City of Petersburg, WV Wastewater Plant,
A unique low O&M cost facility for nutrient reduction

First presented at WEFTEC 2005
Washington, DC
November 1, 2005
Session 45, 8:30 a.m.
CITY OF PETERSBURG, WV WASTEWATER PLANT, A UNIQUE LOW O&M COST FACILITY FOR NUTRIENT REDUCTION
Petersburg, Virginia

ABSTRACT
The City of Petersburg 1.35 MGD capacity wastewater treatment plant discharges to the Potomac River system draining to the Chesapeake Bay. The Bay is deteriorating from excessive nutrient discharges from both point (wastewater plants) and non-point (runoff) sources. The states that drain to the Bay have signed an agreement to reduce the nutrient discharges to stop and reverse its deterioration. This will result in more stringent discharge requirements for point sources, requiring costly and complicated nutrient reduction facilities. Small and remote communities such as Petersburg have insufficient resources to construct and operate complex wastewater plants. This paper will present the case history of the Petersburg wastewater plant, a unique configuration of the oxidation ditch, which has demonstrated nutrient reduction potential without further significant capital improvements or addition of costly chemicals.

INTRODUCTION
The City of Petersburg, West Virginia is a small community (approximately 3,500 population) located in the central eastern portion of the state in the drainage area of the Chesapeake Bay (see Figure 1). In order to protect and revive the Bay, the states that drain to it have agreed to reduce nitrogen and phosphorus loads from land runoff and wastewater plant discharges. For example, the West Virginia draft Potomac tributary strategy calls for treatment plants above 0.4 MGD capacity to reduce annual average discharge of total nitrogen (TN) and total phosphorus (TP) to 5.0 MG/L and 0.5 MG/L, respectively, by year 2010. Plants below 0.4 MGD capacity are to achieve annual average discharges of TN of 8.0 MG/L and TP of 1.0 MG/L by 2010.
The South Branch of the Potomac River, the stream to which the Petersburg plant discharges, is deteriorating from increasing nitrogen and phosphorus loading. This increased nutrient load comes from both point (wastewater plants) and non-point sources (runoff from poultry and other agriculture operations). It is clear that pressures from deterioration of the Chesapeake Bay and the local eastern West Virginia Bay drainage streams will require small communities of this region to implement wastewater plants that can meet ever more stringent nutrient removal requirements. Yet, small remote communities such as the City of Petersburg, West Virginia, typically have insufficient resources to construct and operate complex wastewater treatment facilities. These facilities must be efficient and cost-effective to be affordable. This paper presents the story of such a facility.

**FACILITY HISTORY**

Figure 2 is an aerial view of Petersburg which also indicates the location of the wastewater plant. The City and the plant are protected from flooding by a US Corps of Engineers levee constructed in the late 1990s. The plant was originally designed and implemented by Dewberry for the City in 1987 as a 0.6 MGD capacity facility. By 1997, the average daily flow to the plant exceeded the permitted capacity of 0.6 MGD due to population growth and infiltration, inflow (I/I). The City again retained Dewberry to develop a wastewater facilities plan to evaluate the existing collection system, determine the need for additional treatment capacity, evaluate alternative treatment methodologies, and recommend improvements to provide the additional capacity. The plant, despite it being hydraulically and biologically overloaded, continued to meet discharge requirements except in the area of flow. In 1998, Dewberry aided the City in petitioning the West Virginia Division of Environmental Protection to obtain an interim permitted discharge flow increase to 0.95 MGD until the plant could be expanded and upgraded.

The evaluation of Petersburg’s wastewater facilities included mapping the entire sewage collection system and performing a sanitary sewer evaluation survey (SSES) with an infiltration/inflow analysis. Based on this information, collection system improvements were recommended. Determining the need for additional capacity at the treatment facility was based on the study of the anticipated population growth and associated flows and the anticipated future waste load allocation of the receiving stream. With this information it was determined that a treatment plant capable of handling an average daily flow of 2.4 MGD was needed to meet the population projections. However, the facility plan also included the evaluation of the funds that were available. With the available funds, it was recommended that the treatment plant be expanded to an average daily flow of 1.35 MGD, with capability to conveniently expand the facility to 1.8-MGD capacity by addition of a fourth oxidation ditch.

An evaluation of the treatment alternatives was performed to determine the best process to meet the discharge requirements. With this evaluation an oxidation ditch with integral clarifier was recommended, which was the same process as the existing system. A preliminary design of the required facilities was performed, and approval of the facilities plan was received in July 2000. Construction of the plant expansion and 9,100 LF of sewer were completed in late summer 2004.
The total cost of the project was approximately $5.6 million, of which $4.3 million was expended for the wastewater plant and $1.3 million was required for collection system improvements to reduce infiltration, inflow (I/I). (The plant operators estimate that the collection system improvements have eliminated approximately 250,000 GPD of I/I.) A $990,000 grant was received from the US Economic Development Authority through the efforts of the WV Region 8 Planning District Commission to help fund the plant construction project. The remainder of the $5.56 million was financed through a loan from the state revolving fund (SRF).

Figure 2 - Aerial View of Petersburg, WV Showing Plant Location
TREATMENT FACILITY FEATURES

Figure 3, an aerial view of the treatment plant upgraded and expanded as of September, 2004, includes a numbered legend indicating the location of all major treatment units. The plant consists of an influent pumping station, a mechanical fine screen, a vortex type grit removal unit, two flow splitter boxes, three oxidation ditches (each with integral clarifier), an ultraviolet (UV) disinfection unit, gravity outfall to Lunice Creek, and a high water plant effluent pumping station and force main. Sludge handling facilities consist of three aerobic digesters and a dewatering building with one belt filter press. The plant also has a small building that contains the plant electrical service and influent pumping station controls, a maintenance building, an equipment storage building, and an operations building that houses an office, laboratory, and standby generator. Dewatered sludge cake is hauled to a landfill for disposal.

Aeration for the oxidation ditches is provided by four 60 HP rotary vane centrifugal blowers, each rated at 956 CFM. The blowers are on a manifold, and three blowers provide the designed maximum quantity of air while the fourth acts as a standby. Aeration for the aerobic digesters is by submersible pump aspirating aerator assemblies, one per tank.

Figure 3 - Aerial View with Location of Major Treatment Units
The Petersburg wastewater plant incorporates a unique configuration of an oxidation ditch. This configuration makes use of radial plug flow propelled by two submerged, variable speed horizontal banana blade mixers per tank (see Figure 4). The influent flow is added to each concrete ditch at a series of step feed points.

Figure 4 – Partially Submerged Variable Speed Horizontal Banana Blade Mixers

Further, each concrete tank makes use of fine bubble aeration diffusers (see Figure 5) and an integral clarifier located at the tank center. The integral clarifier in each unit is composed of inclined baffles and plates which return sludge to the treatment process without return sludge pumping (see Figure 6).

Figure 5 - Fine Bubble Diffusers in Oxidation Ditch No. 1
Figure 6 – Oxidation Ditch Sections

Integral Clarifier Section
Not to Scale

Effluent Control Weir
One Required for Each Pipe

Future Aeration Basin

Submerged Effluent
Launder Pipes

Influent Trough

Baffles

Diffuser

Basin Section
Not to Scale
The clarifier effluent weirs are submerged pipes with strategically placed effluent orifices for prevention of short circuiting (see Figure 7). Waste sludge is drawn hydraulically to waste sump areas where it is pumped to aerobic digesters. Scum is also removed from the clarifiers to the waste sump areas by telescoping valves and gravity flow (see Figure 8).

Figure 7 - Submerged Pipe Effluent Weirs with Strategically Placed Orifices
(Shown Dewatered) Oxidation Ditch No. 1

Figure 8 - Typical Scum Removal Telescoping Valve and Submerged Pipe Effluent Weir
Mixed liquor solids tend to accumulate on the inclined baffles and plates of the oxidation ditch integral clarifier. These solids are removed and placed back into suspension by periodically (normally twice weekly) closing off influent flow to each of the three ditches in turn and cranking up their banana blade mixers to full speed for 15 to 20 minutes. The plant operators call this operation, “blowing out the ditch.”

Figure 9 shows the plan view flow paths of the three oxidation ditches. Table 1 provides their nominal dimensions and design hydraulic loadings. This unique oxidation ditch configuration has the ability to pass peak hydraulic wet weather events, much the same as can be done with sequence batch reactors. This is accomplished by turning off the submerged banana blade mixers until high flows abate. This action, plus the efficiency of the integral clarifiers, is able to keep the mixed liquor suspended solids in the plant, rather than losing them over the plant effluent weirs during wet weather, high flow events.

Table 1 – Nominal Dimensions and Hydraulic Loadings of Oxidation Ditches 1, 2, and 3

|Nominal Length| 125 ft. |
|Nominal Width| 32 feet |
|Nominal Depth| 10 feet |
|Volume Each| 300,000 gallons |
|Total Hydraulic Detention @ 1.35 MGD Average Daily Flow (ADF)| 16 hours |

Integral Clarifier:
- Dimensions: 57 x 16 feet
- Surface Area: 912 square feet
- Surface Loading Rate at 1.35 MGD ADF: 1,480 gpd/sq. ft.

1 Ditches 1, 2, and 3 are identical except 1 and 2 have rounded ends (see Figure 9)
Figure 9 – Schematic
Plan View and Flow Paths for Oxidation Ditches No. 1, 2, and 3

LEGEND:

1. Step Feed Influent Trough
2. Banana Blade Mixers
3. Integral Clarifier
4. Effluent Channel
The plant is located on the main road approach from the east into the City, and is in close proximity to local businesses. For example, Figure 10 shows a Pizza Hut restaurant located directly across the street from oxidation ditch number 3. Odors have not been a problem at this facility, as the wastewater arrives quickly from the community and is very fresh. The plant utilizes all aerobic processes and the operational staff takes pride in practicing meticulous housekeeping. As a result, the facility is the destination of many school class tours for teaching students about water environment protection.

Figure 10 - Close Proximity of Pizza Hut Restaurant Across Rt. 55 from Oxidation Ditch No. 3
Table 2 presents the design influent flow and wastewater characteristics and required discharge limits. The influent wastewater generated by Petersburg has gotten stronger over the years. The initial secondary plant constructed in 1987 was designed for 200 MG/L BOD₅ strength wastewater. Despite on-going I/I flow, the wastewater strength increased to the 300 MG/L BOD₅ range by the late 1990’s, primarily due to the discharge from a chicken parts packaging plant. The 1.35 MGD plant was subsequently designed for influent wastewater of 300 MG/L BOD₅ and suspended solids, and 25 MG/L of ammonia. The chicken part packaging plant has since ceased operation, but the influent wastewater has remained in the 300 MG/L BOD₅ range.

<table>
<thead>
<tr>
<th></th>
<th>Average Daily Flow</th>
<th>1.35 MGD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Peak Daily Flow</td>
<td>3.37 MGD</td>
</tr>
<tr>
<td>Influent BOD₅</td>
<td>300 MG/L</td>
<td>3,400 lbs/day</td>
</tr>
<tr>
<td>Influent SS</td>
<td>300 MG/L</td>
<td>3,400 lbs/day</td>
</tr>
<tr>
<td>Influent NH₃-N</td>
<td>25 MG/L</td>
<td>280 lbs/day</td>
</tr>
<tr>
<td>Effluent BOD₅ (≤30 MG/L)</td>
<td></td>
<td>337 lbs/day</td>
</tr>
<tr>
<td>Effluent SS (≤30 MG/L)</td>
<td></td>
<td>337 lbs/day</td>
</tr>
<tr>
<td>Effluent NH₃-N (summer)</td>
<td>≤3 MG/L</td>
<td>33.8 lbs/day</td>
</tr>
<tr>
<td>Effluent NH₃-N (winter)</td>
<td>≤13 MG/L</td>
<td>146 lbs/day</td>
</tr>
</tbody>
</table>

¹ Ditches 1, 2, and 3 are identical except 1 and 2 have rounded ends (see Figure 9)

The City receives flow from a hospital and a nursing home, and has several restaurants, including at least three fast food establishments. The elimination of I/I has probably contributed significantly to maintaining the higher than normal strength of the influent wastewater. In addition, the City has contracted with Tucker County to accept and treat two 6,000 gallon tanker loads per day of landfill leachate. This leachate has tested at strengths in excess of 6,000 MG/L BOD₅, and has significantly increased the plant’s influent biological load since its acceptance for treatment initiated in January, 2005.
Table 3 presents a compilation of the actual operation and maintenance (O&M) costs per month for the Petersburg wastewater plant from January, 2004 through March, 2005, broken down by labor, electrical power, and chemical costs. During this 16 month period, the total average cost per month was $18,013, which equates to $937 per million gallons treated.

<table>
<thead>
<tr>
<th>Month</th>
<th>Labor</th>
<th>Power</th>
<th>Chemicals</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan-04</td>
<td>$13,847</td>
<td>$4,020</td>
<td>$1,131</td>
<td>$18,997</td>
</tr>
<tr>
<td>Feb-04</td>
<td>$10,762</td>
<td>$4,132</td>
<td>$402</td>
<td>$15,296</td>
</tr>
<tr>
<td>Mar-04</td>
<td>$14,018</td>
<td>$4,865</td>
<td>$738</td>
<td>$19,621</td>
</tr>
<tr>
<td>Apr-04</td>
<td>$16,413</td>
<td>$3,450</td>
<td>$952</td>
<td>$20,815</td>
</tr>
<tr>
<td>May-04</td>
<td>$12,333</td>
<td>$6,383</td>
<td>$642</td>
<td>$19,358</td>
</tr>
<tr>
<td>Jun-04</td>
<td>$12,195</td>
<td>$3,416</td>
<td>$0</td>
<td>$15,611</td>
</tr>
<tr>
<td>Jul-04</td>
<td>$10,632</td>
<td>$3,006</td>
<td>$1,047</td>
<td>$14,684</td>
</tr>
<tr>
<td>Aug-04</td>
<td>$11,398</td>
<td>$4,682</td>
<td>$637</td>
<td>$16,716</td>
</tr>
<tr>
<td>Sep-04</td>
<td>$11,398</td>
<td>$441</td>
<td>$372</td>
<td>$12,211</td>
</tr>
<tr>
<td>Oct-04</td>
<td>$17,828</td>
<td>$3,127</td>
<td>$372</td>
<td>$21,327</td>
</tr>
<tr>
<td>Nov-04</td>
<td>$11,718</td>
<td>$3,955</td>
<td>$372</td>
<td>$16,045</td>
</tr>
<tr>
<td>Dec-04</td>
<td>$9,692</td>
<td>$3,962</td>
<td>$372</td>
<td>$14,027</td>
</tr>
<tr>
<td>Jan-05</td>
<td>$12,452</td>
<td>$10,087</td>
<td>$0</td>
<td>$22,540</td>
</tr>
<tr>
<td>Feb-05</td>
<td>$11,134</td>
<td>$558</td>
<td>$507</td>
<td>$12,199</td>
</tr>
<tr>
<td>Mar-05</td>
<td>$14,804</td>
<td>$14,171</td>
<td>$1,772</td>
<td>$30,747</td>
</tr>
<tr>
<td>Average</td>
<td>$12,708</td>
<td>$4,684</td>
<td>$621</td>
<td>$18,013</td>
</tr>
</tbody>
</table>

NUTRIENT REMOVAL
The Petersburg wastewater plant was designed to meet the current two-tiered permit which requires average monthly ammonia discharge of 3.0 MG/L or less in the summer (May 1-October 31) and 13 MG/L or less in the winter (November 1-April 30). It was designed to convert ammonia to nitrate through the process of nitrification, but was not specifically designed for total nitrogen removal which requires denitrification following nitrification. Nor was the process designed for phosphorus removal. However, there are indications that this facility may be able to achieve significant nutrient removal, and perhaps even attain the draft tributary discharge limits of annual average TN of 5.0 MG/L and TP of 0.5 MG/L through alteration of operation procedures and minor facility improvements.

The plant was severely biologically overloaded before the third oxidation ditch was put into operation in late August, 2004. Despite the overloading, analysis of effluent samples showed that nitrification was maintained in all months in 2004 except February. Visual observations of the two existing overloaded oxidation ditches in July and August, 2004 indicated that considerable denitrification was also occurring. Nitrogen gas released during denitrification caused mixed liquor solids to come to the surfaces of the integral clarifiers and accumulate on their baffles. This necessitated more frequent “blowing out the ditches,” as previously described, as often as every other day. Under the overloaded conditions the operators also had difficulty maintaining dissolved oxygen (DO) levels throughout the day. Typically, dissolved oxygen (DO) levels would dip below 1.0 MG/L in the oxidation ditches for several hours during the afternoon.
Analysis of a plant effluent sample taken in early April 2004 showed total phosphorus (TP) content to be non-detectable. Furthermore, subsequent plant influent and effluent sample testing for TP content started in May 2004 also indicated that significant TP removals were being realized. In anticipation of eventual nutrient discharge limits resulting from the Chesapeake Bay program, Dewberry design engineers recommended that plant influent and effluent nitrogen as well as phosphorus content be monitored, at least once monthly to gather background data.

Figure 11 presents plant influent and effluent data from January 2004 through May 2005, the last month that data was available to include in the drafting of this paper. By the time nitrogen and phosphorus testing of the plant influent and effluent started, the plant expansion was completed and the facility was no longer biologically overloaded. DO levels were maintained above 2.0 MG/L at all times in the oxidation ditches, and the visual evidence of denitrification, such as floating mixed liquor suspended solids, was no longer evident. However, available data shown in Figure 11 shows significant TN removals occurred during the period from October 2004 through April 2005 despite the lack of visual evidence that it was occurring.

A program was formulated in late April, 2005 in an attempt to re-establish the conditions that appeared to enable denitrification the previous year. West Virginia Department of Environmental Protection (DEP) authorized expenditure of some of the remaining money in the Petersburg project state revolving loan fund account to pay for increased nitrogen and phosphorus sampling and testing. The Dewberry design engineer and the plant superintendent, in consultation with the DEP project manager, reasoned that a favorable nitrification, denitrification environment might be re-established by reducing oxygen levels in the ditches to create anoxic conditions during at least part of a typical treatment day.

The first step taken was to increase mixed liquor solids from 3,000 to about 4,000 MG/L and reduce the blower input as much as possible while maintaining satisfactory mixing. This was done by operating only one blower instead of two that had been on-line since the start up of the plant expansion in late August 2004. As a result, visual observations at the time of this writing indicate that denitrification activity has increased. Mixed liquor suspended solids have begun to rise and float on the surfaces of the integral clarifiers, as they had done during the summer of 2004 when it was apparent that significant denitrification was occurring. The operators have had to “blow out the ditches” at least 3 times weekly since shortly after the second blower was taken off line in late April.

The next step planned in the program to re-establish favorable denitrification conditions is to further reduce aeration through bleeding off air from the discharge of the single blower that is presently in operation. If this proves helpful, it will indicate that more sophisticated controls should eventually be implemented for the blowers to enable reducing aeration without wasting electrical power. Supposedly, these blower controls would be installed during the next plant upgrade, or when TN removal is required to satisfy the pending Potomac Tributary Strategy.
Figure 11a - Influent and Effluent BOD$_5$, SS & TP
January 2004 through May 2005

Legend:
- BOD$_5$ -
- SS -
- TP -
Figure 11b - Influent and Effluent Ammonia-N, TKN, & TN

Legend:
- Ammonia-N
- TKN
- TN
Cycling the blowers on and off is also under consideration for establishing anoxic conditions to encourage denitrification. However, there is a concern that this will lead to premature fouling of the fine bubble diffusers in the oxidation ditches. Discussions are underway with the diffuser manufacturer to determine if there are ways that the blowers can safely be cycled and avoid fouling, or if the facilities can be modified to enable this mode of operation.

Another method of creating anoxic conditions under consideration is to remove and cap off some diffusers in strategic locations in each oxidation ditch. There is concern that this could lead to mixing problems. If that proves to be the case, the existing banana blade mixers might have to be supplemented with mechanical mixers in these tank zones.

**DISCUSSION**

Recall that denitrifying bacteria under anoxic (absence of oxygen) conditions take oxygen from the nitrate molecules (NO₃) for synthesis. This releases nitrogen gas to the atmosphere, thus removing TN from the wastewater. Utilization of oxygen from the NO₃ molecule theoretically cuts energy costs since power does not have to be expended to diffuse air into the mixed liquor. However power does have to be used for mixing to keep the biological growth suspended.

The plant was severely overloaded until the expansion project was completed and put into operation in late August and early September, 2004. Under the overloaded conditions, the plant struggled to maintain acceptable dissolved oxygen levels in the oxidation ditches due to insufficient blower and diffuser capacity. Further, solids inventory was high in the ditches. Mixed liquor suspended solids were being maintained in the 4,000 to 5,000 MG/L range. This was necessary as the plant only had one aerobic digester unit in service, and it was difficult to properly treat and remove solids. These circumstances undoubtedly led to establishment of anoxic conditions in the tanks that enabled denitrification, and thus TN removal to occur.

Another important consideration is that the Petersburg influent wastewater is relatively strong, which provides sufficient carbon source to drive the nitrification, denitrification biological reactions toward completion.

**CONCLUSIONS**

This paper provided data documenting plant performance from September 2004 through May 2005, the time of drafting of this paper. Total operation and maintenance (O&M) costs as well as plant record data for influent and effluent BOD, SS, TP, and TN were also presented. During the stated 16 month period, plant O&M costs totaled $270,194, and a total of 288.47 million gallons were treated. Average monthly O&M cost was $18,013, and O&M cost per million gallons treated was $937. Energy savings are potentially available from oxygen recovery from breakdown of the NO₃ molecule during denitrification. However, to realize this energy savings, some means of turn-down will have to be implemented for the blowers. Or, the influent loading will have to sufficiently increase so that the output of a single blower will not be sufficient to maintain positive DO levels at least part of a typical day.
It is evident from review of Figure 11 that the influent wastewater got much stronger starting in January, 2005 with the initiation of accepting the Tucker County landfill leachate for treatment at the plant. For example, average monthly influent BOD\textsubscript{5} jumped from 238 MG/L in December, 2004 to 398 MG/L in January, 2005, and has remained over 400 MG/L since. The leachate has had little effect on TP loadings on the plant, but TN has increased dramatically from late 2004 to early 2005. In addition, one plant effluent sample tested at TKN (total Kjedahl nitrogen) of 4.42 MG/L while effluent ammonia has remained only at trace levels. This indicates that the 4.42 MG/L TKN value is probably mostly organic nitrogen, since TKN by definition is ammonia nitrogen plus organic nitrogen.

Organic nitrogen (refractory nitrogen) normally is not broken down by activated sludge processes, which leads to the probability that a limit of TN of 5.0 MG/L cannot be met if the influent wastewater has a high content of organic nitrogen. The landfill leachate is the prime suspect as the source of the high organic nitrogen loading, as will be determined by further testing.

Despite the increased BOD\textsubscript{5} and nitrogen loading from landfill leachate, the plant in 2005 so far has still been able to maintain TN removal efficiency between 60 and 80 percent. Further testing and evaluation of revised plant operational modes to encourage denitrification will continue through 2005.

ACKNOWLEDGEMENTS
The co-authors greatly appreciate the support and cooperation of the mayor, the Honorable Gary Michaels, and council and staff of the City of Petersburg, WV without which this project and paper would not have been possible. Special thanks is expressed to Councilman Bill Deadrick who served as the council point of contact with the project team and provided timely and effective leadership throughout the project. The efforts of Lori Crites of the City staff in assembling the operations and maintenance cost information presented in this paper are very much appreciated. The proactive actions and cooperation of Ken Dyche and Terry Lively and the staff of the West Virginia Region 8 Planning District Commission were vital to the success of the project. And finally, the leadership and support provided by Elbert Morton, PE of the WV Department of Environmental Protection greatly contributed to the success of the project and the development of this technical paper.

REFERENCES
Jay Landers, Treatment Plants in Chesapeake Bay Watershed Face Strict Nutrient Limits, Civil Engineering, March 2005.