases could exceed projected estimates.
- Water conservation programs could fall short of their goals or per capita demand could exceed the projections.
- Quantico Marine Corps Base could request more water than projected.
- A water intensive industry could locate in Stafford.
- Customer water use patterns could change.

4.4.2 Potential Additional Water Supply Sources

The average day buildout demand is projected to be 22.7 mgd. The available safe yield (17 mgd) is expected to be sufficient to meet water demands through about 2045. The County could consider the following options (at a minimum):

- Potomac River Intake (Unlimited).
- Rappahannock River Intake below Fall Line (Unlimited).
- Groundwater.
- Vulcan Quarry (3.2 mgd).
- Abel Lake Reservoir (4 mgd).
- Water recycling.

A brief description and summary of the advantages and disadvantages of each option follows.

- Potomac River Intake. A water intake on the Potomac River would provide an almost unlimited supply of water. However, a high degree of water treatment would have to be provided due to the salt content of the river during droughts, and this source is miles away from the County's existing water treatment and distribution system. As improvements in treatment technology (i.e., reverse osmosis membranes) are made and if the County growth expands towards the Potomac River, this option could become more viable in the future.
- Rappahannock River Intake below Fall Line. A water intake on the Rappahannock River below the Fall Line could provide an almost unlimited supply of water. The water could be treated at either a new water treatment facility adjacent to the intake or it could be pumped to the Lake Mooney Reservoir. Permitting issues exist under current regulatory agency requirements (including several wastewater treatment facilities that discharge to this section of the river). An unknown is the risk of high salt content during a drought.
- Groundwater. Groundwater from the Middle Potomac aquifer could be a viable option that would require multiple well fields spread out over a large area east of the existing service area. The amount of groundwater available could be limited by the groundwater concerns in the Coastal Plain

Aquifer (i.e., declining water levels, salt water intrusion, and subsidence and loss of storage). The area east of I-95 in Stafford County is located in Virginia's Groundwater Management Area (GWMA) that was established in 2014. The Eastern Virginia Groundwater Management Advisory Committee was established in 2015 and is developing, revising, and implementing a management strategy for groundwater in the Eastern Virginia Groundwater Management Area.

- Vulcan Quarry. This option considers construction of a pumping station at the quarry and a 12-inch or 16-inch bi-directional raw water main from the Vulcan Quarry along Garrisonville Road to Smith Lake WTP (3.5 miles). This configuration would allow the County to pump storage directly from the quarry to the WTP if Smith Lake Reservoir or raw water facilities were offline for maintenance or an emergency or if storage was needed during a drought. This storage would also likely not be subject to the release requirements downstream of Smith Lake if it was pumped directly to Smith Lake WTP. In addition, water could be pumped directly from Smith Lake through the proposed pipeline to the quarry when Smith Lake is full and spilling water downstream and the quarry needs to be refilled. There is a proffer for the Vulcan Quarry that requires the owner of the quarry to provide the quarry to the County in 2035. The owner and the County are currently discussing options to continue mining through 2055. Using the quarry as supplemental storage for Smith Lake could increase the safe yield by about 3.2 mgd assuming 2 BG of storage in the quarry. The cost is estimated at approximately $5 million for raw water pumping station and 16-inch raw water main from Vulcan Quarry to Smith Lake WTP. This option has the advantage of being close to the existing customer water demands and the Smith Lake Water Treatment Plant.
- Abel Lake. This option considers transferring raw water from Abel Lake through a 16-inch raw water main directly to the Lake Mooney WTP (approximately 6 miles). For Abel Lake, the 1991 study identified that the usable storage volume was estimated to be 1,140 MG and dead storage is approximately 25% of the existing total storage (1,512 MG) or 370 MG. The safe yield for Abel Lake based on the period of record (1/1/30 – 12/27/16) and 60 days of reserve storage is approximately 4 mgd. Water from Abel Lake could be used to supplement yields from Lake Mooney Reservoir during drought conditions or if the County has Lake Mooney raw water facilities offline for maintenance. Pumping water directly from Abel Lake to Lake Mooney WTP would likely mean that this storage would not be subject to the release requirements downstream of Lake Mooney and would not impact the ability to withdraw water from the Rappahannock River to refill Lake Mooney during drought conditions. The cost is approximately $5.8 million for Abel Lake Dam upgrades, which are currently in design, and $8.7 million for raw water pumping station and 16-inch raw water main from Abel Lake to Lake Mooney WTP.

- Water Recycling. As technologies continue to improve, the recycling of treated wastewater for use as a water supply source becomes more feasible. For example, discharges from the Aquia Wastewater Treatment Facility could be treated with advanced technology, such as membranes, and pumped to Smith Lake Reservoir (roughly 3 miles). Again, current Virginia Department of Health regulations would not allow this practice. This may change in the future due to advancements in treatment and additional research into the recycling of wastewater flows.

4.5 RESERVOIR WATER QUALITY

The County's water comes from Lake Mooney and Smith Lake Reservoirs. As water passes over land and through the ground toward the reservoirs, it may dissolve minerals and pick up substances resulting from the presence of animals or from human activity. By the time it gets to the reservoirs, it may contain microbial contaminants, such as viruses and bacteria, which may come from sewage treatment plants, septic systems, agricultural livestock operations, storm water runoff, industrial or domestic wastewater discharges, and other sources. To ensure that tap water is safe to drink, EPA

prescribes regulations that limit the amount of certain contaminants in water provided to public water systems.

In 2002, the Virginia Department of Health (VDH) conducted an assessment of Smith Lake Reservoir to determine how susceptible it is to contamination. An assessment of Lake Mooney and the Rappahannock River has not yet been completed by VDH. Since there are industrial, commercial, agricultural and residential land uses in the watersheds for both reservoir and these reservoirs are open to the environment, they are considered to be susceptible to contamination.

Through a combination of source water protection and treatment technology, Stafford is committed to multiple-barrier practices of ensuring drinking water quality. Stafford's source water protection efforts include a variety of techniques and programs to keep pollutants out of the water supply reservoirs.

4.6 KEY FINDINGS

- The existing raw water reservoirs have enough storage capacity to provide a combined safe yield of approximately 17 mgd (11.9 mgd for Lake Mooney and 5.1 mgd for Smith Lake) based on the critical drought of record.
- The current raw water system's safe yield (17 mgd) will satisfy projected customer demands through approximately 2045.
- When the County's demands exceed the safe yield of 17 mgd, there are several water supply options that may be viable to meet the County's projected water demands through buildout. The most promising water supply options include the following:
  - Approximately $8.7 million for raw water pumping station and 16-inch raw water main from Abel Lake to Lake Mooney WTP.
  - Approximately $5 million for raw water pumping station and 16-inch raw water main from Vulcan Quarry to Smith Lake WTP.
- The cost for the raw water supply improvements presented in this Master Plan in the near-term (FY2019 - FY2028) is approximately $12 million. This cost includes the following:
  - $6 million for Abel Lake Dam upgrades.
  - $6 million for the regional interconnection between Stafford County and Spotsylvania County.
- The County is budgeting an additional $9 million to cover the cost for development of the Abel Lake option to meet long-term needs (beyond 2045).
- The overall cost for the raw water supply improvements presented in this Master Plan through the buildout condition is approximately $21 million.

4.7 PLAN OF ACTION

- DPW will continue to investigate methods to reduce the per capita use of water.
- DPW will continue to investigate long-term water supply options.
- DPW will continue to monitor and safeguard water quality in the water supply reservoirs.
- DPW will continue the commitment to multiple-barrier practices for ensuring drinking water quality.

4.8 RECOMMENDED WATER SYSTEM IMPROVEMENTS

AL-001: Abel Lake Dam Upgrades

Abel Lake was until recently one of two sources of raw water used by DPW. Water from Abel Lake was treated at the Abel Lake WTP. The Abel Lake WTP was decommissioned when Lake Mooney WTP went into operation in December 2014. The yield from Abel Lake will be needed to meet buildout water demand projections, and as a result, DPW plans to retain this asset. The dam that creates Abel Lake is does not comply with current dam safety design standards. This project includes improvements to the dam such that it is compliant with current standards. Consulting engineers were engaged in 2017 to assess alternatives for the dam upgrades, and the costs shown here may be revised based on the outcome of the ongoing evaluation. Construction is expected to be deferred, if possible, to FY2023 while external funding sources are explored.

Priority	*2 - Necessary (for capacity to meet buildout water demands)*
Design	*FY2023*
Construct	*FY2023*
Total Project Cost	*$6,000,000*

RWI - 001: Regional Water Supply Interconnection

This project involves an emergency water interconnection with Spotsylvania County in the vicinity of the Rocky Pen Run Water Treatment Facility and the Motts Run Water Treatment Facility. This will enable the transfer of treated water from one locality to the other at up to 5 to 10 MGD. Stafford and Spotsylvania are expected to each cover 40% of the total project cost, and Fredericksburg is expected to cover the remaining 20% of the cost. This CIP project is for Stafford's 40% of the total cost. The project will greatly increase the County's capability to transfer treated water to or from Spotsylvania on an emergency basis and will enhance the reliability of each locality's water distribution system. The County is currently limited to a transfer capacity of approximately 1.5 mgd through the existing Chatham and Falmouth interconnections with the City of Fredericksburg.

Priority	*2 - Necessary (reliability)*
Design	*FY2023*
Construct	*FY2024*
Total Project Cost	*$6,000,000*

AL-001: Abel Lake Raw Water Transfer to Lake Mooney

Abel Lake was until recently one of two sources of raw water used by DPW. Water from Abel Lake was treated at the Abel Lake WTP. The Abel Lake WTP was decommissioned when Lake Mooney WTP went into operation in December 2014. The yield from Abel Lake will be needed to meet buildout water demand projections, and as a result, DPW plans to retain this asset. This project includes construction of a new raw water pumping station at Abel Lake and a new 16-inch raw water main from Abel Lake to Lake Mooney WTP (approximately 5.5 miles).

Priority	*2 - Necessary (for capacity to meet buildout water demands)*
Design	*Beyond FY2028*

Construct	*Beyond FY2028*
Total Project Cost	*$9,000,000*