
ANALYSIS AND SUSTAINABILITY OF FOUR CONSTRUCTED WATER FEATURES IN THE NATIONAL CAPITAL REGION OF THE NATIONAL PARK SERVICE



MERIDIAN HILL PARK ❖ WOMEN IN MILITARY SERVICE FOR AMERICA MEMORIAL
FRANKLIN DELANO ROOSEVELT MEMORIAL ❖ CHESAPEAKE & OHIO CANAL NHP

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Title page: NPS staff photo. *Franklin Delano Roosevelt Memorial, Room 4 Fountain, Washington, D.C. 2009.*

TABLE OF CONTENTS

LIST OF FIGURES	V
LIST OF TABLES	IX
ACRONYMS AND ABBREVIATIONS	XI
EXECUTIVE SUMMARY	XIII
ACKNOWLEDGMENTS	XIX

INTRODUCTION	1
---------------------	----------

1.1 Objectives and Approach	4
-----------------------------	---

METHODS AND APPROACH	7
-----------------------------	----------

Chapter 2: Methods and Approach

2.1 Site Selection	9
2.2 Site Visits	9
2.3 Interviews	10
2.4 Research Permits	10
2.5 Determination of Water Flow and Plumbing Layouts	10
2.6 Background Research and Literature Review	10
2.7 Visual Assessment	11
2.8 Photo Documentation	11
2.9 Water Sampling and Laboratory Testing	11
2.10 Nutrients Analysis	12
2.11 Solids and pH Analysis	12
2.12 Field Measurements	12
2.13 Fecal Coliform Analysis	13
2.14 Metals Analysis	13
2.15 Water Budget and Discharge Estimates	13
2.16 Estimation of Phosphorus Sources	15
2.17 Energy Use Estimation	18
2.18 Review of Water Treatment Technologies	19

WATER FEATURES	23
-----------------------	-----------

Chapter 3: Meridian Hill Park

3.1 Background	25
3.2 Methods	26
3.3 Results and Discussion	27
3.4 Conclusion	48

Chapter 4: The Women in Military Service for America Memorial

4.1	Background	49
4.2	Methods	50
4.3	Results and Discussion	51
4.4	Conclusion	63

Chapter 5: The Franklin Delano Roosevelt Memorial

5.1	Background	65
5.2	Methods	66
5.3	Results and Discussion	68
5.4	Conclusion	88

**Chapter 6. Chesapeake and Ohio (CHOH) Canal Historic Park –
Cumberland Terminus Basin**

6.1	Background	91
6.2	Methods	91
6.3	Results and Discussion	93
6.4	Conclusion	109

TECHNOLOGIES & RECOMMENDATIONS 113**Chapter 7. Review of Technologies for Sustainable Water Management.**

7.1	Introduction	115
7.2	Biocides and Algaecides	116
7.3	Pressurized Sand Filters (PSFs)	129
7.4	Nutrient Input Reduction and Manipulation	135
7.5	Alternative Water Sources	143
7.6	Biological Manipulation	146
7.7	Conclusions	147

Chapter 8. Recommendations

8.1.	Technologies and practices to reduce or eliminate nutrients.	149
8.2.	Repair and Maintain Hydraulic Integrity	154
8.3.	Formation of a Water Features Workgroup	155
8.4.	Concluding Remarks	155

REFERENCES 159

Glossary of Terms

Bibliography

APPENDICES 179

Appendix A-1: Visual Study Record Sheet

Appendix A-2: CWF Troubleshooting Checklist

LIST OF FIGURES

Figure 1.1.	Typical flow pattern for National Park Service water features	2
Figure 2.1.	Diagram of annual water budget of a generic water feature	14
Figure 2.2.	Conceptual diagram of a Phosphorus Cycle in a CWF	16
Figure 3.1.	The cascades and lower reflecting pool at Meridian Hill Park	25
Figure 3.2.	Schematic flow diagram of the Meridian Hill Park water feature	28
Figure 3.3.	The 60-HP pump at Meridian Hill Park	30
Figure 3.4.	One of the sand filters in the pump room at Meridian Hill Park	30
Figure 3.5.	The screen filters in the pump room at Meridian Hill Park	30
Figure 3.6.	Foam accumulations in the upper reservoir on July 18, 2014	32
Figure 3.7.	Foam accumulations in the upper reservoir on August 14, 2014	32
Figure 3.8.	The reflecting pool at Meridian Hill Park	33
Figure 3.9.	The green color from algal growth	33
Figure 3.10.	Water temperature in the CWF at Meridian Hill	34
Figure 3.11.	Algae colonies in early stages of development	36
Figure 3.12.	TP levels for CWF water and source water	38
Figure 3.13.	PO_4^{3-} levels for CWF water and source water	38
Figure 3.14.	TN levels for CWF water and source water	38
Figure 3.15.	NH_3 levels for the CWF water and source water	39
Figure 3.16.	NO_3^- levels for the CWF water and source water	39
Figure 3.17.	Total Solids (TS) concentrations for CWF water and source water	40
Figure 3.18.	Total Suspended Solids (TSS) for CWF water and source water	40
Figure 3.19.	Volatile Suspended Solids (VSS) for CWF water and source water	41
Figure 3.20.	Total Dissolved Solids (TDS) for CWF water and source water	41
Figure 3.21.	Turbidity (NTUs) of CWF water at Meridian Hill Park	42
Figure 3.22.	The pH levels for CWF water and source water	43
Figure 3.23.	Dissolved oxygen levels for CWF water in Meridian Hill Park	43
Figure 3.24.	Annual water budget (m^3/yr) for Meridian Hill Park	44
Figure 3.25.	Phosphorus balance of Meridian Hill Park water feature	45
Figure 3.26.	Stains on the walls of the CWF	46
Figure 3.27.	Greenish staining, likely from biofilms and algal growth	47
Figure 3.28.	Blackish staining underneath the top fountain basin	47
Figure 4.1.	Women in Military Service for America Memorial and Fountain	49
Figure 4.2.	Schematic flow diagram of the WIMSA Water Feature	51
Figure 4.3.	The hemicycle fountain and narrow channel	52
Figure 4.4.	Channel connecting the hemicycle fountain to the reflecting pool	52
Figure 4.5.	Leakage along the sides of the reflecting pool	53
Figure 4.6.	The clogged sand filters in the pump room of the WIMSA CWF	54

Figure 4.7.	Foam collecting in the hemicycle fountain	55
Figure 4.8.	Clear water in the WIMSA Memorial reflecting pool	56
Figure 4.9.	Light green water and algae in the main reflecting pool	56
Figure 4.10.	Murky green water in the WIMSA Memorial reflecting pool	56
Figure 4.11.	Plant debris in the reflecting pool	57
Figure 4.12.	Plant debris collecting in the narrow channel	58
Figure 4.13.	Algae are difficult to clean between cobblestones	59
Figure 4.14.	Dragonfly larvae in the CWF at the WIMSA Memorial	59
Figure 4.15.	Annual water inputs and water losses at the WIMSA Memorial	61
Figure 4.16.	Phosphorus balance of WIMSA water feature	62
Figure 5.1.	The Room 4 Fountain at the FDR Memorial	65
Figure 5.2.	Schematic flow diagram for seven water features at FDR Memorial	69
Figure 5.3.	Pressurized Sand Filter assembly diagram taken from FDR	69
Figure 5.4.	Foam accumulation in a corner of the Room 2 Fountain	71
Figure 5.5.	Foam across the water surface in the Room 3 Fountain	71
Figure 5.6.	Foam accumulations during a period of green water at Room 1	71
Figure 5.7.	Foam clumps across the water surface in the Room 4 Fountain	72
Figure 5.8.	Green water in the Room 2 fountain	73
Figure 5.9.	Green water in the Room 3 Fountain	74
Figure 5.10.	Benthic algae covering the basin bottom in the Cortège fountain	76
Figure 5.11.	Algae attached to the basin structure in the Room 2 Fountain	76
Figure 5.12.	TP concentrations for CWF water and source water	78
Figure 5.13.	PO ₄ ³⁻ concentrations in CWF water and source water	78
Figure 5.14.	The Room 2 Fountain at the FDR Memorial being cleaned	78
Figure 5.15.	TN concentrations of the CWF water and source water	79
Figure 5.16.	NH ₃ concentrations of the CWF water and source water	80
Figure 5.17.	NO ₃ ⁻ concentrations of the CWF water and source water	80
Figure 5.18.	Total solids concentrations (mg/l) for CWF water and source	81
Figure 5.19.	Total suspended solids (mg/l) for CWF water and source water	82
Figure 5.20.	Volatile Suspended Solids for the CWF water and source water	83
Figure 5.21.	Total Dissolved Solids for the CWF water and source water	83
Figure 5.22.	pH for the FDR Memorial CWF water and source water	83
Figure 5.23.	Turbidity for the FDR Memorial CWF water and source water	84
Figure 5.24.	Annual water budget (m ³ /yr) for FDR Memorial	85
Figure 5.25.	Phosphorus inputs of FDR Memorial CWF during 2014	86
Figure 6.1.	The CHOH Canal Basin at the Terminus in Cumberland, MD	91
Figure 6.2.	Aerial view of the Cumberland Terminus Basin	92
Figure 6.3.	Overhead view of the Cumberland area	92
Figure 6.4.	Conceptual diagram of the CHOH Canal Basin system	95

Figure 6.5.	Water level in the CHOH Canal Basin	95
Figure 6.6.	Water level in the CHOH Canal Basin	95
Figure 6.7.	Thick mats of algae distributed across the water surface	96
Figure 6.8.	Floating algae collected in the corners of the basin	96
Figure 6.9.	Algal mats in the basin	96
Figure 6.10.	A snapping turtle along the shore of the basin	96
Figure 6.11.	Turbidity of CWF water and source water (Potomac River water)	97
Figure 6.12.	TP concentrations for CWF water and source water	99
Figure 6.13.	PO_4^{3-} concentrations for CWF water and source water	99
Figure 6.14.	TN concentrations for CWF water and source water	100
Figure 6.15.	NH_3 concentrations for CWF water and source water	100
Figure 6.16.	Dead fish in the Canal basin may have caused a spike in NH_3	100
Figure 6.17.	$\text{NO}_3\text{-N}$ concentrations for CWF water and source water	101
Figure 6.18.	Total solids concentrations for CWF water and source water	102
Figure 6.19.	Total dissolved solids for CWF water and source water	103
Figure 6.20.	Total suspended solids for CWF water and source water	103
Figure 6.21.	Volatile suspended solids for CWF water and source water	103
Figure 6.22.	pH levels for CWF water and source water	104
Figure 6.23.	Dissolved oxygen for CWF water and source water	104
Figure 6.24.	Water temperature for CWF water and source water	104
Figure 6.25.	Water budget (m^3/yr) for the Canal basin during leak scenario	105
Figure 6.26.	Water budget (m^3/yr) for the Canal basin in a no-leak scenario.	106
Figure 6.27.	Annual phosphorus inputs (g-TP/yr) for a leak scenario	107
Figure 6.28.	Annual phosphorus inputs (g-TP/yr) for a non-leak scenario	108
Figure 6.29.	Bird droppings along the walkways along the CHOH Canal basin	109
Figure 7.1.	Energy diagram of algal growth in a water feature	114
Figure 7.3.	Hypothetical PSF backwash curve over a five-day period	131
Figure 7.4.	Surface flow wetland diagram	137
Figure 7.5.	Sub-surface flow wetland diagram	137
Figure 7.6.	A small algal turf scrubber in use at an oyster aquaculture facility	141
Figure 7.7.	Sustainability ratings - water treatment technologies for CWFs	148
Figure 8.1	Possible wetland space shaded in blue for the FDR Memorial	150
Figure 8.2.	Wetland is shown shaded in blue at Meridian Hill Park	151
Figure 8.3.	Wetland is shown shaded in blue at the WIMSA Memorial	152
Figure 8.4.	Wetland is shown shaded in blue at the Canal Terminus Basin	153

LIST OF TABLES

Table 2.1.	Visual Assessment Parameters	11
Table 2.2.	Categories of Sustainability for CWF water treatment technologies	19
Table 3.1.	Water Sampling and Visual Observation Dates	26
Table 3.2.	The Water Feature Components at Meridian Hill Park	28
Table 3.3.	Foam coverage on the water surface of the Meridian Hill CWF	31
Table 3.4.	Water-color as observed at Meridian Hill Park	32
Table 3.5.	Odor rating and descriptions at Meridian Hill Park	34
Table 3.6.	Estimated plant debris coverage of the water surface	35
Table 3.7.	Litter counts and type in the CWFs at Meridian Hill Park	35
Table 3.8.	Algae Coverage and Type observed at Meridian Hill Park	36
Table 4.1.	Water Sampling and Visual Observation Dates	50
Table 4.2.	Foam coverage in the WIMSA CWF	55
Table 4.3.	Water-color in the WIMSA CWF	55
Table 4.4.	Odor ratings and descriptions of the WIMSA CWF	57
Table 4.5.	Plant debris coverage on the water surface of the WIMSA CWF	57
Table 4.6.	Algae Coverage in the WIMSA CWF	59
Table 4.7.	Nutrient concentrations for the CWF water at WIMSA	60
Table 4.8.	Solids concentrations for the CWF water at WIMSA	61
Table 5.1.	Water Sampling and Visual Observation Dates	67
Table 5.2.	Main Characteristics of the 7 CWFs at the FDR Memorial.	68
Table 5.3.	Foam coverage on water surface of the different CWFs at FDR	70
Table 5.4.	Water-color of the different CWFs at the FDR Memorial	73
Table 5.6.	Odor rating and description for the FDR CWFs	74
Table 5.5.	Coverage of Plant Debris on the water surface at FDR Memorial	75
Table 5.7.	Odor rating and description for the FDR CWFs	75
Table 5.8.	Counts (#) of Litter and Type in the FDR CWFs	76
Table 6.1.	Water Sampling and Visual Observation Dates	93
Table 6.2.	Percentage of water surface covered in algae	97
Table 6.3.	Water color observations during summer 2014	97
Table 6.4.	Odor ratings and descriptions for the CHOH Canal Basin	98
Table 6.5.	Plant debris coverage on water surface of the CHOH Canal Basin	98
Table 6.6.	Litter and descriptions at the CHOH Canal basin	98

ACRONYMS AND ABBREVIATIONS

CHOH	Chesapeake and Ohio
CWF	Constructed Water Feature
DO	Dissolved oxygen
EEDL	Ecological Engineering Design Lab
FDR	Franklin Delano Roosevelt
GWMP	George Washington Memorial Parkway
HP	Horse-power
mg/l	Milligrams per liter
NAMA	National Mall
NCR	National Capital Region
NPS	National Parks Service
NTU	Nephelometric turbidity units
P	Phosphorus
Pb	Lead
pH	Per hydrogen
RCP	Rock Creek Park
Spp	Species
TDS	Total dissolved solids
TN	Total Nitrogen
TP	Total phosphorus
TS	Total Solids
TSS	Total suspended solids
UMD	University of Maryland
UV	Ultra-violet
VSS	Volatile suspended solids
WIMSA	Women in Military Service for America

EXECUTIVE SUMMARY

The National Park Service (NPS) considers constructed water features (CWFs) to be built features and elements that use water for aesthetic, narrative and/or utilitarian purposes in the landscape. CWFs include fountains, ponds, reflecting pools, canals, cascades, and reservoirs. The NPS has over 300 of these CWFs located in park units across the United States, but the National Capital Region (NCR), which includes parks in the District of Columbia, Virginia, Maryland and West Virginia, has the largest number of CWFs of any NPS region. In recent years, many of these features have been plagued by ongoing nuisance algae blooms that turn the water a green color throughout the summer months. Responses to these issues have been inconsistent and in most cases have not been effective or only temporarily effective. There is a need within the NPS and the NCR in particular to review the present approach to water quality control in water features, assess the options for implementing more sustainable technologies, and develop systematic methods to manage and control of these issues.

During the fall of 2013, the NCR Water Feature Task Force (WFTF) was formed to investigate how NCR could improve the management of more than 30 CWFs located within the region. The Task Force, working through the Chesapeake Watershed Ecosystem Studies Unit (CW CESU), awarded a task agreement with the Ecosystem Engineering Design Lab at the University of Maryland (herein referred to as the UMD Team), directed by Dr. David Tilley in the Environmental Science & Technology Department at the University of Maryland to conduct an extensive study of NCR CWFs. The goal of this study was to assess four representative NCR CWF sites and their associated water quality, and to identify and review sustainable water treatment technologies and best management practices that show promise for maintaining water quality in CWFs, and rate these systems based on their sustainable attributes.

The WFTF selected four CWFs as representative samples of the various types of basins (e.g., concrete, stone, earthen), water sources (i.e., municipal water or river water), discharge practices (e.g., sanitary sewer, direct river outfall), and water management issues (e.g. leakage, algae blooms, malodors). The final list of CWFs was: Women in Military Service for America (WIMSA Memorial), part of the George Washington Memorial Parkway (GWMP), Chesapeake and Ohio (CHOH) Canal Terminus in Cumberland part of the CHOH Canal National Historical Park, Franklin D. Roosevelt (FDR) Memorial, part of the National Mall and Memo-

rial Parks (NAMA) and Meridian Hill Park, part of Rock Creek Park (ROCR). All systems selected had to be operating during the study period.

The UMD Team sampled four sites during the summer of 2014 to test the water quality from CWF water and source water, assess visual appearance, ascertain management practices, and understand the treatment systems and pumping equipment. The UMD Team analyzed water samples for phosphorus, nitrogen, pH, dissolved oxygen, temperature, and solids content from each site. The UMD Team used this data to develop mass balance models of water and phosphorus to determine the total amount and sources of water, and phosphorus inputs at each site. The UMD Team used direct observations and photographs to document the visual appearance, and interviewed staff to gather information about management practices and treatment system maintenance.

The team conducted a literature review of promising water treatment technologies that were assessed for their sustainability, hypothetical efficacy, and compatibility with the discharge regimes and infrastructure of CWFs. Sustainability was quantified by a simplified rating system that gave ratings for eight (8) relevant categories, and an overall composite score was calculated.

The results of the study indicate that algal blooms are re-occurring problems associated with the CWFs examined in this study and occur at all four of the sites. The CWF at Meridian Hill Park was dominated by suspended growth algae with turbid, green water during the entire study period. The FDR Memorial had blooms of attached algae and suspended algae at certain times. These blooms varied depending on the timing of intentional drainage and re-filling of the CWF. Likewise, the WIMSA Memorial displayed visual evidence of algal growth, but at other times the water was clear, due to intentional drainage to control algae blooms. The CHOH Canal Terminus Basin had large floating mats of algae the water surface, throughout the study period. All of the CWFs were often odorous, and aesthetically-impaired by the algae.

The FDR Memorial and Meridian Hill Park CWFs both had staining from salt and mineral deposits and biofilm growth of algae, molds, and bacteria in various locations along water lines or in splash zones. These stains can, over time, damage stone and other surfaces by promoting degradation and corrosion.

The results of the water quality analysis indicated that all of the features in the study were found to have excessive amounts of nitrogen and phosphorus. At Meridian Hill Park, The FDR Memorial, and the WIMSA Memorial, source water, drawn from the Washington Aqueduct System, was found to be loaded with

these nutrients and represented the largest source of nutrients in these CWFs. In contrast, the CHOH Canal Terminus Basin CWF did not draw from a municipal system but drew water directly from the Potomac River at Cumberland, MD. River water was found to have markedly lower concentrations of nutrients than source water in the DC area, but excessive water leakage from the basin led to overuse of river water and allowed the levels of phosphorus to accumulate in the CWF over time. Algal blooms at CHOH Canal Terminus Basin were caused by gradual build-up of phosphorus in sediments and vegetation over the decade that it has been in operation. The water leakage at CHOH Canal Terminus Basin was repaired in the spring of 2015 and it is expected that nutrient loading and water use has been reduced since this study was conducted in the summer of 2014.

Visual inspection by the UMD Team indicated that plant debris, including leaves, twigs, grass clippings, etc., is a regular maintenance issue. At CWFs in close proximity to vegetation, plant debris are blown into the water regularly, regardless of season. Plant debris frequently accumulate in CWFs at the FDR Memorial and alter their visual appearance. Plant debris can also contribute to nutrient concentrations, and alter water-color by leaching tannins and other decomposition by-products. Plant debris can also clog drains and filters, and damage pumps.

Due to age and, in some cases, inadequate maintenance, equipment failures were common at the CWFs studied in this report. The make-up water pumps at the CHOH Terminus Canal Basin failed, and the basin could not be refilled. The sand filters at the WIMSA were plugged due to lack of maintenance over a long period and sand filters at FDR did not appear to be functioning properly for similar reasons.

Based on the analysis of operation and water quality data for the four sites, this report puts forth three broad recommendations.

Firstly, the implementation of technologies that reduce nutrients loadings is recommended. Submerged surface constructed wetlands integrated into the landscape are the most sustainable treatment options for managing water quality in CWFs. Chemical treatment is not compatible with discharge regimes of many CWFs. Three of the four CWFs in this study discharge to natural water bodies when drained. This means that treatment options are limited to those that do not use harmful chemicals, but treat the underlying causes of algal blooms. In this regard, constructed wetlands ranked high in terms of suitability and sustainability. Constructed wetlands are artificial wetlands built for the purpose of treating wastewater, stormwater runoff, or other impaired water source. They have inherent design flexibility regarding size, shape, and plant composition, allowing

integration into existing and future park environments. Additionally most CWFs have strong attribute flows of waterfalls and fountains driven by large pumps. Existing pumps can be utilized to cycle water through a constructed wetland, thereby reducing the need for new pumps and increased energy use.

For earthen lined ponds and canals, P-capping agents are a promising technology that prevents the release of phosphorus from the sediment layer. The sediment layer along the bottom serves as a long-term store of phosphorus that can be internally cycled causing annual algae blooms. P-capping agents block the exchange of phosphorus between the sediment and the water column, thereby preventing algae from accessing it for growth. This technology is passive - it is administered, settles on the sediment layer, and remains in place without additional maintenance as long as nutrient inputs are reduced.

Another promising method of P-removal is the use of P-adsorbing material in existing pressurized sand filters, which appear to be standard for most CWFs. Materials high in Ca and/or Fe can bind phosphorus from the water column and render it inaccessible for algal growth. Although this approach is experimental, scientific studies have validated the concept (Arias and Brix, 2005; Sibrell et al., 2009; Vohla et al., 2011). Businesses have manufactured P-adsorbing media for constructed wetlands and other systems, for the purposes of P-removal. Exploring the use of P-adsorbing media in place of sand in pressurized sand filters is strongly recommended.

Both suspended algae and attached algae growth are a problem in most CWFs. Treatment technologies or chemicals that act to disinfect or kill algae in separate chambers will only reduce suspended algae growth, leaving attached algae and biofilms unharmed. Attached algae remain in place and do not pass through the CWF's treatment systems. Any treatment technology that kills or filters algae from a directed water flow, such as sand filters, UV disinfection units, and ozone generators, will have no effect on attached algae and are not recommended as a promising solution, unless coupled with a method of removing attached algae.

The second recommendation is to repair and maintain hydraulic integrity (i.e. repair and seal leaks whenever possible). Three of the four study sites had problems associated with water leaks. The WIMSA site had a large leak due to a gap in the bottom liner around the edge of the main basin. The Meridian Hill Park CWF had small leaks in piping and along the walls of the reflecting pool and the lower plaza cascade basin. The CHOH Canal Terminus Basin had a very large leak that drained water rapidly, but has since been repaired. Since source water often contains nutrients for algae growth, leaky CWFs will have higher nutrient inputs.

Without watertight basins, the design of any treatment system becomes nearly impossible because nutrient loads cannot be controlled. As such, CWFs with major leaks add to the maintenance burden of the dedicated park staff attempting to maintain clear water in the CWFs.

The final recommendation is to form a work group of individuals, both from within NPS and from without, to share knowledge, discuss problems and find solutions from across the Capital Region. Maintenance will be critical for any existing or future technology used at the CWFs. Any new technology will require its own maintenance and monitoring regime, as well as more frequent debris removal. Without sufficient manpower, training, and technical support, water quality problems and their associated maintenance issues are likely to continue even if new technologies are adopted. Pooling resources and expertise within NCR to address technical problems or developing management expertise could be an important element for insuring operational success. A yearly meeting with staff responsible for water features in the NCR units to discuss problems and solutions for features is a necessity. This insures that institutional knowledge is not lost or ignored in decision-making. Building partnerships through friend's groups, citizen scientists (reaching out to engineering societies), and CESU cooperators could be effective at improving overall maintenance and operation of new and existing technologies. Ultimately, supplying the resources for maintenance needs to be a priority for park planning and operation of constructed water features.

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INTRODUCTION

Section Title Image: Highsmith, C. M., photographer. *Women in the Military Service for America Memorial at Arlington National Cemetery, Arlington, Virginia*. [Between 1980 and 2006] [Image] Retrieved from the Library of Congress, <https://www.loc.gov/item/2011631514/>

INTRODUCTION

The National Park Service (NPS) considers constructed water features (CWFs) to be built features and elements that use water for aesthetic, narrative and/or utilitarian purposes in the landscape. Many designers take advantage of water's unique qualities to convey a story, stimulate internal reflection on historical events, and enhance the visitor experience at important cultural sites (Savage, 2009; Rainey, 2012). Many CWFs are used as story elements that symbolize important cultural and historical events, or form integral elements of a cultural landscape, and therefore greatly aid in the transfer of valuable information to the visitor.

CWFs include fountains, ponds, reflecting pools, canals, cascades, and reservoirs. While the NPS maintains culverts, fish ladders, bridges, weirs, check dams, and other such water features in natural settings, this report only refers to CWFs in the Capital Region at cultural sites. The NPS has over 300 of these CWFs located in park units across the United States. The National Capital Region (NCR), which includes parks in the District of Columbia, Virginia, Maryland and West Virginia, has the largest number of CWFs of any NPS region. These water features are located in some of the most visited parks in the country and are visible to both pedestrian and vehicular traffic. Many of the constructed water features are recognized historic landmarks operating for well over 50 years, while others have just started operation in the past several years, or are in the planning or construction phase. Some features are no longer in use because of their age, disrepair or difficulty associated with their maintenance and operation.

Building materials used for these features range from concrete and various types of stone, to metals such as bronze, stainless steel, or iron, and combinations of these. Some features consist of concrete basins and sophisticated plumbing systems, while others are earthen canals with or without synthetic liners. Treatment systems and/or chemicals used to maintain the CWF's water quality must be compatible with construction materials. Otherwise, staining, discoloration, pitting, corrosion, and dissolution problems could arise from incompatible treatment systems and chemical use.

Many water features are strictly intended to provide only a visual or auditory function that is devoid of biological activity. Other features support complex ecosystems that are functionally linked to the landscape. Some water features are

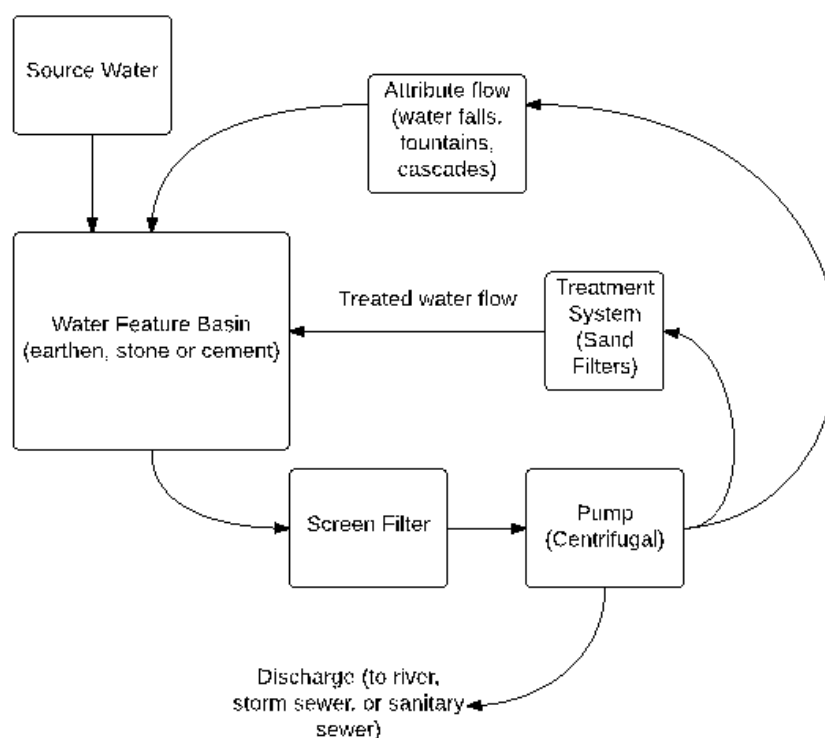


Figure 1.1. Typical Flow Pattern for National Park Service Water Features in the National Capital Region.

relatively closed to atmospheric inputs, drawing water only from the municipal supply. Other features are open to natural hydrological inputs like ground water, runoff, and rainfall.

Figure 1.1 shows the water flow from source water supply to ultimate discharge of typical CWFs presently operating in the NCR. Some of these feature designs incorporate treatment flow loops (sand filters, UV disinfection, or coarse screens). Some operate as flow-through systems where water flows in and out without any treatment. Some CWFs discharge to local water bodies, sewers, or receiving waters. Some are maintained by runoff or groundwater inflow.

Attribute flows, which consist of spray fountains, waterfalls, drop pools, channels, or gentle circulation with no noticeable flow at all, are important components of many water features because designers use them to create mood, or tell a story. Some CWFs do not include attribute flows and operate very much like natural water bodies, such as Constitution Gardens or many segments of the CHOH Canal. Understanding the CWF flow patterns, their contribution to narrative, and their relationship to the materials of construction is critical to sustaining and preserving these important cultural and historic sites for future generations.

Managing CWFs both for water quality and overall appearance under nearly constant public observation and scrutiny is a demanding challenge. CWFs pose

complex management challenges encompassing cultural and natural resources as well as regional planning and engineering and facilities and maintenance divisions. Unfortunately, many CWF designs are ideal for rapid algal and microbial growth with shallow basins of warm water and more than adequate exposure to indirect and direct sunlight conducive to suspended algal growth or highly wetted surface areas that allow molds, attached algae, and other microorganisms to flourish on various structures.

Harmful algal blooms (HABs) are a problematic phenomenon occurring in coastal zones and natural water bodies across the globe (Anderson et al, 2002; Gilbert et al, 2005). Algal blooms can be harmful due to the presence of toxic algae, or due to depletion of dissolved oxygen in the deeper, poorly mixed waters, that indiscriminately kill bottom dwelling organisms and force fish to flee. A recent toxic algal bloom in Lake Erie during the summer of 2014 disrupted the supply of drinking water to 500,000 local residents and made national headlines (Wines, 2014). Closer to the Capital Region, algal blooms in the Chesapeake Bay occur annually in the spring and cause damage to sensitive ecosystems and local fisheries.

CWFs may overtime develop leaks or cracks in the basins or piping, and may render basins and attribute flows inoperative or result in large water losses. Excessive leakage can also tarnish the visual appearance by creating puddles around the site and stains from minerals and salts left during evaporation on surfaces. Other hydraulic problems may develop. Fountain spouts and nozzles may clog, reducing flow and disrupting the narrative elements of the feature. Other critical practices that can negatively impact water features include: overspray from chemical pesticide and herbicide use, inputs of grass clippings and fertilizer applications from adjacent area maintenance, waterfowl, water borne pathogens, regulatory compliance for discharge waters, plant debris deposition, trash inputs, seasonal variations in storm events, tides, water table levels, precipitation, droughts, high temperatures, and freezing.

In all cases, successful management of a CWF requires an understanding of the design intent, site-specific objectives, structure, water supply, drainage or discharge, and mechanical systems. Currently, basic support information is either out of date or lacking in sufficient detail to provide guidance. The Park Landscape Maintenance Handbook for the National Capital Region last revised in 1990 (USDOI/NPS/NCR 1990) is the only reference for managing the Region's systems. This reference provides no information regarding water conservation, waste reduction, energy use, alternative energy sources, sustainability, green technology alternatives, or comprehensive information about specific sites in NCR. Beyond this, there are no guidelines for the sustainable management of water features

across the nation. A more comprehensive approach is needed to update and improve the management of CWFs leading to the development a service-wide guidance plan for Natural and Cultural Resource Managers, as well as Facility Maintenance and operations staff, for the permitting, maintenance, design, and operation of these structures.

1.1 OBJECTIVES AND APPROACH

The overall goal of this study is to assess and evaluate sustainable technologies and practices that could be implemented for existing CWFs in the NCR. This report is based on four selected NCR sites and forms a preliminary basis for the development of a comprehensive service-wide sustainable management plan for water features. In order to achieve this goal, four main tasks were conducted as outlined below.

TASK 1. FORMATION OF THE WATER FEATURE TASK FORCE

The NCR Water Feature Task Force (WFTF) was formed from NPS Staff in 2013. The WFTF, working through the Chesapeake Watershed Ecosystem Studies Unit (CW CESU), awarded a task agreement to the University of Maryland Team (UMD Team) from the Ecosystem Engineering Design Lab (EED Lab). The team was directed by Dr. David Tilley in the Environmental Science & Technology Department to collaborate on the development of this report. The WFTF along with the UMD Team developed a list of potential water feature sites, working definitions of sustainable technologies, and desired future conditions for sustainable CWFs in the NCR.

TASK 2. ASSESSMENT OF THE FOUR REPRESENTATIVE WATER FEATURE SITES

The UMD Team collected detailed information and scientific data about the selected sites through site visits, water sampling and analysis, visual observation, interviews with NPS staff, engineering and architectural plans, formal literature, and technical reports. The UMD Team developed flow diagrams, photo-documentation of the four sites, maintenance and operation schedules, energy use estimates, materials, flow rates, discharge estimates, chemical usage, age of water features, layout and plumbing systems, nutrient input estimates, plant litter estimates, and other pertinent information. CWF waters and source waters were sampled and analyzed for various water quality parameters (nitrogen and phosphorus species, solids content, temperature, pH, dissolved oxygen, and fecal coliform counts).

Task 3. Sustainable Technology Assessment and Analysis

The UMD Team assisted by the WFTF conducted a literature review and market research in order to evaluate possible sustainable water treatment technologies appropriate for CWFs.

TASK 4. RECOMMENDATIONS

Based on the goals and attributes identified by the WFTF in Task 1 and results from Tasks 2 and 3, the UMD team, working with the WFTF and CESU coordinator, provided recommendations for improving water quality and the visual quality of the four CWFs. These recommendations included promising technologies for water treatment and incorporated considerations for the environmental sustainability of the four sites.



METHODS AND APPROACH

Section Title Image: *Chesapeake and Ohio Canal Cumberland terminus turning basin (milepost 184.5), looking south.* July 20, 2013 [Image]
Retrieved from Wikipedia, https://en.wikipedia.org/wiki/Chesapeake_and_Ohio_Canal_National_Historical_Park#/media/File:Cumberland_Basin_looking_towards_Georgetown.jpg

CHAPTER 2: METHODS AND APPROACH

This section details how the site evaluations, sustainability assessments and technology analysis were conducted and which methods were used to collect information, take samples, and perform sample analysis.

2.1 SITE SELECTION

Through meetings held with the UMD Team and the WFTF, sites for the study were proposed and criteria developed for the ultimate selection of four sites. The major criteria were based on source water for the feature, materials of construction (e.g., earthen, concrete or stone), discharge receiving water body (e.g., sewer, river or other), operating status, and existing treatment technology. From a list of eight to ten sites considered, four sites were ultimately selected for the study. The final list of CWFs was: The Women in Military Service for America Memorial (GWMP), CHOH Canal Terminus in Cumberland (CHOH), the Franklin D. Roosevelt Memorial (NAMA), and Meridian Hill Park (ROCR). Contacts were developed and liaison NPS staff from the WFTF assigned to each site. These NPS staff members assisted with obtaining permits, coordinating various park contacts, arranging site visits, and informing park superintendents and other personnel of the progress and activities of the cooperator.

2.2 SITE VISITS

Once sites were confirmed collaborators scheduled site visits with site supervisors, site managers, the CESU coordinator, and the UMD Team. The WFTF and the UMD Team developed general guidelines for questions. The purpose of these initial visits was to familiarize the UMD Team and CESU coordinator with the sites, the current maintenance practices, and the general layout of the plumbing and CWF systems. During these visits, CESU coordinator and the UMD Team were given tours of the sites, CWFs including main plumbing systems and pump rooms, and the park grounds. Site managers provided basic information on the major management issues and problems, current management practices, and seasonal scheduling (i.e. when CWFs were filled at the beginning of the season and when they were drained at the end of the season). The UMD Team and CESU coordinator interviewed NPS staff to ascertain recent history of the CWF, environmental stressors, visitor-related stressors, and other related information. In addition site visits were conducted during July, August, and September during which the UMD

Team made visual observations and took water samples using procedures outlined below.

2.3 INTERVIEWS

Throughout the process, the UMD Team contacted relevant NPS staff for informal interviews to gain further insight into the management and technology issues of each site. These were conducted either via email, telephone, or in person as was practical. These informal interviews occurred between June and September of 2014. Interviews were followed up with one-day workshops with NPS staff at each site. These sessions presented findings and included questions and answer sessions. This also allowed clarification of details of operation and technology. These were held in the fall of 2014 for all sites except for WIMSA.

2.4 RESEARCH PERMITS

Research permits were required by all the Parks participating in the study and sampling could not begin until permits were finalized. The UMD Team submitted research permit applications for approval of water sample collection. Permits were submitted for approval in June 2014 and were received by July 5 for Meridian Hill Park and the CHOH Canal Terminus. Permits for WIMSA and the FDR Memorial were approved in September 2014.

2.5 DETERMINATION OF WATER FLOW AND PLUMBING LAYOUTS

In order to understand water flow and plumbing layouts, engineering plans and layouts were obtained by the UMD Team through site supervisors, the WFTF, or by obtaining them from the National Archives in College Park, MD. From these records, simple water flow diagrams were developed in order to better understand plumbing systems without extensive detail, such as the location of valves and backflow preventers. Discharge regimes for each site were confirmed by engineering drawings and site plans. When engineering drawings were not available, site tours with NPS staff served as a guide for developing water flow diagrams.

2.6 BACKGROUND RESEARCH AND LITERATURE REVIEW

The UMD Team reviewed literature from NPS reports, such as published books, and scientific journals. Since many of the features draw water from the municipal water supply in Washington, DC and surrounding area, a thorough review of reports on water quality and other issues pertaining to these municipal supplies were conducted.

2.7 VISUAL ASSESSMENT

The UMD Team developed a criterion for making visual observations of the CWFs during the study period. Qualitative measures were developed and rating scale determined using a standard form (provided in Appendix A-1) that was used to evaluate CWFs during sampling visits. Up to three members of UMD Team made independent observations that they wrote down before being averaged to make a single representative sample. Table 2.1 shows the parameters observed, the rating scale method used, and whether a written description was given for that parameter. During initial site visits and tours, the UMD Team observed visual indicators of poor water quality and other stressors and developed a systematic method for future observations.

Table 2.1. Visual Assessment Parameters

PARAMETERS OF OBSERVATION	MEASUREMENT SCALE	WRITTEN OBSERVATIONS?
Foam on Water Surface	% Coverage	No
Water Color	Descriptor	Yes
Odor	1-10 Rating	Yes
Plant Litter on Water Surface	% Coverage	No
Trash / Litter in CWFs	# of Trash Items	Yes
Algae Coverage on Water Surface or Basin Bottom	% Coverage	Yes

2.8 PHOTO DOCUMENTATION

During visual assessments, the UMD Team also photographed the CWFs from various locations, focusing on overall appearance, problem areas such as plant debris and trash build-up, algal blooms, foam build-up, and other occurrences of note. Photographs served as references for comparative analysis of the visual appearance of the water features.

2.9 WATER SAMPLING AND LABORATORY TESTING

Water samples were collected from CWFs during the scheduled site visits. In all cases, samples were taken in triplicate using water-sampling methods in accordance with standard methods (APHA, 2005). Where CWFs were composed of multiple basins or pools, such as at Meridian Hill Park and the FDR Memorial, sample locations were randomly determined based on their volumetric size.

Water samples were taken in triplicate. Half liter (0.5-l) Nalgene sample bottles were completely submerged and rinsed three times in CWF water before samples were taken. Sample bottles were completely submerged to eliminate headspace in

water samples. In cases where source water could not be accessed from a water basin, a 19-l plastic bucket was filled and rinsed 3 times. Once rinsed, it was filled completely and water samples were taken by submerging sample bottles completely to eliminate headspace. These samples were stored in a cooler with ice upon collection and during transport.

2.10 NUTRIENTS ANALYSIS

Water samples for nutrient analysis were stored in ice and express shipped to the University of Maryland Center for Environmental Science (UMCES) Appalachian Lab in Frostburg, MD within 48 hours of sampling. These samples were then filtered to suppress microbial action, and frozen for storage until analyzed. All methods of analysis followed procedures according to Standard Methods (APHA, 2005). Measurements of total nitrogen (TN), nitrate (NO_3^-), ammonia (NH_3), total phosphorus (TP), and orthophosphates (PO_4^{3-}) were taken from the samples.

2.11 SOLIDS AND PH ANALYSIS

Prior to sampling, lab equipment was prepared for pH and solids analysis. All the crucibles used for solids testing were cleaned and desiccated in order to achieve a constant weight. Vacuum pumps, apparatuses and filters were cleaned, dried, and assembled. The 1-l water samples were then taken to the Ecosystems Engineering Design Lab in College Park, MD within 4 hours of sampling. Solids analysis was completed within 24 hours of sampling using methods 2540 B for total solids (TS), 2540 C for total dissolved solids (TDS), 2540 D for total suspended solids (TSS) and 2540 E for volatile suspended solids from APHA (2005). The rest of the sample within the bottle was used to measure the pH of the water using a pH probe (Acumet, Fisher Scientific, Vernon Hills, IL, USA).

2.12 FIELD MEASUREMENTS

Water temperature, dissolved oxygen, and turbidity measurements were made in the field at each site. Water temperature and dissolved oxygen (DO) measurements were obtained by a DO probe (YSI Instruments, Yellow Springs, OH, USA). The probe was gently jostled underwater at 0.3 meters depth. When a reading became stable, DO and temperature were recorded. After each measurement, the probe was rinsed with deionized water. A turbidity meter (Hach, Loveland, CO, USA) was used to measure water clarity. Each sample bottle was rinsed three times before use. In order to get a clear measurement, the outside of the bottle was rinsed with deionized water before it was placed into the turbidity meter. Each of these tasks was completed in triplicate for each CWF and its source water.

2.13 FECAL COLIFORM ANALYSIS

At Meridian Hill Park and at the CHOH Canal Terminus Basin, a single triplicate sample was taken with a sterile sample bottle. This sample was put on ice and shipped to UMCES for microbial analysis using the multiple tube fermentation technique (APHA, 2005).

2.14 METALS ANALYSIS

Samples from the Cortège Fountain at the FDR Memorial (see Chapter 5) were analyzed for metals because of concern for corrosion of its metal plaque. Metals were analyzed using Standard Methods (APHA, 2005).

2.15 WATER BUDGET AND DISCHARGE ESTIMATES

In order to obtain water discharge estimates, a water budget analysis was conducted. Figure 2.1 shows the conceptual water budget model for a typical CWF.

Principal CWF inflows are represented by circles on the diagram. These inflows include source water from either the municipal water or nearby water bodies, overland flow, and precipitation. Since the CWFs observed in this study were composed of lined basins, it was assumed that significant groundwater flows were present and thus excluded from the water budget. Water outflows included evaporation, splashing losses, drainage¹, and leakage.

Based on the conservation of matter, inflows of water are set to equal outflows. Therefore, the CWF water budget was based on equation 2.1:

$$S+P+O=E+Sp+D+L$$

Equation 2.1.

Where S is the amount of source water used per year (m³/yr), P is the amount of precipitation (m³/yr), O is the amount of overland flow (m³/yr), E is the water lost to evaporation (m³/yr), Sp is the amount of splashing losses (m³/yr), D is the amount of water lost to flushing events (m³/yr) and L is the amount of water lost to leaks (m³/yr).

The water budget was estimated for each of the four water features based on this conceptual model and observations made during the 2014 season. We assumed that these features were in operation from April 1 to October 31 every year—a

¹ Intentional drainage occurs at the end of the season when CWFs are shut down for the winter. Intentional drainage also occurs during the season in order to rid features of discolored water from algal booms.

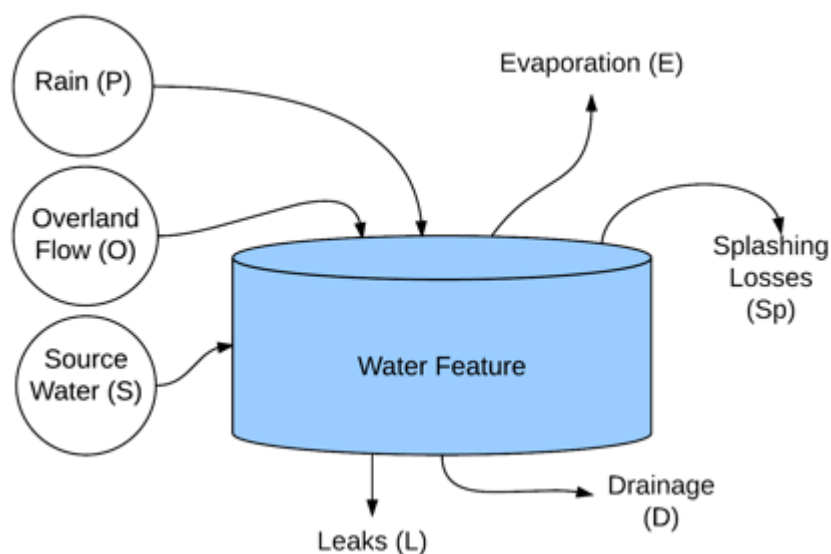


Figure 2.1. Diagram of annual water budget of a generic water feature.

period of 214 calendar days. The water budget analysis excluded water use at drinking water fountains, public restrooms, and irrigation systems.

We obtained precipitation and evaporation data from 30-year data series maintained by the National Oceanic and Atmosphere Administration (NOAA, 1982; NOAA, 2015). We determined the frequency of discharge based on interviews with NPS staff. A discharge event was assumed to equal 100% of the CWFs volume. The volume of each CWF was provided by Park staff, estimated from measurements made by the UMD Team, or estimated from drawings. Next we entered the flow data into water budget spreadsheets and calculated water inflows and outflows. Once the table was made, we developed indices to be able to compare water features of different sizes and volumes to one another.

The Water Use Ratio was developed to describe the number of times that a feature's water volume was replaced during a season. It was defined using Equation 2.2.

$$\text{Water Use ratio} = \frac{W}{V}$$

Equation 2.2.

Where W is the total water used from source water (m^3/yr); excluding precipitation, overland flow (i.e. surface runoff) and groundwater contributions, and V is the water volume of the water feature (m^3). A higher Water Use Ratio indicates a greater amount of water consumption by the water feature.

We also developed the City-Water Use (CWU) index to determine the amount of municipal water provided to a feature relative to the amount provided by precipitation using Equation 2.3.

$$CWU = \frac{W_c}{W_p}$$

Equation 2.3.

Where W_c is the amount of city water used per year (m^3/yr) and W_p is the amount of precipitation contributed per year (m^3/yr). A number above 1 indicates that a feature relies more on city water than on rainwater. This index can be used to assess the sustainability of water use since using less treated water and more free renewable rainwater increases sustainability.

We calculated the percentage of water lost to various outflows by determining the volume lost and dividing it by the total water consumption of the feature.

2.16 ESTIMATION OF PHOSPHORUS SOURCES

In order to understand the nutrient inputs to CWFs, we developed a phosphorus (P) mass balance analysis. The system boundary for the phosphorus balance model was defined as the physical boundary of the CWF itself (i.e. the wetted surface area of the CWF). Sources of P included 1) the municipal water supply, 2) litterfall from trees and landscape materials, 3) bird feces, 4) rainfall (i.e., wet atmospheric deposition), and 5) dust (i.e., dry atmospheric deposition). Drainage is the main pathway for P to leave a CWF during the operating season, but it is also removed as sludge (i.e., accumulated dead organic material) at the end of the season in some features. Other P sources were not considered in this analysis, such as inputs from trash litter, food given to waterfowl, or P contained in water treatment chemicals such as algaecides or dyes.

The conceptual diagram (Figure 2.2) is a simplified model of the flow of P in CWFs. Source water flows into the CWF bringing with it dissolved P, which can bind to surfaces and particles and settle as Bound P in the diagram. Dissolved P from the water supply is also taken up by algae, which becomes part of Organic Matter P. Leaves and other vegetation particles also add to Organic Matter P. Organic Matter P decomposes back to Dissolved P, or sinks to become Bound P. Rainwater contributes a tiny amount of dissolved P to the CWF, and dust from the atmosphere does as well, although in greater amounts. Litterfall represents trees dropping leaves into the water, contributing to Organic Matter P. These can

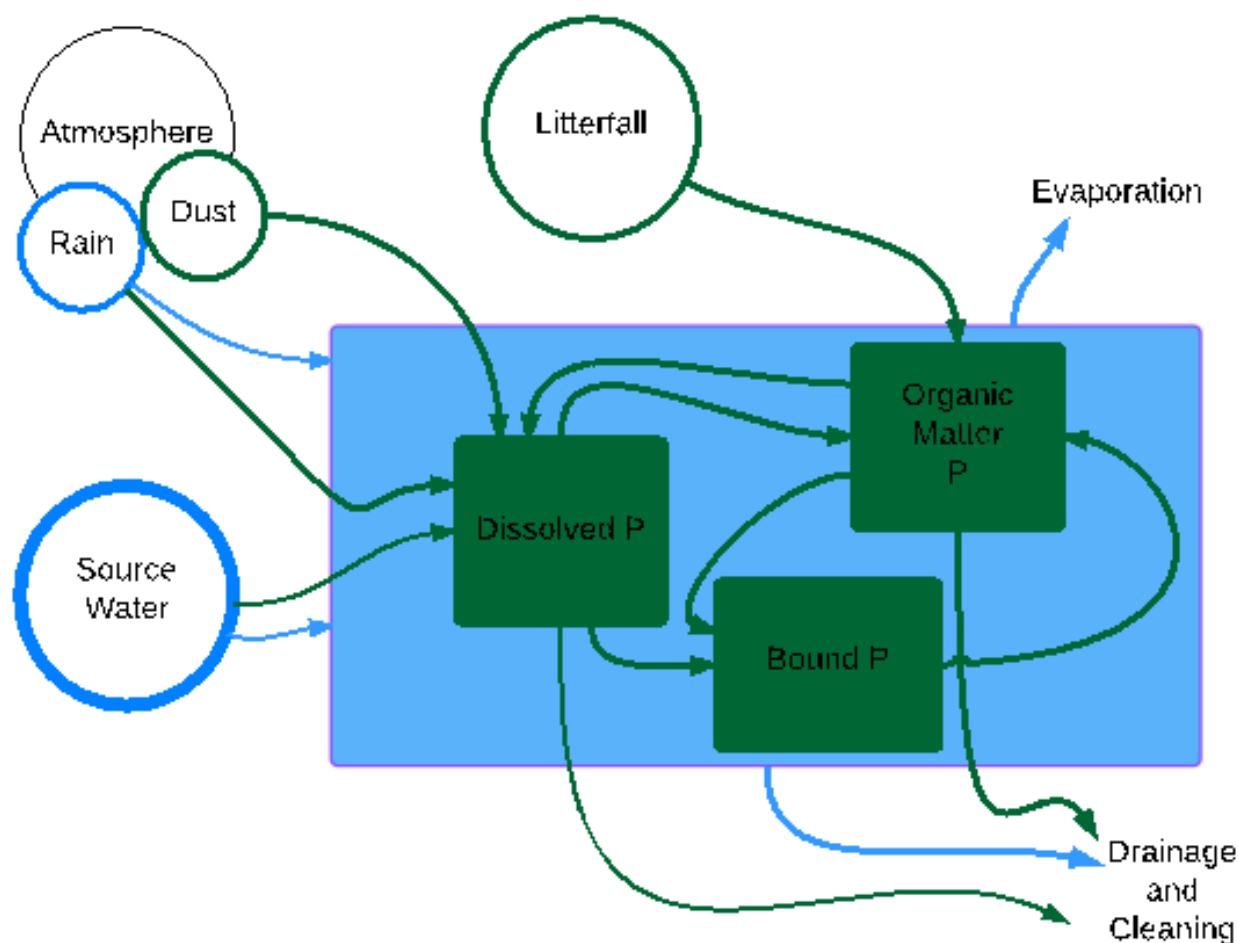


Figure 2.2. Conceptual Diagram of a Phosphorus cycle in a Constructed Water Feature. P flows and stores are in green, and water is in blue.

degrade quickly and release P into the water column or to the sediment. When CWFs are drained and cleaned, this represents a removal of P from the system.

With this conceptual model, we conducted the evaluation for a hypothetical year of operation, from April 1 to October 31 (as in the water budget analysis above). Rates of P flow from atmospheric and bird sources were estimated based on rates published by Koelliker et al, 2004; Ahn and James, 2000; Chen et al, 2008; Delumyea and Petel, 1978; and Sun et al, 2013. Where no documentation existed for P flows, we presumed a most probable rate for P flows after a thorough literature review.

To determine the mass balance we used equation 2.4.

$$M_{in} = \Delta M_Q + M_{out}$$

Equation 2.4.

Where M_{in} is the mass of phosphorus inputs per year (g-P/yr); ΔM_Q is the change in storage of P (g-P/yr); and M_{out} is the mass of P outputs (g-P/yr).

Atmospheric deposition of P varies greatly from year to year (Koelliker et al, 2004; Ahn and James, 2000) and entails a small expected contribution of P compared to other sources, namely source water inputs; therefore a close approximation of atmospheric deposition was warranted in the absence of site-specific data. Dry deposition was determined by obtaining an average value from literature (Delumyea and Petel, 1978; Post et al, 1998; Ahn and James, 2000; Chen et al, 2008; Sun et al, 2013). Wet deposition was based on the amount of rainwater entering the systems, as estimated in the water budget analysis and the average concentrations of P in rainwater from Koelliker et al (2004).

Plant litter entering the fountains was estimated from photo-documentation collected during the course of the study. P content of vegetation was obtained from literature (Duan et al, 2014; Hobbies et al, 2014) and calculated P inputs were based on assumed decomposition rates. In managed systems, such as at FDR and Meridian Hill Parks, the tree litter was assumed to be removed once per day as observed during the study; therefore we calculated the P release after 24 hours based on rates from existing scientific literature on nutrient release from leaf litter in urban environments.

Quantification of source water P was based on the amount of source water use from the water budget estimations and average concentrations of P in source water as determined during this water quality analysis.

The impact of bird feces on the P concentrations within water bodies is not well understood. Some studies have proposed that nutrients from bird feces quickly sink to the bottom and remain there until a mixing event occurs that re-suspends the matter (Pettigrew et al, 1997; Unckless and Makarewicz, 2007). This means that nutrient inputs from birds have few, short-term effects on the water body but may be significant in the long-term. Olson et al (2005) recorded nutrient inputs from migrating geese and determined that bird inputs of P contributed 85-93% of the annual P inputs to the system. Clearly, bird feces contribute P to CWFs, whether P from feces is deposited to the water itself or the sediment is not important since P can be cycled between the water and sediment. In the P balance model, bird feces were assumed to contribute to the “bound P” portion of the conceptual model, since it is bound up in organic forms and must be re-mineralized before it can be dissolved into the water body. A median daily excretion rate for P of 0.45 g-P/day/bird was taken from Post et al (1998). We estimated that 20 waterfowl frequented the CHOH Canal basin per day, and none at the other sites.

Once we obtained reasonable estimations of P inputs from various sources, we created a ratio of the mass of P inputs to water volume contained within the feature in order to obtain a comparable number. This ratio was determined by equation 2.5.

$$Q_p = P_{in} \div W$$

Equation 2.5.

Where Q_p is the P input to volume ratio (g-P/l/yr), P_{in} is the sum of the P inputs (g-P/yr) and W is the water volume of the feature at any given time during operation. This gives us an estimation of the magnitude of incoming P that is comparable between the sites and excludes size as a factor.

2.17 ENERGY USE ESTIMATION

Records of electrical use were requested from site supervisors and obtained where possible. When electrical use records were not obtainable, it was estimated from the following equations. First, the necessary output power was determined using Equation 2.6.

$$P_o = g * z * q$$

Equation 2.6.

Where P_o is the output power needed to move water through the system (W), and g is the gravitational acceleration (m/sec²), z is the change in elevation (m), and q is the flow rate of the water (kg sec).

Equation 2.7 then determined the input power.

$$P_i = \frac{P_o}{Ef}$$

Equation 2.7.

Where P_i is the input power (W), and Ef pump efficiency (%) and for this equation we assumed that all pumps operated at 0.8 efficiency. Then we determined total annual energy used for pumping with equation 2.8.

$$E = P_i * t$$

Equation 2.8.

Where E is the total annual energy use by pumps (J), and t is the length of operation per year (sec/yr). Thus, Equation 2.8 gives the total joules used to move water in the CWF during each year.

2.18 REVIEW OF WATER TREATMENT TECHNOLOGIES

As outlined in Task 3, Chapter 7 of this report provides a literature review of scientific research on water treatment, market research, and published books was conducted to identify useful technologies for CWFs, and their environmental impacts. In order to understand the sustainability issues of such technologies, a literature review of environmental accounting research (Life Cycle Assessments research papers) was conducted. Although vendor literature was viewed and in some cases, vendors were contacted, no endorsement of any particular vendor is presented in this report. CWFs entail, by their nature, two basic impediments to sustainability. First, there are unavoidable water losses to evaporation and end-of-season discharge and second, moving water through treatment systems and attribute flow requires energy from the electrical grid. Therefore a sustainable CWF was defined as safe, and chemical-free, devoid of invasive species, easy to maintain, with clean, clear water that is conserved without being excessively wasted. Since CWFs are used to convey valuable cultural heritage to visitors, preservation of the design intent and cultural messaging must be preserved and unaltered in a sustainable CWF.

Technologies were assessed by a rating system, based on principles of sustainable construction, as outlined by the US Green Building Council (Kibert, 2008). The rating system uses 8 categories that are relevant to the operation of water feature at high-traffic cultural sites (Table 2.2). Water treatment systems are given a score from 0 to 4 (4 being the highest) for each category. These categories are then averaged and the technology or method is given an overall score. Systems with scores closer to 4 are considered sustainable, those with lower scores are considered less so.

Table 2.2. Categories of Sustainability for CWF water treatment technologies

CATEGORY	CENTRAL QUESTION
Preservation of Design Intent	Does the new technology alter the physical appearance of the site, and / or disrupt the narrative elements of the CWF?
Human Safety	What are the human safety concerns for operators and other maintenance staff tasked with CWF management?
Environmental Impact	What are the environmental impacts, including discharge of toxic chemicals, and other harm to ecosystems and other life?

CATEGORY	CENTRAL QUESTION
Energy Use and Greenhouse Gas (GHG) Emissions	What are the on-site energy requirements for the new technology
Water Use	How does the new technology affect water use?
Resource Intensity	What are the resource requirements of the technology?
Labor Intensity	What are the labor requirements of operating the new technology?
Efficacy	How well does the technology treat algal blooms and water quality?
Cost Estimate	How expensive is the technology for capital and operating costs?

Economic sustainability was not addressed in this study. Since National Parks are not for profit-oriented systems, such a question hinges upon a cost-benefit analysis. Cost is a matter of developing budgets and can be done elsewhere by those with the expertise; however, quantifying the benefit of cultural sites with CWFs is not a simple matter and could not be obtained during the course of this study. Instead, cost estimates are used to address cost in general terms.



WATER FEATURES

- ❖ *MERIDIAN HILL PARK*
- ❖ *THE WOMEN IN MILITARY SERVICE FOR AMERICAL MEMORIAL*
- ❖ *THE FRANKLIN DELANO ROOSEVELT MEMORIAL*
- ❖ *CHESAPEAKE AND OHIO CANAL NHP*

CHAPTER 3: MERIDIAN HILL PARK



Figure 3.1. The cascades and lower reflecting pool at Meridian Hill Park.

3.1 BACKGROUND

Meridian Hill Park is an urban neighborhood park located at 2400 15th Street Northwest in Washington, DC. The most notable features of the park are the elaborate water features that include a number of small fountains, three large fountains, reflecting pools and cascade feature (shown in Figure 3.1). Construction of this park began in 1914 and lasted until 1936 when the entire park was opened to the public. A detailed account of the construction of the park is provided in the Meridian Hill Park Cultural Landscapes Report Vol. 1 (NPS, 2001).

Over the last 50 years, two reports have noted the degrading structural integrity of the electrical and plumbing systems of the water features. In 1966, a report detailed serious damage to the plumbing systems such that none of the water features were operational (Cobb and Youssef, 1966). It is unclear how long the water features were not operational and when they were first shut down.

Later in 1977, Symphonic Fountains studied the fountains and made similar conclusions about the need for repair (NPS, 2001). At this time, funds were obtained to repair the damage and the water features were presumably operational once more. This report also detailed considerable criminal activity and vandalism at the park that has since been mitigated with help from the local community.

The Meridian Hill Park CWF was chosen as a candidate for study because of the reoccurring problems with algae and green water, its age, and the deterioration of the CWF over time. The CWF at Meridian Hill Park is the largest and oldest stone

lined CWFs in this study. This chapter presents the results of a visual assessment, water quality analysis, water and phosphorus accounting analysis and discusses possible methods to improve the maintenance and longevity of the system.

3.2 METHODS

3.2.1 WATER FLOW AND PLUMBING LAYOUT

A site visit and tour of the park and pump room served to familiarize the UMD Team with the layout of the CWF and the plumbing system. Further information about the plumbing system was gleaned from the Cultural Landscapes Report on Meridian Hill (NPS, 2001) and original engineering plans and plumbing layouts obtained from the National Archives in College Park, MD. Information on water volumes was not available in plans and documents, so water volumes were estimated through calculations based by on measured water depth and surface area of basins and waterfall features. The volumes of water, contained within plumbing systems, such as piping, sand filters and pumps, were not estimated.

3.2.2 WATER QUALITY SAMPLING AND VISUAL OBSERVATIONS DATES

Three (3) water samples were taken from the water feature during each site visit at randomly determined basins. Sampling points were determined by estimating the volumes of each basin, then determining their percentage of the total water volume. Then a random number from 1 to 100 was randomly determined. This number was then used to determine which feature would be sampled. Source water samples were taken from a drinking water fountain by the upper reservoir at the park. See Chapter 2 for details of the water analysis methods used in this study. Research permits for water sample collection were obtained on July 5, 2014. Water samples were taken from 10:30 am to 11:30 am on the dates presented in Table 3.1. The UMD Team made seven (7) visits to Meridian Hill Park in order to update photo documentation and make visual observations based on a set criterion as outlined in Chapter 2. The CWF and its components were photographed numerous times to document water-color, debris in the feature, and general appearance. Visual observations were made on the dates presented in Table 3.1.

Table 3.1. Water Sampling and Visual Observation Dates

DATE	WATER SAMPLES TAKEN	VISUAL OBSERVATIONS
6/6/14		X
6/17/14		X
7/1/14		X
7/7/14	X	X
7/18/14	X	X
7/31/14	X	X
8/14/14	X	X
8/28/14	X	

3.2.3 ENERGY USE ESTIMATES

Changes in elevation from the pump to the highest point in the CWF were estimated by referring to topographic maps from Google Earth, accessed in August 2014. These estimates were then used in Equation 2.6, 2.7 and 2.8 to obtain an estimate of total energy use for all of the CWFs at the park.

3.2.4 DISCHARGE ESTIMATES AND WATER BUDGET ANALYSIS

Site managers and supervisors were interviewed to estimate how often the CWF was completely drained and re-filled during a year of operation to determine discharge estimates. In the absence of recent local data, estimated rates for evaporation were taken from pan evaporation rates for Baltimore, MD during 1956-1970 for April through October (NOAA, 1982). Precipitation rates were taken from NOAA (2015). The data presented here should be considered estimates of discharge and water use, rather than observed data.

3.2.5 PHOSPHORUS INPUTS

Phosphorus inputs were estimated as outlined in Chapter 2. No waterfowl were assumed to contribute significant phosphorus flows into the CWFs at Meridian Hill Park. Meridian Hill Park includes significant vegetation and tree cover in close proximity to the CWF, so leaf litter estimates were taken from estimates of a typical deciduous forest (Bell et al, 1978) and rates of phosphorus release were taken from previous studies (Duan et al, 2014; Hobbies et al, 2014). Rates of phosphorus flow into the system from source water were calculated from observed concentrations of phosphorus in this study. Rates of atmospheric deposition of phosphorus were averaged from Koelliker et al (2004), Ahn and James, (2000); Chen et al, (2008), Delumyea and Petel (1978) and Sun et al (2013).

3.3 RESULTS AND DISCUSSION

3.3.1 PLUMBING LAYOUT AND SYSTEM DIAGRAM

The Meridian Hill Park system consists of several connected water features located on the hillside, the upper terrace, the lower plaza and the walls along 16th Street (see Table 3.2 for a complete list). The major water features include three large fountains (two on the upper terrace and one along the wall facing 16th street), a cascade and a reflecting pool on the lower plaza. Two vegetative strips of *Iris* spp. and *Typha* Spp (cattail) flank the cascade.

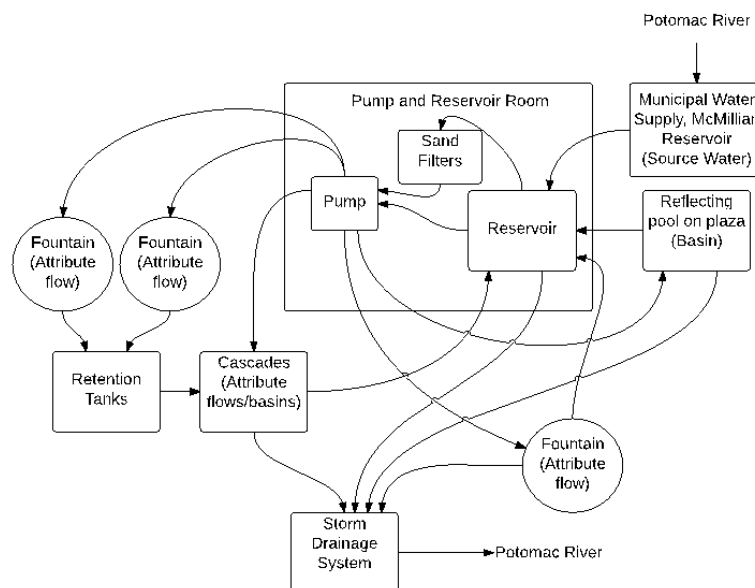
Table 3.2. The Water Feature Components at Meridian Hill Park.

Component	Amount
Fountains	3
Fountain Niches	5
Oval Spills	2
Pools	1
Cascading Basins	14
Receiving Basin	1
Dolphin Spouts	2
Urn Jets	4
Reflecting Pool with Spray Jets	1
Pump Room Reservoir	1
Small Retention Tanks	2

A simplified conceptual diagram of the plumbing system is presented in Figure 3.2. Although they are separated, all of the water features are part of a single plumbing system. The total volume of the system was estimated to be 132,000 gallons. A single 60 horsepower pump drives the CWF. The current pump is relatively new and was installed in 2009 under a capital improvement plan (Donald Kirk, pers comm, 2014). The water feature is lined with a coarse aggregate. Piping is composed of polyvinyl chloride (PVC), iron and brass fittings. The overall surface area of the basins is 11,754 ft².

The main reservoir, located in the pump room beneath the cascades, receives all of the water flowing down from the fountains, pools and basins, as well as make-up water from the municipal water supply. The pump-room reservoir was initially intended as a location to add chemicals for water treatment, although chemical treatment was not reported at this CWF, beyond a simple water dye used to mask

Figure 3.2. Schematic flow diagram of the Meridian Hill Park water feature.



the algae (discussed later in this chapter). A 60 HP pump sends the water back through the various components of the water feature (Figure 3.3). From the fountains and other features, water flows via gravity back to the reservoir. When water is discharged, it flows to the municipal sewer.

The water feature system includes two pressurized sand filters (PSFs) that treat approximately 5-10% of the water flow during each pass (Figure 3.4). A third sand filter was off-line during the site visit on June 6. The PSFs are 30 inches in diameter and about 30 inches high. The operational sand filters are backwashed once per week by maintenance staff (Anthony Smith, pers. comm, 2014). The sand filters were installed in 2009 and have been operated continuously. There is no record of whether new sand has been added or replaced since their installation. In addition to the sand filters, two inline coarse screen filters are used to treat all of the water flow to the pump by removing large solids (Figure 3.5). These are cleaned on a daily basis.

PSFs appear to be standard technology for the many of the NPS water feature designs and system upgrades installed in the 1990- 2005 time period. These sand filters were sized to take less than 5% of the total volume of the feature on a single pass flow basis, but should result in at least one turnover of the total volume of the water feature per day. Typically they are commercial, all-steel or fiberglass, enclosed tanks 3 to 5 feet in height and have a diameter of 24 to 48 inches. They operate in a downflow configuration with 15 to 30 inches of silica sand media typically U.S. Standard Sieve #20 x #30 (ASTM E11 – .850mm x .600mm) silica sand. Water to be filtered is pumped into the top of the filter and distributed over the sand bed. The sand bed is supported by 12-18 inches of coarse gravel, although this is mainly for support. The filtered water is picked up by underdrain piping in the gravel bed and returned to the water feature. A simple pressure gauge on the inlet side of the PSF provide information on the operating pressure of the system (psi). Monitoring this pressure provides the operator with data about the normal operating pressure for an individual system. This data will also give the operator guidance as to when the PSF must be backwashed. Over time the pressure will rise and when it reaches a pressure 8 to 15 psi above the normal operating pressure the sand bed needs to be backwashed. Valving allows the flow to be reversed up through the gravel and sand and expands the sand bed to release entrapped particles of various sizes including algae, fine dirt, and organic debris. This in effect cleans the sand bed. The valving is then reversed and the sand bed resettles and the filtering process resumes and the pressure on the gauge returns to a normal operating pressure.



Figure 3.3. The 60-HP pump at Meridian Hill Park.



Figure 3.4. One of the sand filters in the pump room at Meridian Hill Park.

Figure 3.5. The screen filters in the pump room at Meridian Hill Park.



The size of the media determines the general size of the materials that can filtered from the water. Media used in PSFs can include anthracite coal, sand, garnet, magnetite, and other specialized materials (Wheaton, 1993; Arndt and Wagner, 2004; Sabiri et al, 2011). PSF media can be a mixture of these materials as well. Additionally, the shape of the filter media affect the efficiency of the solids removal. Sharp, angular media form large voids and remove less fine material than rounded media of equivalent size. The sand must be coarse enough to allow solids to penetrate the bed for 1 to 6 inches. Most suspended materials are trapped near the surface or in the first 1 to 2 inches. As the system is operated sand grains are worn down or lost from the bed during backwash, new sand must be added to make up for these losses. In some cases, the sand forms aggregates and channels that short circuit the flow and reduce the efficacy of the filtration. In these cases the sand bed must be replaced. The life of the sand bed under typical operating conditions can be as long as 5 to 8 years (Sabiri et al, 2011). But sand levels should be checked and sand refilled as needed at the beginning of each operating season. Filter hydraulic loading rates for PSFs vary from 5 to more than 25 gpm ft⁻² depending on the media choice and the size of particle that needs to be filtered.

The CWF and other features of the park were constructed from a special coarse aggregate concrete that was considered technologically advanced at the time of installation. It is important to note that the structure is nearly 80 years old. There are some locations in the water feature that leak. Leak repairs are dealt with by the maintenance staff.

3.3.2 FOAM

Foam development never appeared to be extreme in the water features, but in July and August, the upper reservoir accumulated foam along the edges of the pool. Table 3.3 shows the percentage of water surface covered in foam during the study.

Table 3.3. Foam coverage (%) on the water surface of the Meridian Hill CWF.

DATE	UPPER FOUNTAIN	UPPER RESERVOIR	CASCADE	LOWER RESERVOIR	REFLECTING POOL
6/6/14	2%	5%	0%	2%	2%
6/17/14	2%	1%	0%	0%	0%
7/1/14	6%	2%	1%	5%	0%
7/7/14	4%	3%	0%	5%	0%
7/18/14	2%	13%	0%	1%	1%
7/31/14	1%	3%	0%	3%	1%
8/14/14	2%	28%	0%	9%	1%

When foam was present, it had a different appearance from the foam observed at the FDR Memorial (see Chapter 5). The bubble size was larger and the foam was less densely packed in corners. Foam development appears to be related to algal

Figure 3.6. Foam accumulations in the upper reservoir on July 18, 2014.



Figure 3.7. Foam accumulations in the upper reservoir on August 14, 2014.



growth or materials derived from organics, rather than a foreign foaming agent. Figures 3.6 and 3.7 are examples of the type of foam levels observed at Meridian Hill Park.

3.3.3 WATER-COLOR

Table 3.4 shows the pattern of water coloration during the summer of 2014. The CWF water appeared green most of the time, with a brief period of black water in July caused by the addition of a chemical dye called nigrosine (US patent # 4624709 A) to turn the water black in response to complaints about algae (Figure 3.8). The dye was

Table 3.4. Water-color as observed at Meridian Hill Park.

DATE	UPPER FOUNTAIN	UPPER RESERVOIR	CASCADE	LOWER RESERVOIR	REFLECTING POOL
6/6/14	Pea Green	Pea Green	Pea Green	Pea Green	Pea Green
6/17/14	Dark Green, Olive Green	Dark Green, Olive Green	Dark Green, Olive Green	Dark Green, Olive Green	Dark Green, Olive Green
7/1/14	Slightly Darker Pea Green	Slightly Darker Pea Green	Slightly Darker Pea Green	Slightly Darker Pea Green	Slightly Darker Pea Green
7/7/14	Black	Black	Black	Black	Black
7/18/14	Black	Black	Black	Black	Black
7/31/14	Olive Green	Olive Green	Olive Green	Olive Green	Olive Green
8/14/14	Dark Green	Dark Green	Dark Green	Dark Green	Dark Green

added in early July and but by July 31, the water had returned to a green color (Figure 3.9), indicating that affect of the applied dyes were relatively short-lived.

The CWF water never appeared clear during this study. The green coloration indicates that suspended or planktonic algae are in full bloom in the CWF. The elevated concentration of TSS (discussed below) also supported this. The PSFs should be able to remove suspended algae from the water column if they were working properly but not if they are clogged, have developed internal channels that allow short circuiting or if insufficient quantities of sand are present in the sand. PSFs can be operated to remove small size particles such as suspended algae by chemical addition of coagulants or with proper selection of filter media followed by more frequent backwashing. Further inspection of the sand filters is warranted at Meridian Hill Park, to determine if they are functioning properly or if other optimization steps can be taken to improve their performance.



Figure 3.8. The reflecting pool at Meridian Hill Park was a blackish color after dye had been applied. Photo taken July 7, 2014.

Figure 3.9. The green color from algal growth had returned within 3 weeks of the last observation of black water. Photo taken July 31, 2014.



3.3.4 ODOR

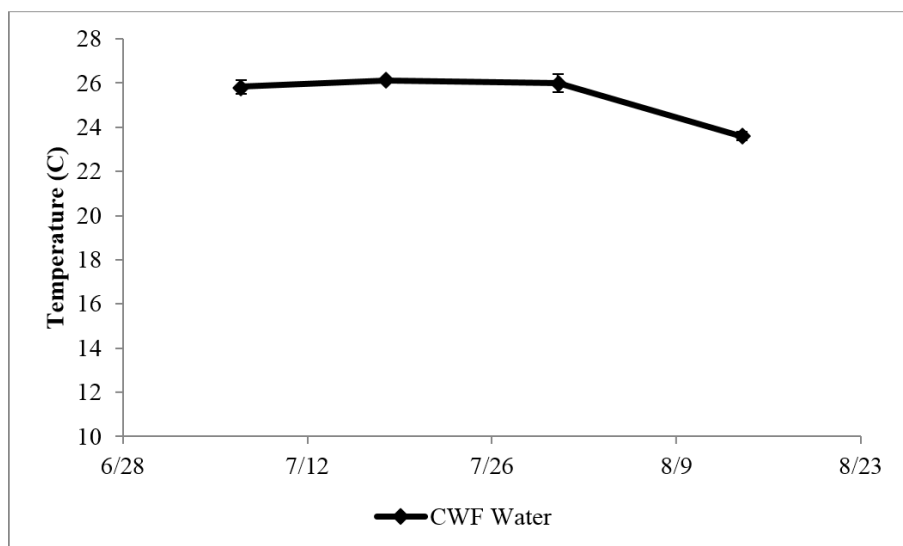
Table 3.5 shows the odor ratings and written descriptions. Algae-like odors were the most common odors described by the UMD Team, as expected from the obvious algal growth from the water-color observations. Odor was worst at the end of July, but improved in mid-August. The assessment of odor is assumed to be related to algae and microbial growth in the water feature.

Table 3.5. Odor rating (10 is the strongest odor) and descriptions during the sample period at Meridian Hill Park.

DATE	UPPER FOUNTAIN	UPPER RESERVOIR	CASCADE	LOWER RESERVOIR	REFLECTING POOL
6/6/14	2 - Mild	2 - Mild	2 - None	2 - None	2 - None
6/17/14	1 - None	1 - None	1 - None	1 - None	1 - None
7/1/14	1.5 - Mild	1.5 - Mild	1.5 - Mild	1.5 - Mild	1.5 - Mild
7/7/14	3 - Plant / Dead Algae	3 - Plant / Dead Algae	3 - Plant / Dead Algae	3 - Plant / Dead Algae	3 - Plant / Dead Algae
7/18/14	5 - Plant / Dead Algae	5 - Plant / Dead Algae	5 - Plant / Dead Algae	5 - Plant / Dead Algae	5 - Plant / Dead Algae
7/31/14	7.5 - Algae	7.5 - Algae	7.5 - Algae	7.5 - Algae	7.5 - Algae
8/14/14	4 - Algae	4 - Algae	4 - Algae	4 - Algae	4 - Algae

Warm water temperatures enhance algae and microbial growth (McQueen and Lean, 1986; Paerl and Huisman, 2008; Davis et al, 2009) and as shown in Figure 3.10, water temperatures were higher in July (26.0° C) than in August (23.6° C), but only by a small difference. Other factors may play more of a role, such as recent rainfall that dilutes the water, wind, the amount of TSS in the water, and the availability of oxygen for aerobic decomposition. Regardless, odor certainly indicates poor CWF quality, but without further data, factors that control the strength of the odor are unknown.

Figure 3.10. Water Temperature in the CWF at Meridian Hill.



3.3.5 PLANT DEBRIS

Plant debris coverage is shown in Table 3.6 and suggested that regular removal of plant debris is part of daily maintenance, or that plant debris sinks beyond sight. The water was turbid and discolored so if the plant debris sinks; it is likely that the UMD Team was unable to see it.

Table 3.6. Estimated plant debris coverage (%) of the water surface at Meridian Hill Park.

DATE	UPPER FOUNTAIN	UPPER RESERVOIR	CASCADE	LOWER RESERVOIR	REFLECTING POOL
6/6/14	4%	1%	1%	3%	2%
6/17/14	2%	2%	3%	9%	1%
7/1/14	9%	1%	4%	7%	2%
7/7/14	13%	2%	4%	4%	1%
7/18/14	4%	2%	1%	2%	2%
7/31/14	2%	3%	3%	2%	1%
8/14/14	4%	4%	4%	2%	2%

3.3.6 LITTER

Table 3.7 shows the amount and type of litter in the CWFs at Meridian Hill Park. The amount of litter reflected that tourists and residents frequent the park in large numbers, although litter was never excessive.

Table 3.7. Litter counts and type in the CWFs at Meridian Hill Park.

DATE	UPPER FOUNTAIN	UPPER RESERVOIR	CASCADE	LOWER RESERVOIR	REFLECTING POOL
6/6/14	2 - Wrappers	1 - Plastic Drinking Bottle	0 - None	0 - None	1 - Paper
6/17/14	1 - Slip of Paper	1 - Plastic Bottle	2 Plastic Bottle / Aluminum Can	0 - None	0 - None
7/1/14	1 - Bottle Cap	2 Plastic Wrapper / Cigarette	0 - None	0 - None	1 - Paper
7/7/14	0 - None	2 - Soda Can / Cigarette	0 - None	0 - None	0 - None
7/18/14	0 - None	2 - Wrappers / Plastic Bottle	0 - None	0 - None	0 - None
7/31/14	0 - None	3 - Cigarettes	4 - Broken Metal Bowl / Red Plastic	2 - Band-Aid / Paper	0 - None
8/14/14	0 - None	0 - None	1 - Wrapper	0 - None	1 - Bread

3.3.7 ALGAE

Table 3.8 shows the coverage of algae on the water surface and type, as observed by the UMD Team. As indicated by water-color, odor descriptions, and TSS concentrations (discussed below), algae was observed in high concentrations during the study period. When waters were dyed black, algae was still visible in clumps but had been discolored by the dye. Further, when the water was disturbed, it was evident that a large mass of algae had settled to the bottom of the water feature.

Table 3.8. Algae Coverage and Type observed at Meridian Hill Park.

DATE	UPPER FOUNTAIN			UPPER RESERVOIR			CASCADE			LOWER RESERVOIR			REFLECTING POOL		
	COVERAGE	P	B	COVERAGE	P	B	COVERAGE	P	B	COVERAGE	P	B	COVERAGE	P	B
6/6/14	100%	X		100%	X		100%	X		100%	X		100%	X	
6/17/14	100%	X		100%	X		100%	X		100%	X		100%	X	
7/1/14	100%	X		100%	X		100%	X		100%	X		100%	X	
7/7/14	0%			0%			0%			0%			0%		
7/18/14	0%			6%	X		0%			0%			0%		
7/31/14	100%	X		100%	X		100%	X		100%	X		100%	X	
8/14/14	100%	X		100%	X		100%	X		100%	X		100%	X	

P = Planktonic algae | B = Benthic attached algae

**Figure 3.11.** Algae colonies in early stages of development at Meridian Hill Park. Photo taken July 1, 2014.

This shows that the use of dyes were merely cosmetic and did not affect algal growth substantially. In early July, site managers reported that the CWF had been drained, re-filled, and dyed black in response to public complaints about algal growth and malodors (Simone Monteleone, pers. comm. 2014). Prior to this we observed concentrated floating mats or colonies of algae beginning to form (Figure 3.11). After draining and refilling, the colonies were not observed until July 18, and then were not observed until later in the season.

3.3.8 NUTRIENT ANALYSIS

Phosphorus is considered one of the main drivers of harmful algal blooms (Conley et al, 2009). Total phosphorus (TP) is amount of phosphorus in organic and inorganic sources. Figure 3.12 shows that concentrations of TP were at or near 0.8 mg-TP/l throughout July and August. This was more than twice the level observed in the source water, which consistently measured around 0.3 mg-TP/l. These concentrations are lower than those found in source water used at the FDR Memorial, but are alarming nonetheless. TP levels above 0.05 mg-TP/l can cause algal blooms (Conley et al, 2009; Schindler et al, 2012). It is clear that the water feature at Meridian Hill Park is showing signs of intensive over-enrichment from nutrients without any mechanism for dealing with algal growth.

Orthophosphate (PO_4^{3-}) is the soluble form of phosphorus that is readily available for uptake by algae. PO_4^{3-} concentrations were lower and more variable than concentrations of TP (Figure 3.13). The variable concentrations that we observed could be related to cycles of rapid growth and depletion of algae biomass in the water column during the study. Most of the samples indicated that orthophosphates were higher than source water concentrations, as were concentrations of TP. This suggests that both forms of phosphorus are accumulating in the CWF to amounts greater than that in the source water. Phosphorus is not dispersed to the atmosphere like nitrogen and therefore is conserved in aquatic systems. Accumulations occur by evaporation of water, replenishing with phosphorus-rich source water, and phosphorus contributions by other sources (such as bird feces, leaf litter, pollen, etc.). The conservation of TP by accumulation in the Meridian Hill Park water features does indicate that very little water is lost or wasted.

Nitrogen is another essential nutrient that contributes to algal growth (Conley et al, 2009). Concentrations of TN measured in the Meridian Hill Park shown in Figure 3.14 varied from 0.9 to 1.3 mg/l in the water feature over the study period. The source water was consistently higher varying from 1.6 to 2.5 mg/l over the same period. These concentrations were sufficient to contribute to algal bloom development. The higher concentrations of TN for source water are largely a measure of the chloramines added by the municipalities to improve the performance of chlorination for disinfection. Chloramines provide longer lasting residuals needed to insure the safety of public water supplies. The other forms of nitrogen shown in Figures 3.15 and 3.16 were more variable and there was no significant difference between the feature water and the source water (Figure 3.14).

NH_3 concentrations were consistently about 0.1 mg/l over the study period. These concentrations were low compared to TN concentrations. This could be expected in a system exposed to oxygen where NH_3 would be converted rapidly to NO_3^- by microbial action (Figure 3.15). However NO_3^- was also low in the CWF, even lower than source water concentrations (Figure 3.16). This could suggest the intense algal blooms in the system were utilizing the NO_3^- for growth as soon as it was available. These concentrations were sufficient to contribute to algal blooms (Schindler et al, 2012).

Figure 3.12. TP levels for CWF water (solid lines) and source water (dashed lines).

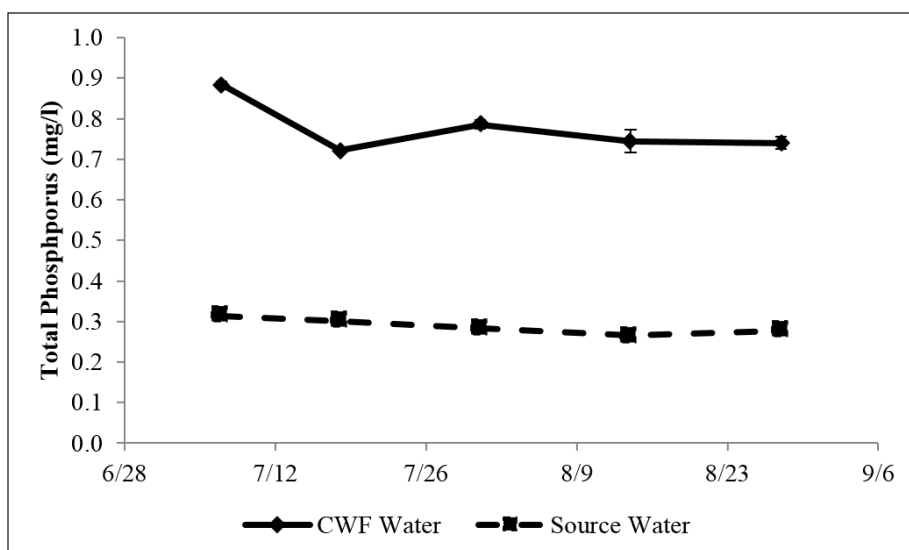


Figure 3.13. PO_4^{3-} levels for CWF water (solid lines) and source water (dashed lines).

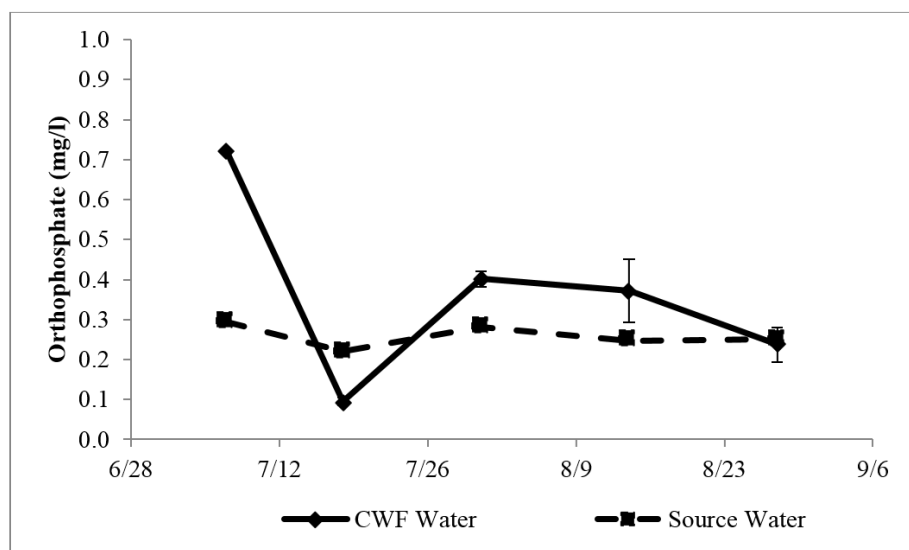
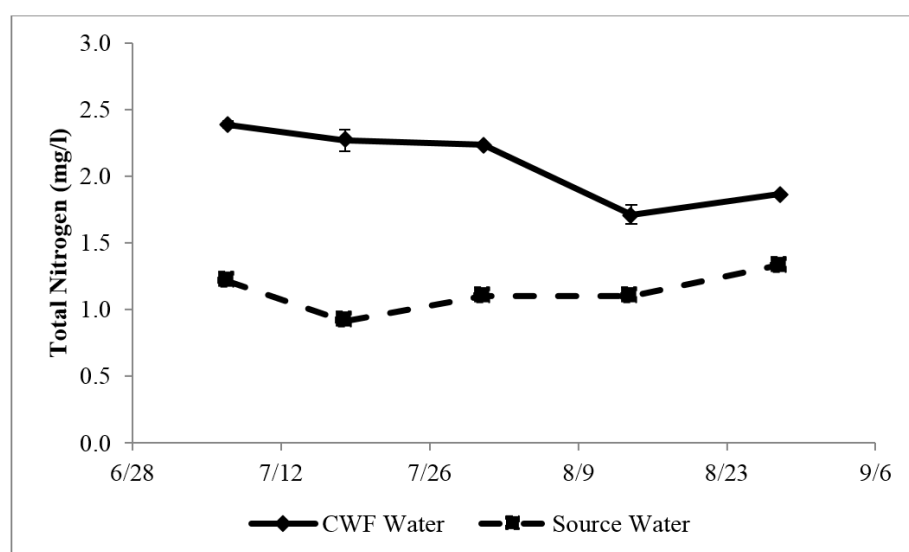


Figure 3.14. TN levels for CWF water (solid lines) and source water (dashed lines) at Meridian Hill Park.



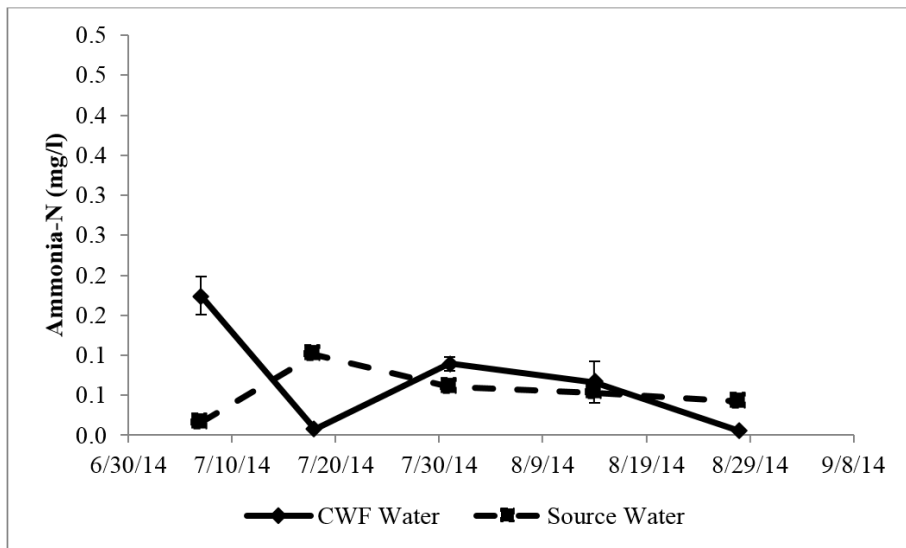


Figure 3.15. NH_3 levels for the CWF water (solid lines) and source water (dashed lines) at Meridian Hill Park.

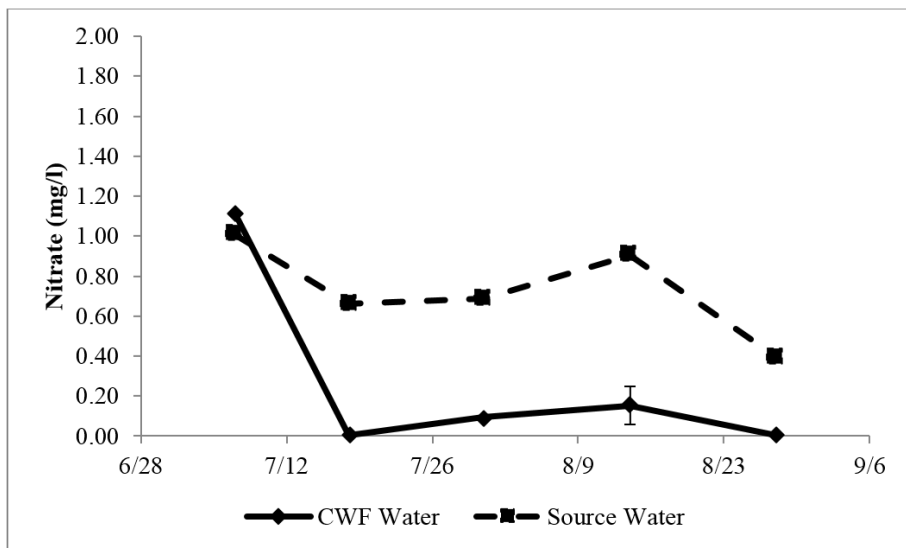


Figure 3.16. NO_3^- levels for the CWF water (solid lines) and source water (dashed lines) at Meridian Hill Park.

3.3.9 SOLIDS ANALYSIS

Total solids (shown in Figure 3.17) were higher in CWF water due to the growth of algae. This is evident by reviewing the amounts of suspended solids (Figure 3.18) and the volatile suspended solids portion (Figure 3.17), which is used as a proxy for measuring algal biomass in the water. Dissolved solids (Figure 3.18) in CWF and source water were no different. The difference in suspended solids (both TSS and VSS) provide further evidence that the sand filters are either inoperable or are not large enough to handle the amount of algae produced in the CWFs.

There was a decline in suspended solids in mid-August, which may be linked to a decline in water temperature (Figure 3.10), which reduced growth in algae.

Figure 3.17. Total Solids (TS) concentrations for CWF water (solid lines) and source water (dashed lines).

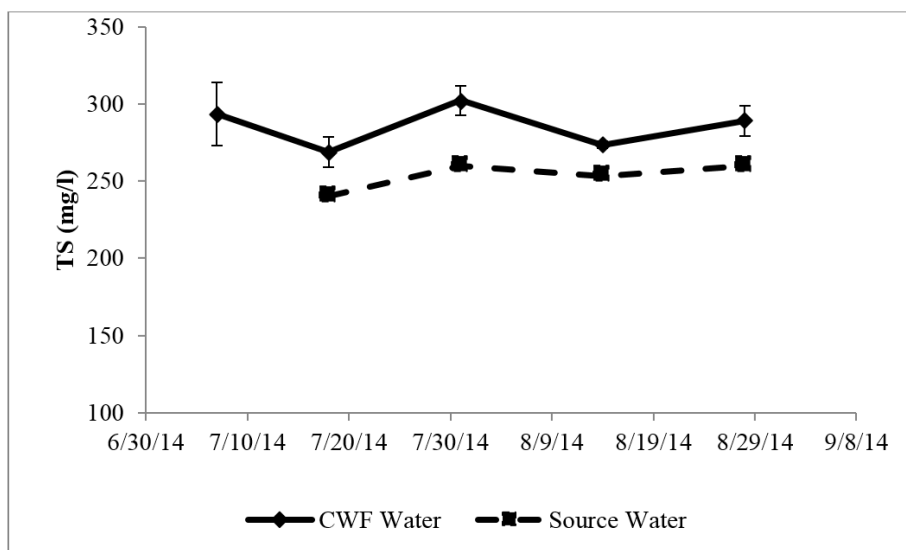
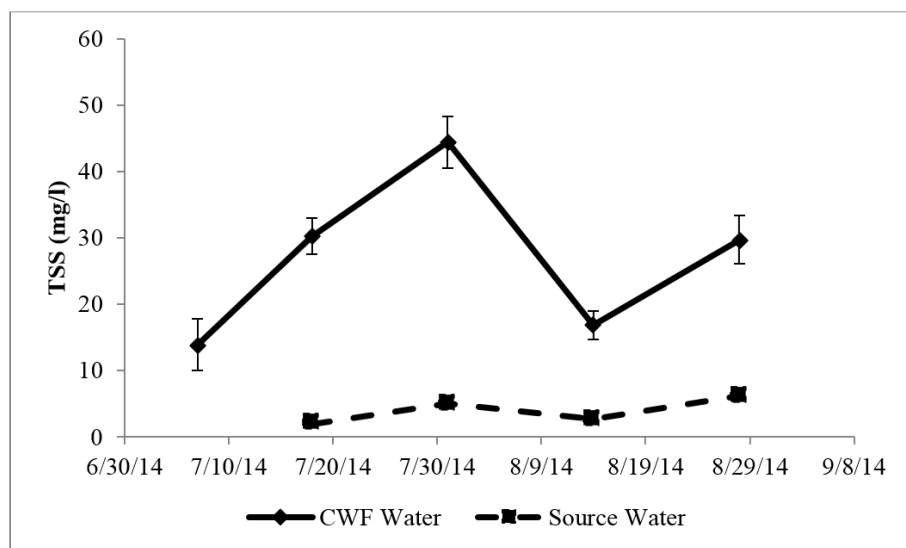


Figure 3.18. Total Suspended Solids (TSS) concentrations for CWF water (solid lines) and source water (dashed lines).



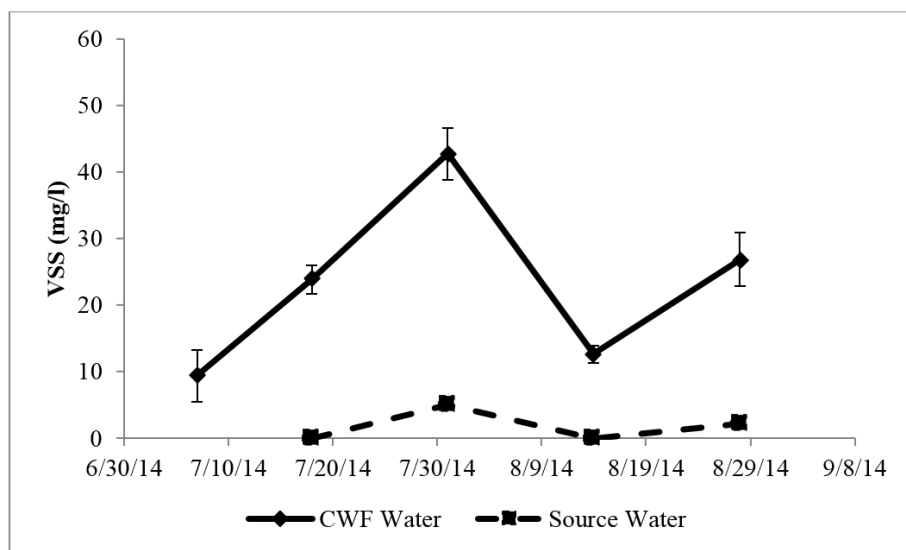


Figure 3.19. Volatile Suspended Solids (VSS) concentrations for CWF water (solid lines) and source water (dashed lines).

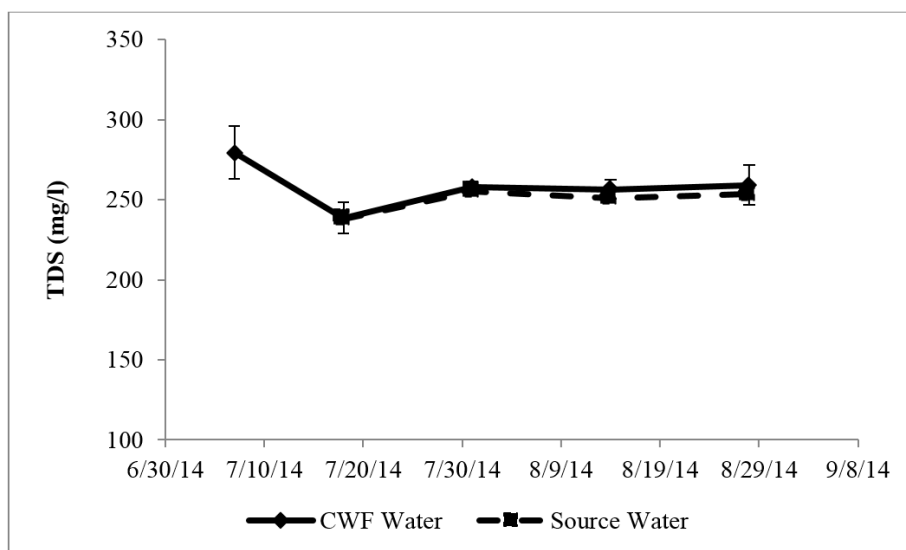


Figure 3.20. Total Dissolved Solids (TDS) concentrations for CWF water (solid lines) and source water (dashed lines).

3.3.10 TURBIDITY, PH AND DISSOLVED OXYGEN

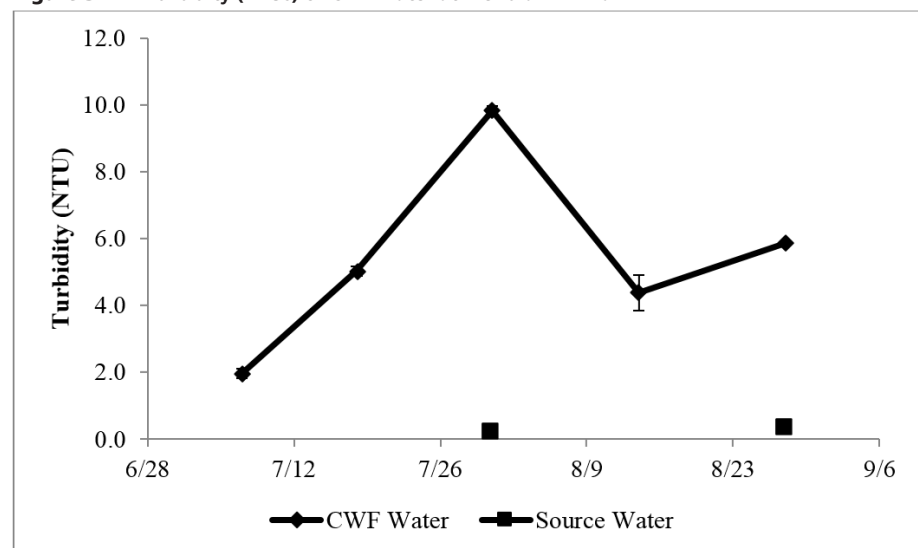
Turbidity followed a similar pattern to solids (Figure 3.21), which is expected because the two parameters are typically closely linked. It peaked late July and declined into August. Turbidity can be used as a simple measure to determine the performance of treatment systems, notably PSFs. Monitoring is strongly encouraged to improve the operation of the systems at Meridian Hill Park. This measurement is quick and inexpensive once the equipment is available, recorded data can pinpoint changes in water quality.

The pH of the CWF and source water ranged from 8.7 to 9.9 over the study period as shown in Figure 3.22. In the CWF water, elevated pH could be expected resulting from intense algal growth, since algae respiration tends to raise pH during the daylight period of photosynthesis. The high pH of source water (mean 9.0)

was unexpected and much higher than the reported mean of 7.7 reported by US Army Corps of Engineers (2013) for water from the Washington Aqueduct (the municipal water supply). Chlorination is less effective in high pH waters so greater dosages must be used. Therefore chlorination may not be an effective water treatment option for Meridian Hill Park. More discussion on chlorination and pH can be found in Chapter 7.

The dissolved oxygen (DO) levels in the CWF water indicated that water was saturated with oxygen (Figure 3.23) throughout the study period. This is another indicator of intense algal growth from the release of oxygen into the water during photosynthesis. These measurements were taken during the day when photosynthesis occurs. At night when photosynthesis ceases and much lower concentrations of DO could be expected. Low DO concentrations during the nighttime hours could lead to potential odor problems under anaerobic conditions. This could lead to additional complaints from the local population from hydrogen sulfide formation. If this were a natural system used as habitat for fish, benthic invertebrates and others, these levels of algal growth would be alarming and might cause a die-off of aquatic animals, as all of the oxygen could be consumed by algae at night and decomposition of algal biomass, leaving none for other organisms.

Figure 3.21. Turbidity (NTUs) of CWF water at Meridian Hill Park.



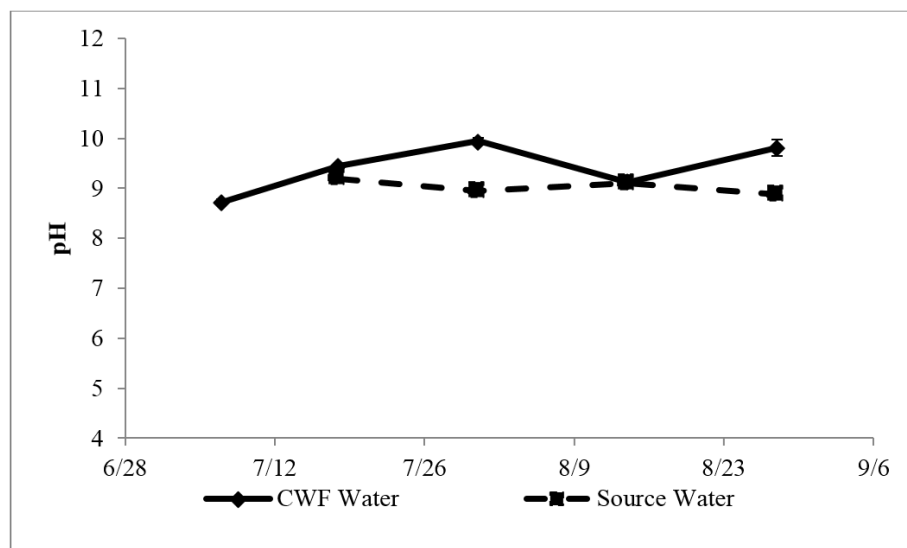


Figure 3.22. The pH levels for CWF water (solid lines) and source water (dashed lines).

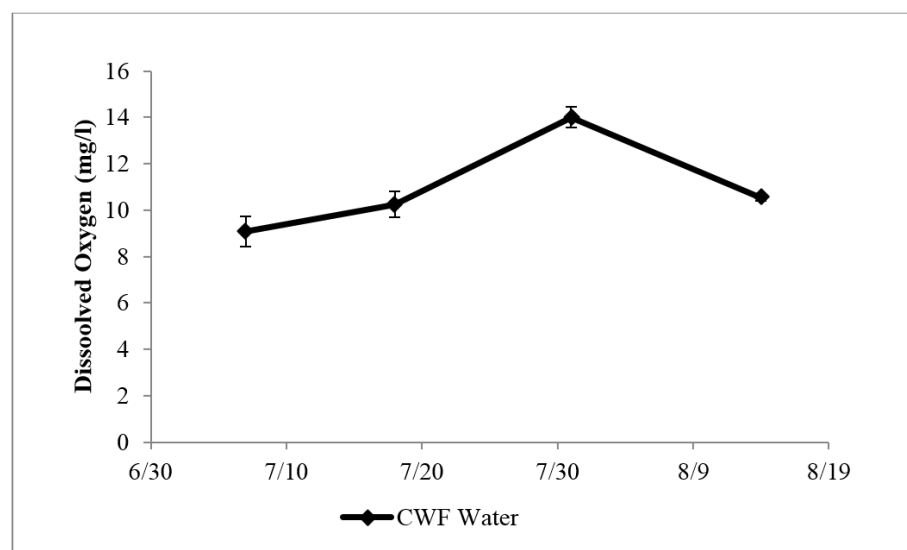
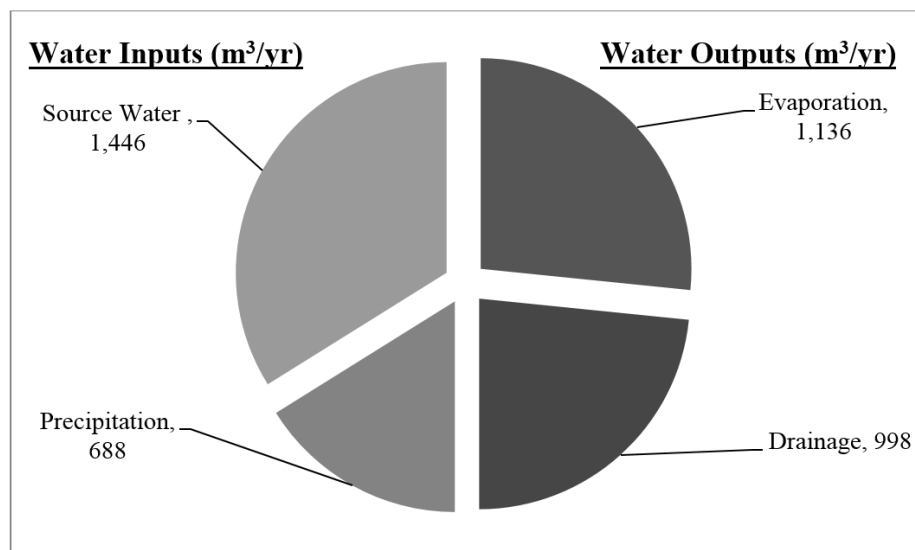


Figure 3.23. Dissolved oxygen levels for CWF water in Meridian Hill Park.

3.3.11 WATER BUDGET

The UMD Team estimated that the Meridian Hill Park water feature holds about 132,000 gallons (499 m³). The feature was estimated to lose more than twice that volume (299,900 US gal/yr or 1,135 m³/yr) to evaporation each year (Figure 3.24). Municipal source water makes up 382,019 gallons (1,446 m³/yr) of its annual water use, nearly 3 times its total volume. The Water Use ratio is 2.9, meaning that it consumes almost 3 times its volume in water from precipitation and the city water supply. The CWU ratio was 2.1, indicating that the CWF uses a little more than 2 times its volume from the city water supply. It loses 53% of water to evaporation each year and the rest (47%) lost to intentional drainage, leakage, and decommissioning at the end of the year.

Figure 3.24. Annual water budget (m³/yr) for Meridian Hill Park.



FOOTNOTES:

Evaporation (m³/yr) = Surface area (m²) * Evaporation (m/yr; data source: NOAA, 1982) = 1,092 m² * 1.04 m = 1,136 m³/yr

Drainage (m³/yr) = storage volume lost/event (m³/event) * # of times drained each year (events/yr; data source: direct observation) = 499.21 m³/event * 2 events/yr = 998 m³/yr

Precipitation (m³/yr) = surface area (m²) * precipitation (m/yr; data source: NOAA, 2015) = 1,092 m² * 0.6 m/yr = 688 m³/yr

Source Water (m³/yr) = Evaporative losses (m³/yr) + Drainage (m³/yr) – Precipitation (m³/yr) = 1,136 m³/yr + 998.4 m³/yr – 688 m³/yr = 1,446 m³/yr

During the summer of 2014, the water feature was intentionally drained and re-filled once in early July to manage algae, and nigrosine dye was added. Within weeks, the water was green and solids content was high. It is possible that the feature is drained and re-filled to deal with algal blooms more often during other years. Intentional drainage helps to restore clearer water in CWFs, but with nutrient concentrations elevated in source water, recovery of algae is quick. Thus, this kind of management is a short-term solution that serves to increase the CWF's

water use without lasting effects on algae levels. Further evidence of this lies in the phosphorus input analysis of the next section.

3.3.12 PHOSPHORUS SOURCES

Nearly all of the phosphorus inputs to the Meridian Hill Park water feature came from the municipal source water (419 g-P/yr; Figure 3.25), while a smaller portion came from rain, dust and litterfall (66 g-P/yr).

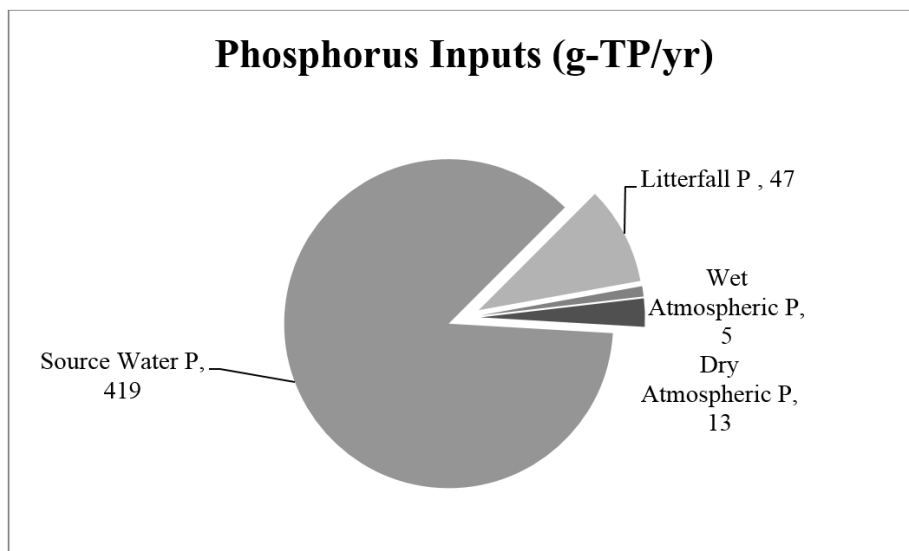


Figure 3.25. Phosphorus balance of Meridian Hill Park water feature during 2014.

FOOTNOTES:

Litterfall P = Rate of litterfall (g/m²/d) * Surface area (m²) * Annual days of operation (214 days/yr)
 * P released after 24 hrs. of decomposition (mg-P/g-leaf litter) = 1 g-leaf/m²/day * 1091/9 m² * 214days/yr * 0.2 mg-P/g * 1e-3 g/mg = 47 g - TP / yr

Wet Atmospheric P = Concentration of P in rainfall (µg/l) * Conversion to kg (1e-9 kg/µg) * Annual precipitation inputs (m³/yr) * conversion to liters (1000 l/m³) = 7.1 µg/l * 1e-6 g/µg * 687.9 m³/yr * 1000 l/m³ = 5 g - TP / yr

Dry Atmospheric P = Rate of deposition (kg-P/m²/yr * surface area (m²) * 1 year/12 months * 8 months/yr = 18.4 mg-P * 1e-3 g/mg * 1091.9 m² * 8/12 = 13 g - TP / yr

Source Water P = Concentration of P in Source Water (mg/l) * Annual source water inputs (l) * 1e-3 g/mg = 0.29 mg-TP/l * 1e-3 g/mg * 1446.1 m³/yr * 1000 l/m³ = 419 g - TP / yr

Thus, much of the phosphorus load could be avoided by using rainwater in place of municipal water. The phosphorus budget also suggests that if municipal water continues to be used, then it should be pre-treated to remove nutrients prior to being used.

Finally, the phosphorus budget shows that simply avoiding the use of municipal water minimizes phosphorus inputs but the other three major inflows (i.e., rainfall, dry fall, and litterfall) add amounts of phosphorus to the water that could result in algal blooms. Therefore some sort of phosphorus removal technology that continually treats the CWF water is warranted in order to control algae levels.

This could be constructed wetlands integrated into the landscape or modifications to existing PSFs to enhance their phosphorus removal capacity.

3.3.13 STAINING

Staining on the walls was documented in the Cultural Landscapes Report of 2001 and was evident during the summer of 2014 (Figure 3.26); however algal blooms were not mentioned in the Cultural Landscapes Report and may be a more recent development due to changes in water treatment in the municipal system (as discussed in Chapter 3). Staining is likely from the deposition of minerals from water during evaporation. Bersani et al (2008) investigated the causes of stains on a 17th-century water feature and used a suite of spectroscopies to identify the causes of white staining. They found deposits of “Laurionite” (PbOHCl), calcite, and lead carbonate. Other substances, such as lead compounds and sodium chloride, were found to degrade the stone structure through crystallization and dissolution cycles. They recommended repeated washes of de-ionized water at 40 C° to remove staining from the stone structures. This technique should further considered as a possible management solution for removal of white staining.



Figure 3.26. This photo shows the stains on the walls of the CWF. Photo taken June 6, 2014.

Algae, molds and other microbial growth could contribute to staining. Figure 3.27 shows greenish stains found on the walls of CWF while Figure 3.28 shows blackish staining underneath a fountain basin on the upper terrace. Sarro et al (2006) characterized biofilms and microbial growth on a water feature in Spain and found that biofilms consisting of algae, bacteria, fungi, and even mosses accelerate or cause a number deterioration processes on old water features. These organisms not only adjust the biochemical conditions of the substrate (altering localized pH, concentrations of CO₂ and H₂S) but also are able to physically penetrate surfaces and form fissures (Gaylarde and Morton, 1999; Sarro et al, 2006; Suihko et al, 2007;). Algae, in particular, are coated in a gelatinous material, that expands in volume

when hydrated. The result is physical deterioration of stone through the “wedge” effect, much like water damage during thawing and freezing cycles (Sarro et al, 2006). Sarro et al (2006) and other experts (Gaylarde and Morton, 1999) noted that in addition to mechanical deterioration, these organisms produce metabolites (often organic acids) that accelerate the degradation of stone material through chemical weathering. The types of organisms present on a biofilm are site-specific, but all very likely exhibit the deterioration effects discussed here (Gaylarde and Morton, 1999; Suihko et al, 2007).

Biofilm growth can occur in humid microclimates, or where splashing water keeps surfaces hydrated. The chief factor in controlling biofilm growth is moisture, although nutrient availability also plays a role (Gaylarde and Morton, 1999). Thus one method to reduce the growth of biofilms would be careful control of water flow, such as the adjustment of fountain spouts so that water does not constantly flow over surfaces; but the control of nutrients (nitrogen and phosphorus) could also help control or reduce the development and growth of biofilms in these features.



Figure 3.27. Greenish staining, likely from biofilms and algal growth on the walls of the CWF. Photo taken June 6, 2014.



Figure 3.28. Blackish staining underneath the top fountain basin. Photo taken July 1, 2014.

3.4 CONCLUSION

This study indicates that the cause of algal growth in the CWF at Meridian Hill Park is the highly eutrophic water source being used for make-up and filling the CWF. Without any nutrient management strategy in place, elevated nutrients in source water cause rapid algal growth in the CWF. PSFs for the removal of solids are currently unable to filter algae out, and need to be evaluated further to determine whether the filters need to be repaired, unclogged, or upgraded to improve performance.

In order to prevent algal growth in the feature, nutrient management specifically targeting nitrogen and phosphorus and a better solids filtration system are needed. The use of any disinfectant must be accompanied by a thorough investigation also into compatibility of the disinfectant with the materials used in construction of the CWF (exposed aggregate concrete, brass, iron and PVC plastic pipe fittings). Chlorination may be incompatible due to its high corrosive properties, and reduced efficacy in high pH waters. Possible solutions are discussed later in this document (see Chapter 7).

CHAPTER 4: THE WOMEN IN MILITARY SERVICE FOR AMERICA MEMORIAL



Figure 4.1. The Women in Military Service for America (WIMSA) Memorial and Fountain.

4.1 BACKGROUND

The Women in Military Service for America (WIMSA) Memorial is dedicated to the women who served in the US armed forces over the years. The structure of the memorial is a hemicycle or semicircle structure that was built in 1932 as a gateway to Arlington National Cemetery. In the 1990s, the gateway was reconstructed to house a museum and memorial to women in the US military that includes an innovative database of women who served.

The WIMSA Memorial includes a stone-lined CWF that uses municipal water for initial fill and make-up water (Figure 4.1). Like the CWF at the FDR Memorial, the WIMSA CWF is central to the visitor experience. The water flow and reflecting pool create a reflective atmosphere and symbolize the contributions of women in the military. The memorial was dedicated in October of 1997 with a fully functional water feature.

WIMSA was chosen late in the study to replace the Theodore Roosevelt (TR) Memorial. TR was canceled as a study subject because it had mechanical plumbing problems that rendered the CWF inoperable. After some deliberation, WIMSA was chosen as a replacement in August 2014.

4.2 METHODS

4.2.1 WATER FLOW AND PLUMBING LAYOUT

A site visit and tour of the park and pump room served to familiarize the UMD Team with the layout of the CWF and the plumbing system. Original engineering plans and plumbing layouts were obtained from the NPS Office in Arlington, VA. Information on water volumes was not available in plans and documents, so water volumes were estimated through calculations based by on measured water depth and surface area of the basin, raceway, and waterfall feature. The volumes of water, contained within plumbing systems, such as piping, sand filters and pumps, were not estimated.

4.2.2 WATER QUALITY SAMPLING

Research permits for water sample collection were obtained on September 26, 2014. Three water samples were taken from the WIMSA Memorial CWF at 11:00am on October 30, 2014 for analysis. Before this time, water samples could not be taken because the CWF had no water and was empty. There was no access to source water during this sampling visit. After this visit, the WIMSA CWF was shut down and winterized for the remained of the year. See Chapter 2 for details of the water analysis methods used in this study.

The UMD Team made four (4) visits to the WIMSA Memorial in order to update photo documentation and make visual observations based on a set criterion as outlined in Chapter 2. The CWF and its components were photographed numerous times to document water color, debris in the feature, and general appearance. Visual observations were made on the dates listed in Table 4.1.

Table 4.1. Water Sampling and Visual Observation Dates

DATE	WATER SAMPLES TAKEN	VISUAL OBSERVATIONS
8/6/14		X
9/17/14		X
10/1/14		X
10/24/14		X
10/30/14	X	

4.2.3 DISCHARGE ESTIMATES AND WATER BUDGET ANALYSIS

Site managers and supervisors were interviewed on October 24, 2014 to estimate how often the CWF was completely drained and re-filled during a year of operation to determine discharge estimates. Estimated rates for evaporation were taken from pan evaporation rates for Baltimore, MD during 1956-1970 for April through October (NOAA, 1982) in the absence of recent local data. Estimated precipitation rates were taken from NOAA (2015). The data presented here are estimates of discharge and water use based on a more limited study period.

4.2.4 PHOSPHORUS INPUTS

Phosphorus inputs were estimated as outlined in Chapter 2. No waterfowl were assumed to contribute significant phosphorus flows into the WIMSA CWFs because none were observed during the study. Adjacent to the WIMSA Memorial are several mature trees and other vegetation. Leaf litter estimates were taken from estimates of a typical deciduous forest (Bell et al, 1978) and rates of phosphorus release were taken from previous studies (Duan et al, 2014; Hobbies et al, 2014). Rates of phosphorus flow into the system from source water were calculated from observed concentrations of phosphorus in this study. Rates of atmospheric deposition of phosphorus were averaged from Koelliker et al (2004), Ahn and James, (2000); Chen et al, (2008), Delumyea and Petel (1978) and Sun et al (2013).

4.3 RESULTS AND DISCUSSION

4.3.1 PLUMBING LAYOUT AND SYSTEM DIAGRAM

Figure 4.2 is a conceptual diagram of the plumbing system and water flow of the WIMSA CWF. Water is drawn from the Washington DC municipal water supply (i.e., Washington Aqueduct) to fill the feature and for makeup. Discharge is to the storm drain that directs water to an outfall on the Potomac River. Discharge to a natural water body severely limits the use of biocides at this site. The water flows from the reflecting pool to a 20 HP centrifugal pump, which diverts a portion of the flow to the PSFs and the remainder to a second 20 HP pump that returns water to the hemicycle fountains.

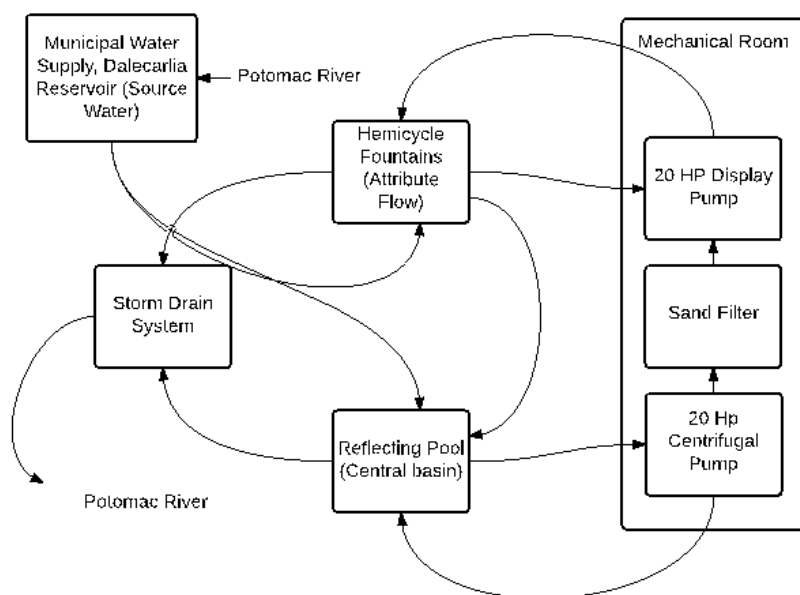


Figure 4.2. Schematic flow diagram of the WIMSA Water Feature. Only a portion of the water flow is delivered to the sand filters.

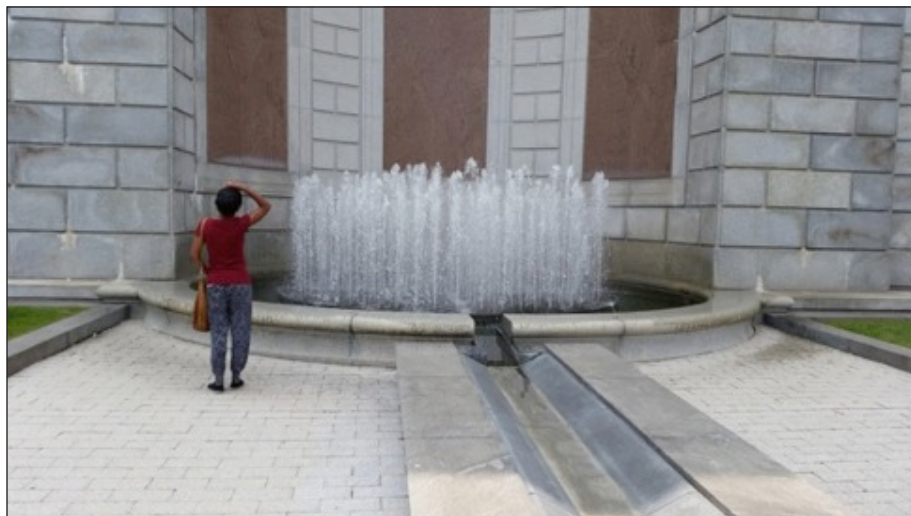


Figure 4.3. The hemicycle fountain and narrow channel. Photo taken August 6, 2014.

The hemicycle fountain is a black granite cobblestone basin within an apse with 200 water jets (Figure 4.3). The hemicycle fountain sends water slowly along a narrow channel (Figure 4.4) to a central mortar and cobblestone lined reflecting pool (78 ft. diameter) in the center of the plaza. The entire CWF has a surface area of 4,688 ft² and an average depth of 1 ft. The reflecting pool has an estimated volume of 36,000 gallons. The reflecting pool is lined with a waterproof membrane; however the membrane stops short of reaching the outer edge of the pool leaving about a 1-foot gap around the edge (NPS staff). Due to the incomplete membrane water leaks continuously through the cobblestone and mortar structure near the sides of the pool. Evidence of this seepage is shown in Figure 4.5.

Figure 4.4. The narrow channel that connects the hemicycle fountain to the central reflecting pool. Photo taken August 6, 2014.

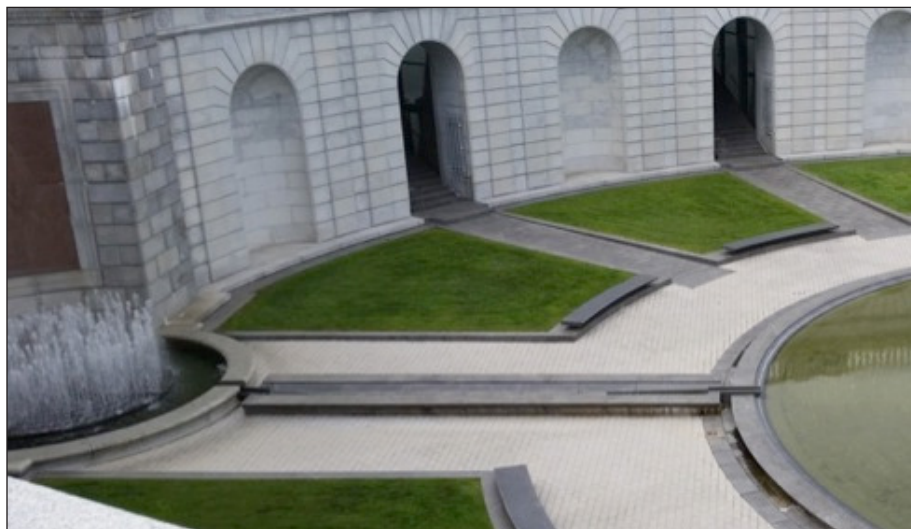




Figure 4.5. Leakage along the sides of the reflecting pool. Photo taken August 6, 2014.

According to NPS WIMSA maintenance staff, the CWF is only operational for 8 to 10 weeks of what is normally an 8-month period (32 weeks) of operation. Algal blooms were difficult to manage and developed quickly so instead of operating it continuously as designed, the feature was filled and operated only during high-visitation weekends and during special events that were expected to draw large numbers of visitors.

When the fountain was operational, staff used sodium carbonate peroxyhydrate (GreenClean Granular Algaecide, BioSafe Systems, East Hartford, CT) to control algae in the feature. The resulting dead algae biomass that settled to the bottom was removed manually by NPS maintenance since power washing would damage the cobblestone mortar. The roughness of the mortar and cobble can harbor viable algal cells that can quickly regrow after the cleaning procedure. The water feature drains directly to the nearby Potomac River and therefore is regulated by the Clean Water Act, restricting the discharge of chlorine compounds to waterways. Chlorination is not permitted in the fountain; however sodium carbonate peroxyhydrate does not harm natural waterways when used according to label instructions (EPA, 2002).

During a UMD Team site visit in September of 2014, the PSFs (Figure 4.6) were off-line due to clogging. Maintenance staff inspected the PSF sand discovered that a cement-like residue had built up on the inlet nozzles and on the drains of the sand filters and the sand bed was heavily caked, severely reducing water flow through the filter. Maintenance staff described the residue within the filter a hardened black coating on the sand bed. They also noted that a white residue occasionally builds up on the hemisphere fountain spouts and clogs them. This may be mineral scale on the spouts as previously discussed in Chapter 3.

These conditions may be due to infrequent backwashing or insufficient backwash duration of the PSF that resulted in a buildup of algae and other organic matter in the sand particles. Maintenance staff noted that the mortar in the reflecting pool had been deteriorating. While the frequent cleaning and natural weathering may be deteriorating the mortar, another explanation is the biocides are contributing to deterioration of the mortar. Further investigation into compatible biocides may be warranted as some biocides can damage stonework and other structures (Gaylarde and Morton, 1999). Whatever the cause of the mortar degradation, the PSFs may have been clogged with the accumulation of mortar degradation by-products, algae, and organic debris.

The shallow nature of the water basin and the full exposure to long periods of sunlight makes it an ideal vessel for growing algae. The dark bottom and shallow water can result in rapidly warming conditions that can further drive the development of algal blooms. Finally the rough bottom with many crevices, pitting, and pockets can harbor attached and settled suspended algae and provide protected areas from effective use of biocides or other chemical controls. This can act as a reservoir for acclimated algae in sufficient quantities to develop rapidly into blooms and be unsightly to the public.



Figure 4.6. The clogged sand filters in the pump room of the WIMSA CWF. Photo taken on October 24, 2014.

4.3.2 FOAM

There was a small amount of foaming in September and early October that collected in the hemicycle fountain (Table 4.2; Figure 4.7) and along the rims of the central reflecting pool. It was minor and may have resulted from the addition of

the sodium carbonate peroxyhydrate (GreenClean Granular Algaecide, BioSafe Systems, East Hartford, CT) used to manage algal blooms. On October 24, no foaming was present at all. The CWF had been filled right before the site visit and chemical biocides had not been added so water quality was relatively pristine at this time.

Table 4.2. Foam coverage in the WIMSA CWF.

DATE	FOAM (% COVER)
8/6/14	3%
9/17/14	10%
10/1/14	10%
10/24/14	0%



Figure 4.7. Foam collecting in the hemicycle fountain on October 1, 2014.

4.3.3 WATER-COLOR

As shown in Table 4.3, the water-color was some shade of green on all three of the site visits until October 24, when it was completely clear (it had recently been filled with clean water; Figure 4.8). The colors were quite different that had been witnessed at Meridian Hill Park. Often times the algae was a very light green (Figure 4.9) and in early August, the water was a murky green (Figure 4.10). The shades of green all indicate algal growth that is either in a different stage of development or a different species.

Table 4.3. Water-color in the WIMSA CWF.

DATE	WATER COLOR
8/6/14	Murkey Green
9/17/14	Light Green
10/1/14	Green
10/24/14	Clear



Figure 4.8. Clear water in the WIMSA Memorial reflecting pool on October 24, 2014. Note the cobble and mortar bottom structure.



Figure 4.9. Light green water and algae in the main reflecting pool on September 17, 2014.



Figure 4.10. Murky green water in the WIMSA Memorial reflecting pool on August 6, 2014.

4.3.4 ODOR

Odor was strongest when the water was discolored and not detectable when the water was clear (Table 4.4). The UMD Team noted a slight chemical smell as well as an odor from algae. The chemical is probably from the biocide used to control algal blooms.

Table 4.4. Odor ratings and descriptions of the WIMSA CWF

DATE	ODOR RATING	DESCRIPTION
8/6/14	6	Algae / Chemical
9/17/14	5.5	Algae / Chemical
10/1/14	6	Algae / Chemical
10/24/14	1	No Odor

4.3.5 PLANT DEBRIS

Plant debris was not observed in large amounts (Table 4.5) and it tended to collect in the reflecting pool and in the narrow channel (Figure 4.11 and Figure 4.12).

This debris was collected manually since the feature was not fitted with skimmers for surface material removal. The use and installation of swimming pool like skimmers could reduce surface material and reduce dependence on daily maintenance.

Table 4.5. Plant debris coverage on the water surface of the WIMSA CWF

DATE	PLANT DEBRIS (% COVER)
8/6/14	6%
9/17/14	5%
10/1/14	5%
10/24/14	0%

Figure 4.11. Plant debris in the reflecting pool on October 24, 2014.



4.3.6 LITTER

In all of the site visits made by the UMD Team, litter was never present in the CWF. The WIMSA Memorial is a reflective CWF where visitors honor those lost in military service, so the visitors may not have foodstuffs, drinks and other trash with them during visits. Possibly the close association of the volunteer staff at the memorial contributed to higher degree of litter collection.



Figure 4.12. Plant debris collecting in the narrow channel on October 24, 2014.

4.3.7 ALGAE

The algae observed in the CWF at WIMSA appeared to be an attached benthic variety on the bottom of the feature (Table 4.6). Other algae suspended in the water column may have been present but it was not visible to the naked eye. The single water sample taken in October 2015 revealed very low concentrations of suspended solids, which would support the visual record of the site. In interviews, maintenance staff noted the difficulty of cleaning the algae off of the basin floor. The basin floor is mortar and granite cobblestone, which makes it difficult to clean. During any scrubbing, algae that lie between the cobblestones cannot be removed by brush and instead the staff turned to low-pressure power-washing so as to not damage the soft mortar between stones. In Figure 4.13, the algae between the individual stones can be clearly viewed, as well as the deterioration of the mortar. In addition to algae, the UMD Team also observed what appeared to be dragonfly larvae in the CWF (Figure 4.14).

Interviews revealed that this staff frequently called to report algal blooms in the water feature. This indicates the value of having a Friends Group or similar organi-

zation to support all the water features as another set of eyes and labor to inspect and help clean these structures.

Table 4.6. Algae Coverage in the WIMSA CWF

DATE	% COVER	P	B
8/6/14	70%		X
9/17/14	70%		X
10/1/14	70%		X
10/24/14	0%		
P = Planktonic suspended algae / indicated by greenish water B = Benthic algae on basin floor			



Figure 4.13. Algae are difficult to clean when it lies in the space between cobblestones. Photo taken October 24, 2014.

Figure 4.14. Dragonfly larvae in the CWF at the WIMSA Memorial. Photo taken on October 1, 2014.



4.3.8 NUTRIENT ANALYSIS

Nutrient concentrations of the CWF at WIMSA Memorial were quite high and could be considered hypereutrophic as shown in Table 4.7. Concentrations of both TP and PO_4^{3-} were substantially above concentrations that would trigger algal blooms. The Florida Department of the Environment's Trophic State Index (TSI) is a system that classifies the extent of nutrient pollution in aquatic water bodies such as lakes, ponds and reservoirs based on the amount of nutrients (either phosphorus or nitrogen) found in the water. The index provides a quick estimation of how productive the water body is by its assigned TSI number within a range of 1 to 100. Once a score is obtained, the water body is placed in a category for water quality. Levels of TP in the WIMSA fountain are above the maximum score of 100 (0.58 mg/l TP; LCWA 2015), placing it in the hypereutrophic/poor category.

TN and NO_3^- were also sufficiently high enough that the TSI placed the CWF water in the hypereutrophic/poor category. Most of the nitrogen was in the NO_3^- form, which is expected in a well-aerated water column (by the fountain jets) where NH_3 is quickly used for microbial metabolism and converted to NO_3^- via nitrifying bacteria. NO_3^- is more soluble than NH_3 and is readily used for growth by algae. Without anoxic microsites that would allow for denitrification of NO_3^- to nitrogen gas (N_2), NO_3^- is likely to remain in the water. Concentrations of NO_3^- are comparable to data from the Washington Aqueduct (the local water supply), which averaged 2.4 mg/l NO_3^- during 2013 (US Army Corps of Engineers, 2013).

Table 4.7. Nutrient concentrations for the CWF water at WIMSA. Sampled on October 30, 2014.

NUTRIENT	CONCENTRATION (mg/l)
TP	0.9
PO_4^{3-}	0.8
TN	2.2
NH_3	0.4
NO_3^-	1.5

4.3.9 SOLIDS ANALYSIS

Given, that nutrient levels are well above what is necessary for algal growth, the water sample collected on October 30, 2014 did not show high concentrations of algae (Table 4.8). The VSS concentrations indicated that all the TSS was in the organic form as algal solids. Maintenance staff informed us during the site visit on October 24, 2014 that the CWF had only been filled a few days before. Algae did not have sufficient time to develop into a bloom. This might have also been due to the shorter photoperiod and declining water temperatures compared to mid-summer.

Table 4.8. Solids concentrations for the CWF water at WIMSA. Sampled on October 30, 2014.

SOLIDS TYPE	CONCENTRATION (mg/L)
TS	291.1
TDS	288.9
TSS	2.2
VSS	2.2

4.3.10 WATER DISCHARGE ESTIMATES AND WATER BUDGET ANALYSIS

WIMSA Memorial has a total volume of 36,000 gallons. The CWF was only filled when there is a special event or a high-use weekend approaching. After 5 to 10 days of operation it is shut down and drained, only to be re-filled later for the next event. This means that 36,000 gallons are wasted every time the CWF is drained for cleaning. It is only operational 8 to 10 weeks of the year for short periods of 10 days or less, rainwater only contributes a very small amount. The water budget presented in Figure 4.15 reflects this type of management. The CWF relies on source water from the municipal water supply for the majority of water inputs, and only receives a small amount of free water from rain. The City Water Use ratio is 15 meaning that it uses 15 times more municipal source water than rainwater. Its overall water use to volume ratio is 10 indicating that it uses 10 times its volume in water (both from the municipal supply and rain) each year. Evaporation only

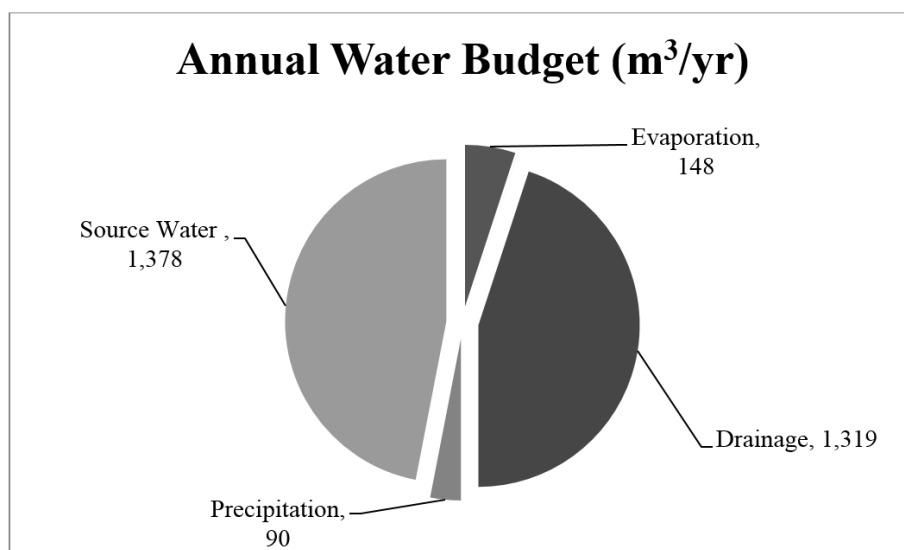


Figure 4.15. Annual water inputs (m³/yr; on left) and water losses (m³/yr; on right) of the CWF at the WIMSA Memorial.

FOOTNOTES:

Evaporative Losses = evaporation rate for 10 weeks (m/yr) * surface area (m²/yr) = 0.34 m/yr * 435.5 m² = 148 m³/yr

Splashing Losses = estimated rate (m³/hr) * hours of operation (hrs/yr) = 0.0001 m³/hr * 1,680 hrs/yr = 0.2 m³/yr

Drainage = storage volume lost/event (m³/event) * # of times drained/yr (events/yr) = (131.91 m³/event) * (10 event/yr) = 1,319 m³/yr

Precipitation = surface area (m²) * precipitation (m/yr) = 6394 m² * 0.014 m/yr = 90 m³/yr

Source Water = Evaporation (m³/yr) + Drainage (m³/yr) + Splashing losses (m³/yr) + Leaks (m³/yr) - Precipitation (m³/yr) - Overland flow (m³/yr) = 148 m³/yr + 0.2 m³/yr + 0 m³/yr + 1319 m³/yr - 90 m³/yr - 0 m³/yr = 1,378 m³/yr

accounts for 11% of water loss in comparison to intentional drainage, which accounts for 89% of the water loss. Since the CWF is drained when algae is evident, water could be conserved by preventing algal growth.

4.3.11 PHOSPHORUS SOURCES

Since source water at WIMSA was not available during sampling visits, concentrations of phosphorus from the Franklin Delano Roosevelt Memorial were assumed (see Chapter 5). According to estimates of phosphorus inputs (Figure 4.15), nearly all of the phosphorus inputs came from the municipal source water at the WIMSA Memorial; phosphorus inputs from the atmosphere, birds, and litterfall were very low because the feature is only operated for 8-10 weeks of the year.

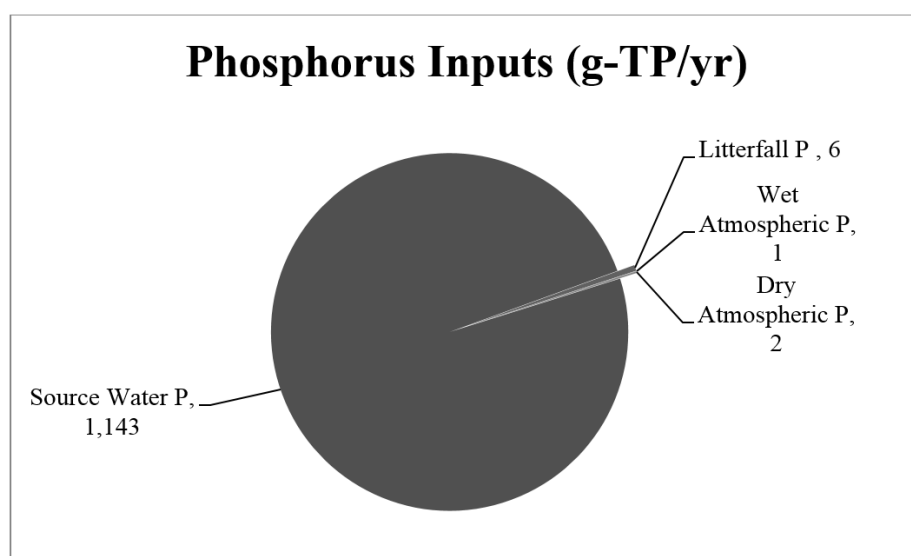


Figure 4.16. Phosphorus balance of WIMSA water feature during 2014.

FOOTNOTES:

Litterfall P = Rate of litterfall (g/m²/d) * Surface area (m²) * Annual days of operation (214 days/yr)
 * P released after 24 hrs of decomposition (mg-P/g-leaf litter) = 1 g-leaf/m²/day * 435.50m² * 70 days/yr * 0.2 mg-P/g * 1e-3 g/mg = 6 g-TP/yr.

Wet Atmospheric Deposited P = Concentration of P in rainfall (µg/l) * Conversion to kg (1e-9 kg/µg) * Annual precipitation inputs (m³/yr) * conversion to liters (1000 l/ m³) = 7 µg/l * 1e-6 g/µg * 89.7 m³/yr * 1000 l/m³ = 0.6 g-TP/yr.

Dry Atmospheric Deposited P = Rate of deposition (kg-P/m²/yr * surface area (m²) * 1 year/12 months * 8 months/yr = 18.4 mg-P * 1e-3 g/mg * 435.50 m² * 8/12 = 2 g-TP/yr.

Source Water P = Concentration of P in Source Water (mg/l) * Annual source water inputs (l) * Grams/milligram (g/mg) = 0.83 mg-TP/l * 1377.7 m³/yr * 1e-3 g/mg * 1000 l/m³ = 1143 g-TP/yr.

A large portion of the incoming phosphorus likely flows out when the feature is drained or leaks, with only a small portion remaining in the feature as sediment or bound to the walls of pipes and stones. Phosphorus does not accumulate in sediments in the CWF during the course of the season, since any debris and sediment is removed by management. Even without accumulation during the season, the concentrations of phosphorus and nitrogen in source water are more than

sufficient to promote algal growth. The use of alternate water sources, such as rain, and/or some sort of phosphorus and nitrogen removal technology are needed to reduce nutrient loads that are favorable to the growth of algae. Reducing water use will not suffice on its own as nutrient reduction, but does help in reducing the CWF's water footprint and enhancing sustainability.

4.4 CONCLUSION

Hypereutrophic source water and the shallow basin exposed to direct sunlight cause rapid algal growth that discolors water. Current methods of water treatment, such as sand filtration and the use of biocides, were not sufficient to manage water quality and, as a result, maintenance staff were draining the CWF of water and re-filled it with clean water 8-10 times per season. This means that much of the time the CWF was empty and not functioning.

Finally the rough bottom with many crevices, pitting, and pockets can harbor attached and settled suspended algae and provide protected areas from effective use of biocides or other chemical controls. This can act as a reservoir for acclimated algae in sufficient quantities to develop rapidly into blooms and be unsightly to the public. It appears that the mortar in the cobblestone basin is deteriorating in certain areas, due in part to frequent draining and cleaning. It may be that deteriorating mortar has caused some water leaks along the sides of the basin. Other leaks may be caused by an incomplete internal liner as suggested by maintenance staff at WIMSA.

Upgrades to the system focusing on nutrient management are needed in order to reduce the intensity, frequency, and rapid growth of algal blooms in the system. In addition, repair or redesign of the main vessel to complete the liner and reduce the bottom roughness would help in maintenance and reduce water loss. Repairing the PSFs and replacing the sand may help, but PSFs with standard #20 filter sand do not remove nutrients and may not work well to reduce intense algal blooms. Additional investigations into optimizing the PSF operation focusing the media (sand) and potential chemical additives (lanthanum chloride or flocculants) is recommended. Integration of submerged surface flow wetlands into the landscape could also provide effective treatment of nitrogen and phosphorus. These could be designed to integrate into any landscape scheme and use a variety of acceptable plants.

CHAPTER 5: THE FRANKLIN DELANO ROOSEVELT MEMORIAL



Figure 5.1. The Room 4 Fountain at the FDR Memorial. Photo taken July 14, 2014.

5.1 BACKGROUND

The Franklin Delano Roosevelt Memorial (FDR Memorial; Figure 5.1) is the most recent and the third most visited presidential memorial on the National Mall with approximately 2.5 million visitors per year (Rainey, 2012). Its popularity may be because the memorial “*celebrates the values and accomplishments of past generations in crisis, and in this case, of one man at the center of that crisis, as it also challenges us to consider seriously their relevance to the tasks of the present*” (Rainey, 2012). Construction of the Memorial took 20 years to complete before it was ceremoniously opened in May 1997. Even once officially opened to the public, a sculpture of Roosevelt in a wheelchair was added to the memorial in 2001 at the request of disabled persons organizations and Congress.

Water is a major component of the FDR Memorial. The design consists of impressive attribute flows (water falls) and basins that convey mood and narrative about the President’s tenure. The water features emphasize the importance of water in FDR’s life and symbolize his love of sailing, his tenure as Assistant Secretary to the Navy, and his therapeutic use of water throughout his life (Halprin, 1997). Each feature is designed to commemorate a portion of FDR’s life and struggle, while creating a deep sensory experience for visitors. These features are positioned across four outdoor rooms that represent each of FDR’s terms of office and his legacy. The water features also have practical purposes of creating narrative and intensity to the memorial while masking the sound of airline jets that frequently fly overhead on their way to nearby Reagan National Airport (Halprin, 1997).

Because water is used as a central narrative element in each of the four rooms, the FDR Memorial is the most complex of the four sites examined in this report. The memorial contains seven (7) water features that operate separately from one another, but share common chemical treatment systems housed in two equipment spaces underneath the memorial. Each of the CWFs have similar water treatment systems consisting of a pressurized sand filter (PSF), screen cartridge filter, and shared chemical treatment assemblages (no longer operational). The features vary in size, water volume, flow rates, and pumps systems.

NPS staff has identified the FDR Memorial as a challenging CWF to manage. It has had re-occurring problems with green water and staining on the granite walls of the structure. Therefore, the site was a good candidate for study, and the WFTF chose it for study based on its characteristics as a complex, highly visited CWF with extensive attribute flows and water sourced from the municipal water supply.

5.2 METHODS

5.2.1 WATER FLOW AND PLUMBING LAYOUT

In order to determine the water flow and plumbing layout, the Franklin Delano Roosevelt As-Constructed Drawings (Drawing No. 897 41013A) were examined. A site tour of the Equipment Spaces and CWFs also served to inform simplified diagrams of water flow and plumbing systems. Information on water volumes was not available in plans and documents, so water volumes were estimated through calculations based on measured water depth and surface area of basins and waterfall features. The volumes of water, contained within plumbing systems, such as piping, sand filters and pumps, were not estimated.

5.2.2 WATER QUALITY SAMPLING AND VISUAL OBSERVATIONS

Research permits for water sample collection were obtained on September 2, 2014. Three (3) water samples were taken from the Room 2 Fountain, Room 3 Fountain, and Room 4 Fountain during each sampling visit (total of 3 samples per visit). These samples were then averaged to obtain a sample mean of the overall system. One sample for metals analysis was taken from the Cortège Fountain based on suspicion of possible metals contamination from corrosion of a bronze plaque, above the water basin. Source water samples were taken in triplicate from a faucet in the Visitor's Center. A total of 4 sample means for each feature with standard error was obtained ($n=4$) and plotted in the results section of this chapter.

The UMD Team made regular visits to the FDR Memorial in order to update photo documentation and make visual observations based on a set criterion as

outlined in Chapter 2. All of the CWFs on site were photographed numerous times to document water-color, foaming, debris in the feature, and general appearance. Table 5.1 shows the sampling dates for water and visual observations.

Table 5.1. Water Sampling and Visual Observation Dates

DATE	WATER SAMPLES TAKEN	VISUAL OBSERVATIONS
6/17/14		X
7/1/14		X
7/14/14		X
7/29/14		X
8/14/14		X
9/17/14	X	X
10/1/14	X	X
10/15/14	X	
10/30/14	X	

5.2.3 ENERGY USE ESTIMATES

Estimates of the change in elevation from the pump to the highest point in the CWF were estimated by referring to the Franklin Delano Roosevelt As-Constructed Drawings (Drawing No. 897 41013A). These estimates were then used in Equation 2.6, 2.7 and 2.8 to obtain an estimate of total energy use for all of the CWFs at the Memorial.

5.2.4 DISCHARGE ESTIMATES AND WATER BUDGET ANALYSIS

For determining water budgets and discharge rates, estimates were determined for all seven CWFs at the Memorial in a single analysis. Individual water budgets for each CWF were not determined. Site managers and supervisors were interviewed to estimate how often the CWFs were completely drained and re-filled during a year of operation to determine discharge estimates. Splashing losses were observed at the Room 3 Fountain, but were estimated at only 200 ml/hr. Estimated rates for evaporation were taken from pan evaporation rates for Baltimore, MD during 1956-1970 for April through October (NOAA, 1982) in the absence of recent local data. Estimated precipitation rates were taken from NOAA (2015). The data presented here should be considered approximate estimates of discharge and water use, rather than observed data.

5.2.5 PHOSPHORUS INPUTS

As in the water budget analysis, the CWFs were aggregated and estimated as a single system. No waterfowl were assumed to contribute significant phosphorus flows into the CWFs at the FDR Memorial. Considering that the FDR Memorial includes significant vegetation and tree cover in close proximity to the CWFs, leaf litter estimates were taken from estimates of a typical deciduous forest (Bell et al, 1978) and rates of phosphorus release were taken from previous studies (Duan

et al, 2014; Hobbies et al, 2014). Rates of phosphorus flow into the system from source water were calculated from observed concentrations of phosphorus in this study. Rates of atmospheric deposition of phosphorus were averaged from Koeliker et al (2004), Ahn and James, (2000), Chen et al, (2008), Delumyea and Petel (1978) and Sun et al (2013).

5.3 RESULTS AND DISCUSSION

5.3.1 PLUMBING LAYOUT AND SYSTEM DIAGRAM

The FDR Memorial consists of seven (7) different CWFs that operate independently by pumps housed in two “Equipment Space” rooms. Volumes and pumps are summarized in Table 5.2 below. Water for the fountains at the memorial is drawn from the municipal water supply from the Washington Aqueduct treated by the Dalecarlia and McMillan Treatment Plants. The individual CWFs varied in volume from 682 gallons to an estimated 16,700 gallons and the surface areas varied from 73 ft² to 2,320 ft².

Table 5.2. Summary of Main Characteristics of the 7 CWFs at the FDR Memorial.

FOUNTAIN	ESTIMATED VOLUME (GALLONS)	BASIN SURFACE AREA (FT ²)	PUMP SIZES	SAND FILTER SIZE (DIAMETER)	EQUIPMENT SPACE
Room 1	4,260	428	50-hp display 1.5-hp filter	24"	1
Room 2	10,869	1,345	50-hp display 1.5-hp filter	36"	1
Room 3	3,960	577	40-hp display 1.5-hp filter	24"	2
Room 4	16,700	2,320	3 x 40-hp display 5-hp filter	48"	2
Niche 1	682	73	5-hp display	24"	1
Niche 2	2,350	220	5-hp display	24"	1
Cortege	5,827	519	40-hp display 1.5-hp filter	48"	2

Figure 5.2 shows a basic diagram of water flow for CWFs at the FDR Memorial. Each of the CWFs at FDR was installed with a single PSF (sizes listed on Table 5.1). The sand filters were filled with sand for filtration and a coarse gravel to support the medium (Franklin Delano Roosevelt As-Constructed Drawings, Drawing No. 897 41013A; Figure 5.3). Staff interviews suggested that the PSFs had not been operating properly and that the filter sand had not been changed since their installation. These filters remove solids from the water by flowing it from an influent pipe at the top through sand and subsequent gravel medium before it exits an effluent pipe at the bottom. Solids removal efficiencies are controlled by sand grain size, sand bed height, and flow rates (i.e. how thick the bed of sand is; Sabiri et al,

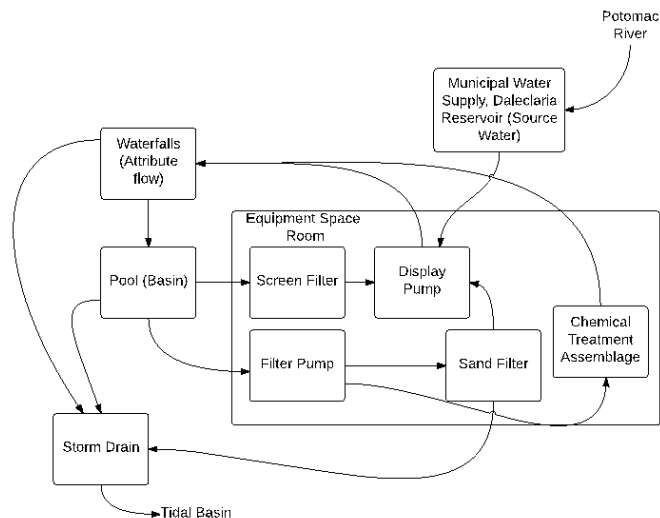
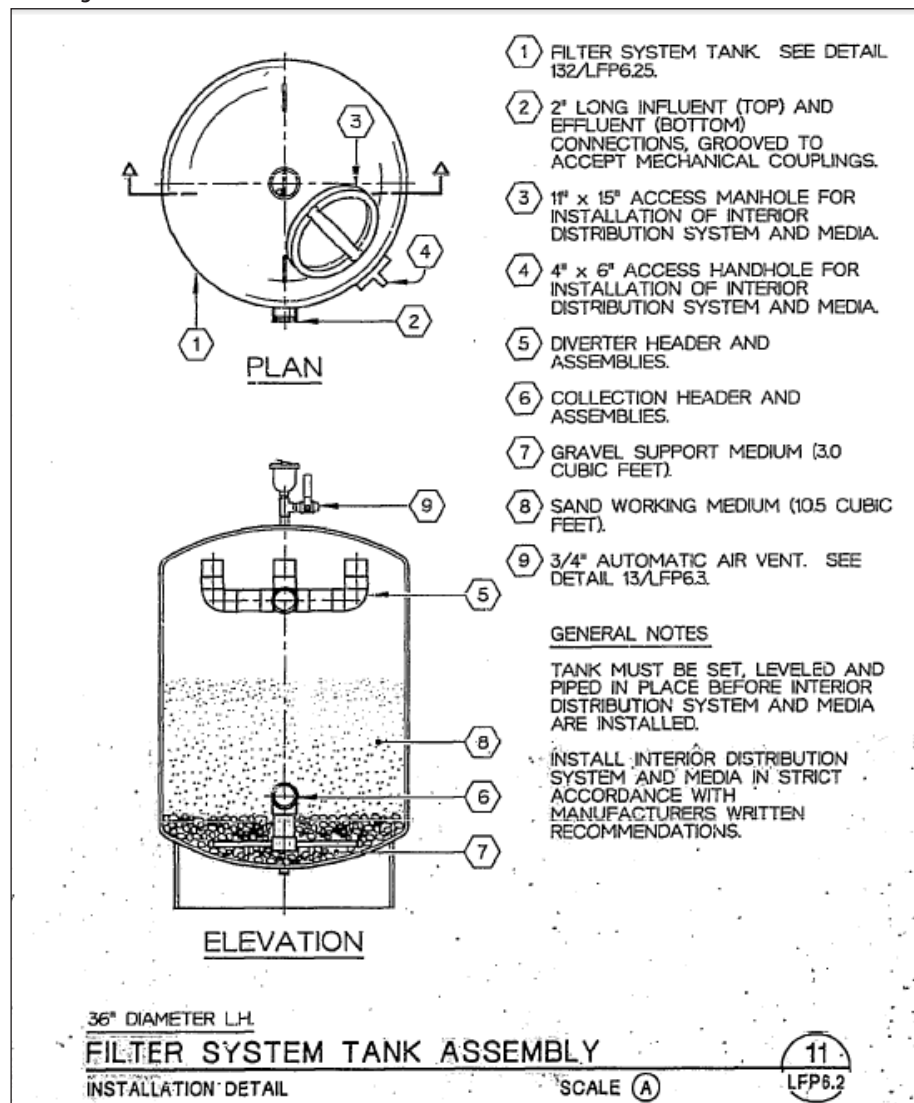


Figure 5.2. Schematic flow diagram for seven water features at the FDR Memorial.

Figure 5.3. Pressurized Sand Filter (PSF) assembly diagram taken from FDR As-Constructed Drawings.



2012). Grain size was not listed in the As-Constructed Drawings, but presumably sufficient grain size was selected during the initial design.

The CWFs at the FDR Memorial share two chemical treatment assemblages (CTAs) that are housed in the two equipment rooms. The CTAs are automated systems that were initially installed in 1997 to manage water quality, prevent algal blooms, and reduce public health risks. The systems are no longer used due to concerns about chemical use in systems that discharge to an open water body (the Tidal Basin) and lack of maintenance. When installed, the systems used four chemicals for adjusting water quality. Caustic soda and muriatic acid were used to manage pH and adjust the solubility of total dissolved solids (TDS), while a biocide was used to disinfect the water and prevent bacterial and algal growth. An inhibitor chemical was used, but the UMD Team could not identify their purpose or any explanation of their use. It is likely that the inhibitor chemical prevented corrosion of the pipes and metal components or it could have been used to stabilize the biocide chemical.

5.3.2 FOAM

Table 5.3 shows the estimates of foam coverage in water basins of the CWFs at the Memorial. The room 2, 3, and 4 Fountains had accumulations of foam at times when water was clear and had no obvious algal growth as noted in the next section. Room 3 and 4 had the most foam, but Room 1 and 2 Fountains had obvious foaming problems as well, but they weren't as pronounced. Foam never covered the water surface of the Cortège Fountain and Niche Fountain 2, and this could be related to water dynamics. The Cortège Fountain does not feature any waterfalls and would never produce foam, even if a foaming substance were present. In contrast, the Niche Fountain 2 does feature a waterfall, but did not accumulate foam, perhaps because the Niche Fountain 2 was often offline during site visits.

Table 5.3. Foam coverage on water surface of the different CWFs at the FDR Memorial as estimated by visual observations.

DATE	ROOM 1	NICHE 1	ROOM 2	NICHE 2	ROOM 3	CORTEGE	ROOM 4
6/17/14	3.5%	2%	9%	6%	30%	0%	11%
7/1/14	15%	8%	43%	0%	35%	0%	45%
7/14/14	18%	5%	18%	0%	25%	0%	15%
7/29/14	15%	3%	6%	0%	15%	0%	25%
8/14/14	15%	1%	18%	0%	33%	0%	30%
9/17/14	NW	2%	NW	0%	58%	0%	30%
10/1/14	NW	0%	15%	0%	28%	0%	25%
NW = No water present in the basin during the observation.							



Figure 5.4. Foam accumulation in a corner of the Room 2 Fountain on October 1, 2014.



Figure 5.5. Foam across the water surface in the Room 3 Fountain on September 17, 2014.

Figure 5.6. Foam accumulations during a period of green water at Room 1 on July 14, 2014.





Figure 5.7. Scattered foam clumps across the water surface in the Room 4 Fountain on July 1, 2014.

At times, foam had collected in corners of the basins and was quite thick, as shown in Figure 5.4. At other times, the foam was thin and spread across the entire water surface with accumulations in corners (Figure 5.4). It was present when water was clear (Figures 5.4 and Figure 5.5) and when water was green (Figure 5.6). Other times the foam was thin and scattered across the water surface, without thick accumulations (Figure 5.6).

Reasons for the accumulation of foam in water features were not determined, but there is no reported use of foaming agents in either the municipal water source or the feature water. Other sites in this study with significant algae problems did not display the amount of foaming that was observed in some of the CWFs at the FDR Memorial. Foaming agents are not likely to have originated from algae, because foaming occurred during periods of low algal growth as evidenced by the clear water (Figure 5.6, Figure 5.7). Another possibility is that residues from detergents and other cleaning products were not fully rinsed from the CWFs. These residues may then mix with the water once it is refilled, leading to foam formation in the CWFs. Foaming could have been enhanced by the large percentage of pine trees contributing organic foaming agents to the fountains. Further study is warranted to examine this issue in detail.

5.3.3 WATER-COLOR

Table 5.4 shows the observations of water-color during the visual assessment period. Many observations of green water indicated algal growth. At other times the water was observed to be quite clear. The observations of green water refer only to the water-color, not to whether there were algae growing on the surfaces of the basin. Those observations are presented in the next section. Certain CWFs at FDR Memorial stand out as relatively clear during the summer, such as the Cor-

tege Fountain, both of the Niche Fountains, and Room 4 Fountain. Other features appeared to have significant algal growth that discolored water, such as the Room 2 Fountain and the Room 3 Fountain (Figure 5.8, Figure 5.9).

Table 5.4. Water-color of the different CWFs at the FDR Memorial as recorded by visual observations by the UMD Team.

DATE	ROOM 1	NICHE 1	ROOM 2	NICHE 2	ROOM 3	CORTEGE	ROOM 4
6/17/14	Clear	Clear	Dark Green	Clear	Olive Green	Clear	Pea Green
7/1/14	Clear	Clear	Clear	Clear	Light Murkey Green	Clear	Clear
7/14/14	Olive Green	Clear	Olive Green	Clear	Olive Green	Clear	Olive
7/29/14	Olive Green	Clear	Olive Green	Clear	Olive Green	Clear	Clear
8/14/14	Olive Green	Clear	Green	Clear	Light Green	Clear	Clear
9/17/14	NW	Clear	NW	Clear	Light Green	Clear	Clear
10/1/14	NW	Greenish	Olive Green	Clear	Light Green	Clear	Clear
NW = No water present in the basin during the observation.							

Green water is indicative of the growth of both suspended and attached algae; the suspended algae can be controlled by a properly operated PSF (Sabiri et al, 2012). It may be that those features with clearer water have fully functioning PSFs, while those that are discolored more often (Room 1, Room 2, and Room 3 Fountains), may have malfunctioning PSFs. Based on the TSS data presented in Section 3.3.9 below indicated that the amount of suspended algae present in FDR was much lower than other sites such as Meridian Hill Park. Thus it appears that these fountains at FDR were dominated by attached algae. It is possible that despite the long period since filter sand had been added or changed, the PSFs were working well enough to control this type of algae. Alternatively, it may be that the UMD Team made observations of a CWF after it had been drained and re-filled by Park staff.



Figure 5.8. Green water in the Room 2 fountain. Photo taken June 17, 2014

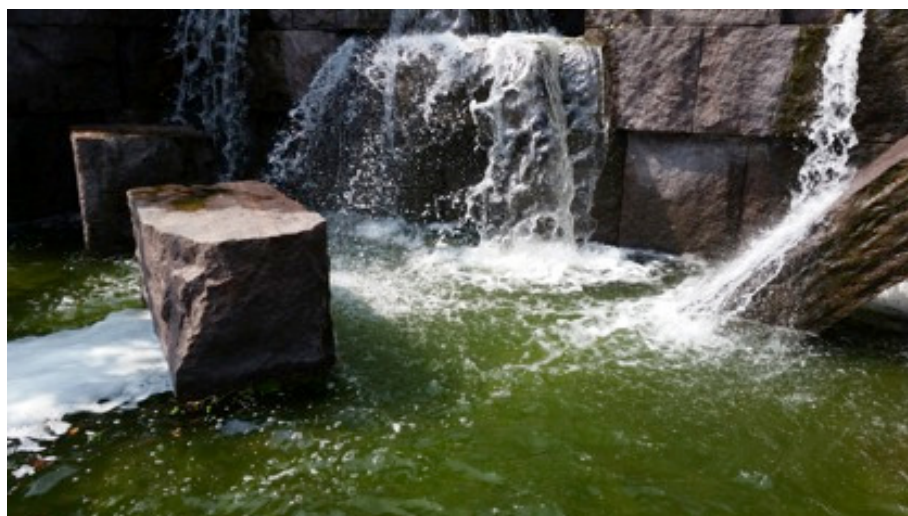


Figure 5.9. Green water in the Room 3 Fountain on July 29, 2014.

5.3.4 ODOR

Table 5.5 shows the odor ratings and written descriptions of odors for each of the CWFs at the FDR Memorial. Overall, odors were most noticeable at the Room 1 and Room 3 fountains, moderately noticeable at the Rooms 2 and 4. Room 4 had the strongest odor of all of the systems on July 1. On this date, Room 4 was recorded as having clear water and 45% of the water surface covered in foam. The UMD Team noted that the system had a strong odor of algae though none was present. Room 3 also had a strong odor on this date, and was noted for green water (Table 5.4) and 35% coverage of foam (Table 5.2).

Most of the time when odor was recorded as being noticeable, the UMD Team noted an algal smell, but at certain times, a chemical smell was noted in the Room 3 fountain water, Cortège Fountain water, and Room 4 Fountain. The Niche Fountains were never found to exhibit any odor.

Table 5.6. Odor rating and description for the FDR CWFs.

DATE	ROOM 1	NICHE 1	ROOM 2	NICHE 2	ROOM 3	CORTEGE	ROOM 4
6/17/14	1 - None	1 - None	3.5 - Algae & Plant Matter	1 - None	2.5 - Slight Algal	1 - None	1 - None
7/1/14	3 - Algal	1 - None	2.5 - Algae & Plant Matter	1 - None	6 - Chlorine & Algal	1 - None	7 - Strong Algal
7/14/14	6 - Algal	1.5 - None	4.5 Algae & Plant Matter	1 - None	3 - Slight Algal	1 - None	4 - Slight Algal
7/29/14	6 - Algal & Chemical	1 - None	4 - Slight Algae & Plant Matter	1 - None	3.5 - Slight Algal	1 - None	3 Slight Chemical & Algal
8/14/14	5.5 - Dying Algal	2.5 - Algal	3.5 - Slight Algae & Plant Matter	1 - None	4 - Slight Algal	1 - None	1 - None
9/17/14	NW	1 - None	NW	1 - None	4.5 Strong Chemical & Algal	2 - Chemical	1 - None
10/1/14	NW	1 - None	4.5 Algae & Plant Matter	1 - None	2.5 Slight Algal	1 - None	4.5 Algal

NW = No water present in the basin during the observation.

5.3.5 PLANT DEBRIS

Table 5.6 shows the percentage of the basin that was covered in plant debris, such as leaves, pine needles, pollen, and woody debris such as twigs and sticks. Plant debris was most pronounced in Niche Fountain 2 and the Cortège Fountain, although the Room 4 Fountain often had a significant amount as well. It is important to note that these observations took place during the summer and early fall, showing that plant debris is not a management concern only during the autumn months.

Plant debris is a significant contributor of nutrients in stream and lake systems through leaching, and breakdown (Vannote et al, 1980; Duan et al, 2014; Hobbies et al, 2014). Later in this report, plant debris is incorporated into the phosphorus balance for the systems to estimate of how this input could affect the nutrient levels and water quality.

Table 5.5. Coverage of Plant Debris on the water surface for each of the water features at the FDR Memorial.

DATE	ROOM 1	NICHE 1	ROOM 2	NICHE 2	ROOM 3	CORTEGE	ROOM 4
6/17/14	8%	2%	3%	38%	8%	5%	4%
7/1/14	1%	6%	13%	11%	10%	23%	13%
7/14/14	3%	4%	3%	25%	15%	4%	11%
7/29/14	2%	4%	5%	40%	4%	19%	10%
8/14/14	2%	2%	3%	13%	7%	9%	9%
9/17/14	NW	8%	NW	15%	6%	4%	9%
10/1/14	NW	20%	2%	20%	5%	14%	10%

NW = No water present in the basin during the observation.

5.3.6 ALGAE COVERAGE ON WATER FEATURES

The observations made by the UMD Team on algae coverage and type (whether plankton or benthic) of the CWFs are presented in Table 5.7. Often the water was clear, allowing researchers a view of the basin bottoms, which were covered in some variety of benthic algae. The Cortège fountain often had a substantial amount of its basin bottom covered in benthic algae that appeared not to be at-

Table 5.7. Odor rating and description for the FDR CWFs.

DATE	ROOM 1			NICHE 1			ROOM 2			NICHE 2			ROOM 3			CORTEGE			ROOM 4		
	COVER	P	B	COVER	P	B	COVER	P	B	COVER	P	B	COVER	P	B	COVER	P	B	COVER	P	B
6/17/14	80%		X	71%		X	100%	X	X	100%		X	100%	X	X	94%	X	X	100%	X	X
7/1/14	0%			0%			100%	X	X	0%			100%	X		20%	X	X	0%		
7/14/14	100%	X	X	53%		X	100%	X		0%			100%	X	X	99%	X	X	100%	X	X
7/29/14	100%	X		80%		X	100%	X		4%		X	100%	X		100%	X	X	100%	X	X
8/14/14	100%	X		15%		X	100%		X	100%		X	100%	X	X	100%	X	X	95%		X
9/17/14	NW			5%		X	NW			100%		X	53%	X	X	0%			95%		X
10/1/14	NW			63%		X	50%	X		8%		X	50%		X	95%	X	X	95%	X	X

NW = No water present in the basin during the observation

P = Planktonic suspended algae / indicated by greenish water | B = Benthic algae on basin floor



Figure 5.10. Benthic algae covering the basin bottom in the Cortège fountain on July 29, 2014.

Figure 5.11. Algae attached to the basin structure in the Room 2 Fountain on July 14, 2014.



Table 5.8. Counts (#) of Litter and Type in the FDR CWFs.

DATE	ROOM 1		NICHE 1		ROOM 2			NICHE 2		ROOM 3		CORTEGE		ROOM 4	
	#	TYPE	#	TYPE	#	TYPE	#	TYPE	#	TYPE	#	TYPE	#	TYPE	
6/17/14	0	None	10	Coins, Candy Wrapper, Hair Tie, Paper	50	Coins	0	None	100	Coins	100	Coins	150	Coins	
7/1/14	10	Coins	1	Coin	0	None	0	None	0	None	102	Coins, Clothes Pin, Bottle Label	100	Coins	
7/14/14	0	None	11	Coins, Plastic Straw	3	Coins	1	Bottle Wrapper	0	None	12	Coins, Rubber Band, Clothes Pin, Wrapper	11	Coins	
7/29/14	0	None	18	Coins	0	None	11	Pieces of Paper, Coins	1	Plastic Water Bottle	14	Coins, Rubber Band, Clothes Pin	0	None	
8/14/14	0	None	12	Coins	11	Coins	12	Coins	10	Coins	15	Coins	10	Coins	
9/17/14	NW	N/A	7	Coins	NW	N/A	7	Coins	6	Coins	0	None	10	Coins	
10/1/14	NW	N/A	0	None	0	None	0	None	0	None	0	None	0	None	
NW = No water present in the basin during the observation															

tached (Figure 5.10). In the Room 2 fountain attached algae were often observed on the submerged walls and other hard surfaces (Figure 5.11).

5.3.7 LITTER

Counts of litter in the CWFs were higher early in the summer and lower later in the season (Table 5.8). It mostly consisted of coins, which are an unavoidable aspect of public CWFs. Plastic litter, such as bottles, bottle caps, and food wrappers, was often found, but not in large amounts. The management of litter collection appeared to well taken care for the management of the CWF.

5.3.8 NUTRIENT ANALYSIS

The visual assessment data presented above clearly indicates that algal growth is a concern in the CWFs at the FDR Memorial. It is generally accepted that elevated levels of nutrients—namely nitrogen and phosphorus—are often the cause of algal blooms in freshwater systems (Sellner et al, 2003; Heisler et al, 2008). The link between algal blooms and over-enrichment of essential nutrients, a process known as eutrophication, has been understood for the past 35 years (Anderson et al, 2002). Although nitrogen and phosphorus are both essential for algal growth, elevated levels of bio-available phosphorus (soluble reactive phosphorus) are known to cause explosive algal growth in freshwater systems (Guildford & Hecky, 2000; Steffan, 2014; Kane et al, 2014).

Harmful algal blooms (HABs) are a problematic phenomenon occurring in coastal zones and natural water bodies across the globe (Anderson et al, 2002; Gilbert et al, 2005). Algal blooms can be harmful due to the presence of toxic algae, or due to depletion of dissolved oxygen in the deeper, poorly mixed waters, that indiscriminately kill bottom dwelling organisms and force fish to flee. A recent toxic algal bloom in Lake Erie during the summer of 2014 disrupted the supply of drinking water to 500,000 local residents and made national headlines (Wines, 2014). Closer to the Capital Region, algal blooms in the Chesapeake Bay occur annually in the spring and cause damage to sensitive ecosystems and local fisheries.

On September 1, the UMD Team received an approved research permit to take water samples for nitrogen and phosphorus analysis and other water quality parameters.

Our results indicated that source water, used for make-up and filling the FDR Memorial CWFs had high amounts of TP (TP). Waters with phosphorus levels greater than 0.05 mg-TP/l are considered sufficiently enriched to cause algal blooms (exact acceptable levels of phosphorus is never certain, as even 0.02 mg/l can be a problem; Correll, 1998; Sellner et al, 2003; Heisler et al, 2008). As

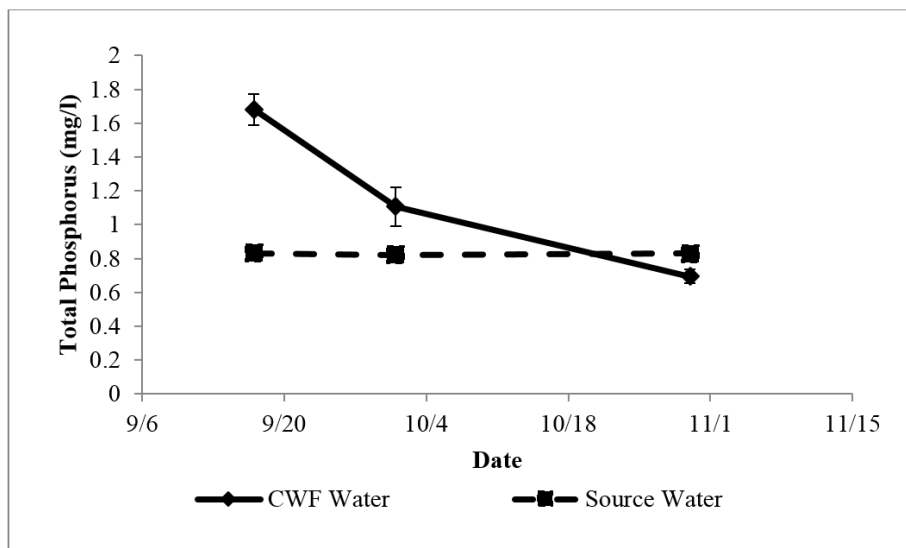


Figure 5.12. TP concentrations for CWF water (solid lines) and source water.

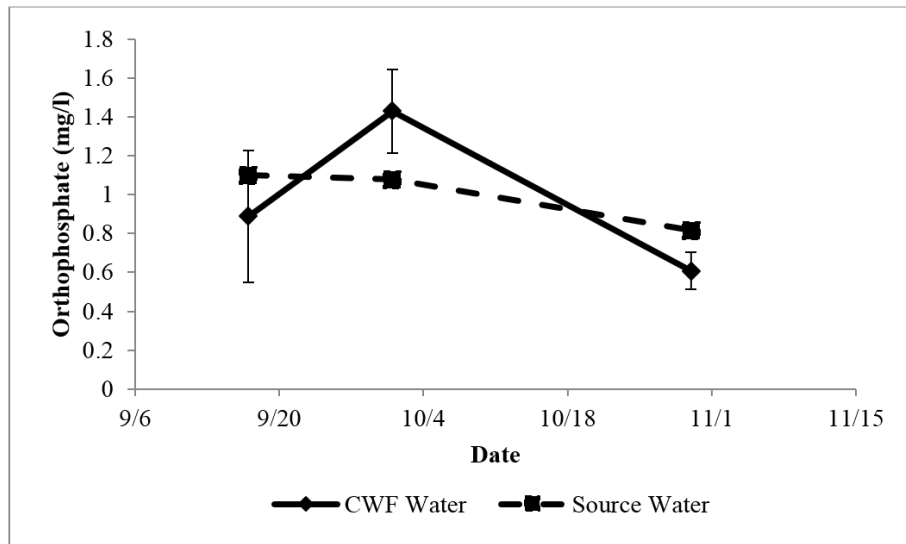


Figure 5.13. PO_4^{3-} concentrations in CWF water (solid lines) and source water (dashed lines).

Figure 5.14. The Room 2 Fountain at the FDR Memorial being cleaned during the first sampling visit on September 17, 2014.

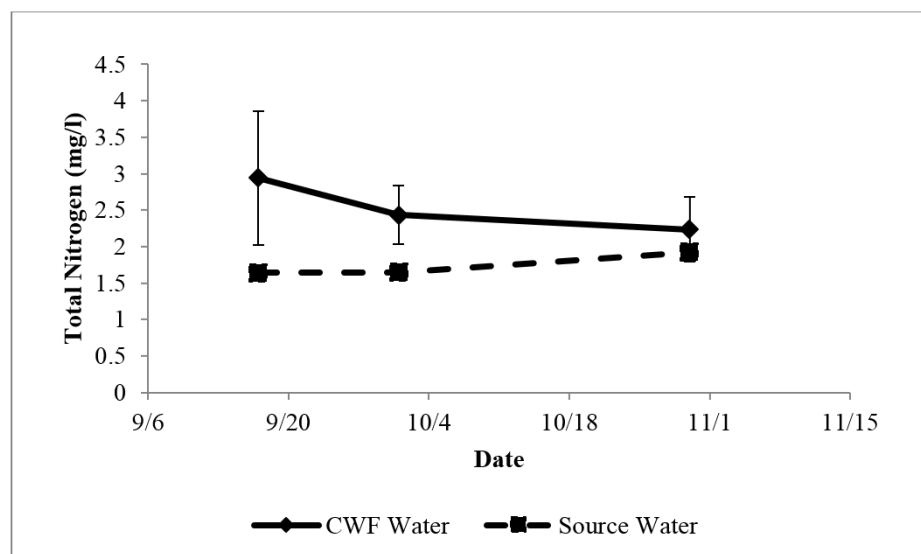


expected, concentrations of TP in the CWFs were also sufficiently enriched to cause rapid algal growth (Figure 5.12). Concentrations of TP were 58 times higher (1.16 ± 0.29 mg-TP/l in CWF water) than acceptable levels (0.02 mg/l TP). On the Florida Department of Environment's Trophic State Index (FTSI) for lakes and estuaries, the TP levels of FDR were well above the maximum score of 0.58 mg/l TP (LCWA 2015), placing it in the hypereutrophic/poor category. Therefore rapid algal growth is expected in these systems when no nutrient removal system is in place.

Due to the replenishment of evaporated water with make-up water, TP would be expected to accumulate in the CWF. Instead TP levels in the CWF and source water tended to be alike over the course of the sampling period. Concentrations of orthophosphate (PO_4) also showed this trend (Figure 5.13). The first sampling date (9/17/2014) occurred during a thorough cleaning of the features (Figure 5.14) so we probably sampled CWF water right after the features had been re-filled.

TN concentrations were consistently greater than 1.5 mg-TN/l for both CWF water and source water (Figure 5.15). Thus, in addition to the hypereutrophic levels due to phosphorus, TN levels were high enough to score a 60 to 80 (out of 100) on the Florida Department of Environment's Trophic State Index (FTSI, LCWA 2015), which places FDR in the hypereutrophic/poor category. The TN levels of the CWFs were never significantly different than source water concentrations (Figure 5.15). TN followed the same trend exhibited by phosphorus. NH_3 was lower in concentration than source water and also declined over time (Figure 5.16). This was likely due to the nitrification of NH_3 to NO_3^- by aerobic bacteria when oxygen was available for microbial metabolism. NO_3^- was higher in concen-

Figure 5.15. TN concentrations of the CWF water (solid lines) and source water (dashed lines).



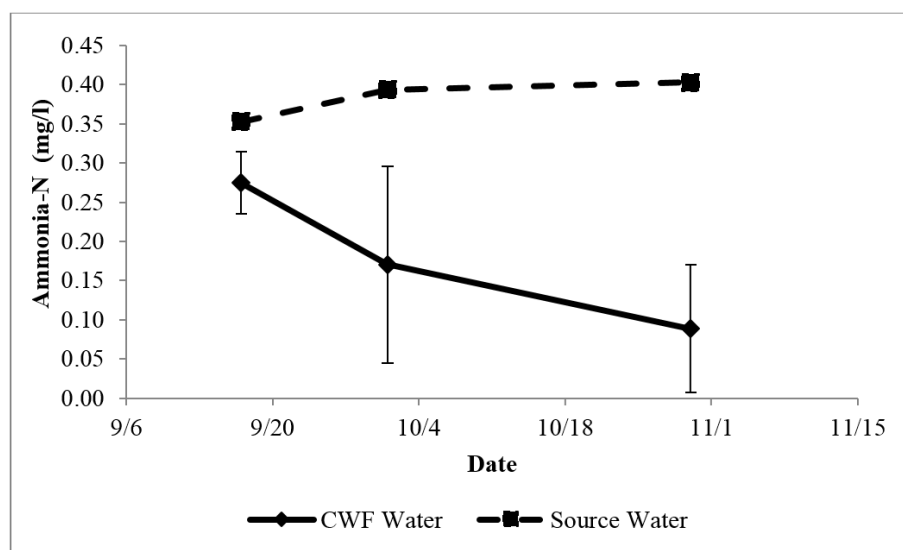


Figure 5.16. NH_3 concentrations of the CWF water (solid lines) and source water (dashed lines).

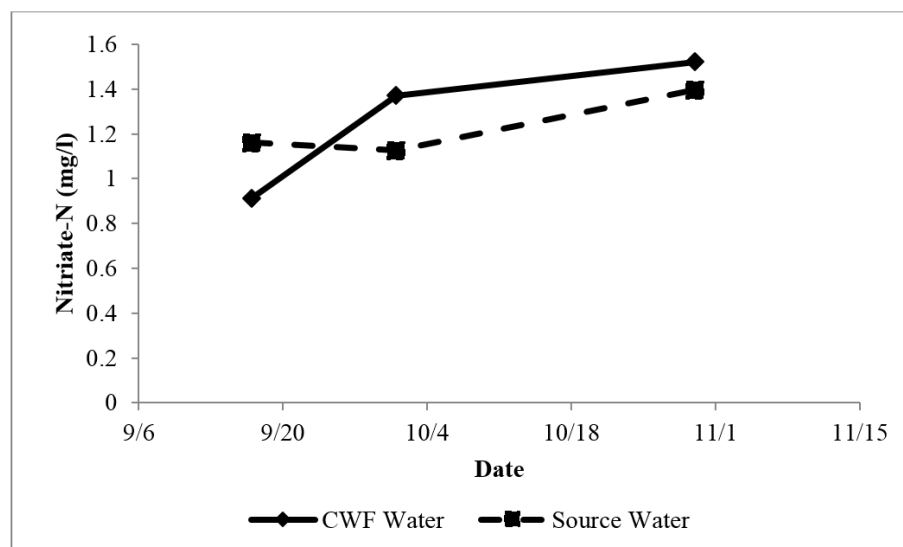


Figure 5.17. NO_3^- concentrations of the CWF water (solid lines) and source water (dashed lines).

tration than NH_3 —it ranged from 0.8 to 1.5 $\text{mg-NO}_3/\text{l}$ (Figure 5.16)—which was expected since there was plenty of dissolved oxygen available for nitrification and unlikely few anoxic microsites within the CWF that could promote denitrification (i.e., conversion of NO_3^- to nitrogen gas; NO_3^- concentrations shown in Figure 5.17). As we will reveal in the treatment technology section below, there are ways to rapidly increase denitrification, which could remove large amounts of TN from FDR.

Water for the fountains at the FDR Memorial is drawn from the municipal water supply from the Washington Aqueduct treated by the Dalecarlia and McMillan Treatment Plants. This municipal treatment process relies primarily on solids removal and chemical treatment including sedimentation, fluoridation, pH adjustment, and disinfection using free chlorine and chloramines, and corrosion inhibi-

tion using orthophosphate. In 2000, the District of Columbia Water and Sewer Authority (DCWASA) detected elevated levels of coliform bacteria in the drinking water supply, so they doubled the dosage of free chlorine. The high amount of free chlorine reacted with old lead pipes and allowed for the formation of Pb (IV) as the dominant scale in the system, in the form of lead dioxide (PbO_2). These Pb (IV) scales are only mildly soluble under normal water conditions. Therefore even during lower than normal pH levels, the dominant scale of Pb (IV) did not solubilize. In late 2002, the disinfectant was changed from free chlorine to chloramines, due to health concerns. Chloramine chemistry modified redox conditions and shifted the dominant scale from the mildly soluble Pb (IV) to the highly soluble Pb (II). This is why dissolved Pb was released into the drinking water, creating a public health hazard and major discoloration of the drinking water in 2003 and 2004.

To reduce the amount of lead in the water, Washington Aqueduct treatment plant operators began adding orthophosphate to bond to the free lead, thereby reducing public health risks from lead exposure (US EPA, 2007). Unfortunately, orthophosphate is also an essential nutrient for algal growth. This unintentionally increased the load of phosphorus to CWFs in the NCR, which use municipal water, such as the FDR Memorial.

5.3.9 SOLIDS ANALYSIS

Contrary to what the results of the Visual Assessment and nutrient analysis suggest, the solids analysis did not indicate high levels of algae or other organic particulates in the systems or source water because the water samples were taken much later in the season. CWF total solids (TS) concentrations were higher than source water concentrations (Figure 5.18). Since the CWF receives an influx of particulate and dissolved materials and loses water molecules due to evaporation,

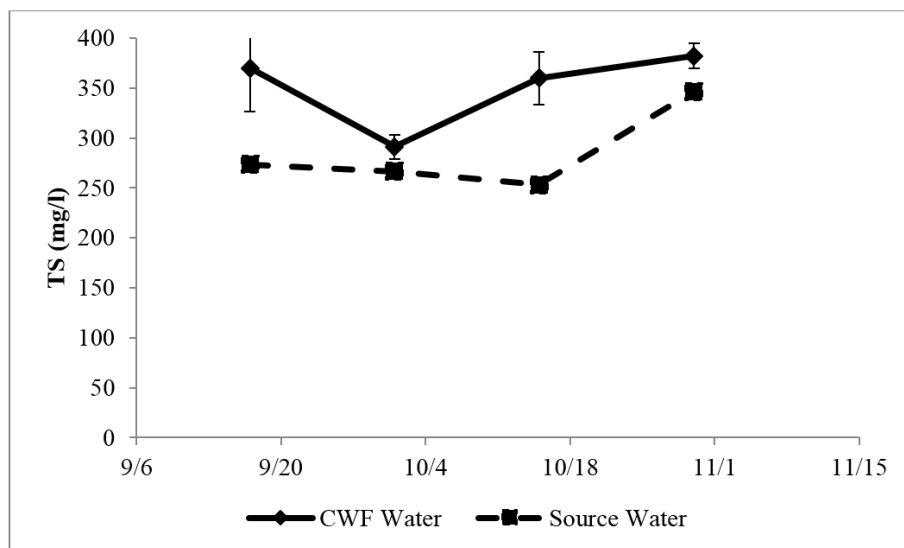
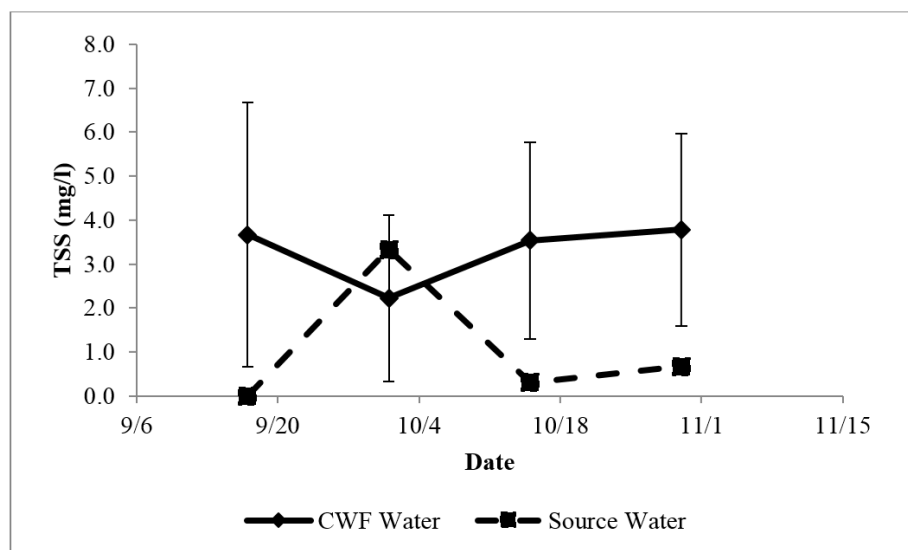


Figure 5.18. Total solids concentrations (mg/l) for CWF water (solid lines) and source water (dashed lines).

Figure 5.19. Total suspended solids concentrations (mg/l) for CWF water (solid lines) and source water (dashed lines).



one would expect the TS of the CWF to be higher than its main source. Rainfall inputs, which are typically lower in dissolved solids than source or CWF water, would decrease the TS in the CWFs.

Figure 5.19 shows the levels of total suspended solids for the CWF water and source water. Volatile suspended solids (VSS) were relatively low in both the CWFs and source water (Figure 5.20). The low VSS readings in the CWF reflect the visual assessment, which did not detect suspended algae. Attached benthic algae, which were noted in the visual assessment, would not add to VSS.

Total Dissolved Solids (TDS) followed the same pattern as TS concentrations, with the CWF water always having a higher reading (Figure 5.21). TDS consists mostly of conservative elements and would not be taken up by algae or biomass. Thus, we would expect TDS to increase over time due to evaporation losses. This phenomenon is noted earlier, in the nutrient analysis as an explanation as to why nutrient levels were similar to source water concentrations, when the process of evaporation and re-filling with make-up water would have resulted in greater concentrations of phosphorus over time. Instead both the TDS concentration and phosphorus concentrations remained nearly equal to the source water, indicating that the FDR water feature was being refilled frequently from the source water. This occurred either from draining for maintenance or from the backwash from the sand filter system.

5.3.10 pH

CWF water pH levels were almost identical to source water levels (Figure 5.22). The presence of algae in the CWF will tend to increase the pH as CO_2 is taken up by the algae during photosynthesis. This lowering of CO_2 shifts the balance of the carbonate system to a more alkaline condition. Explanations for the increase in

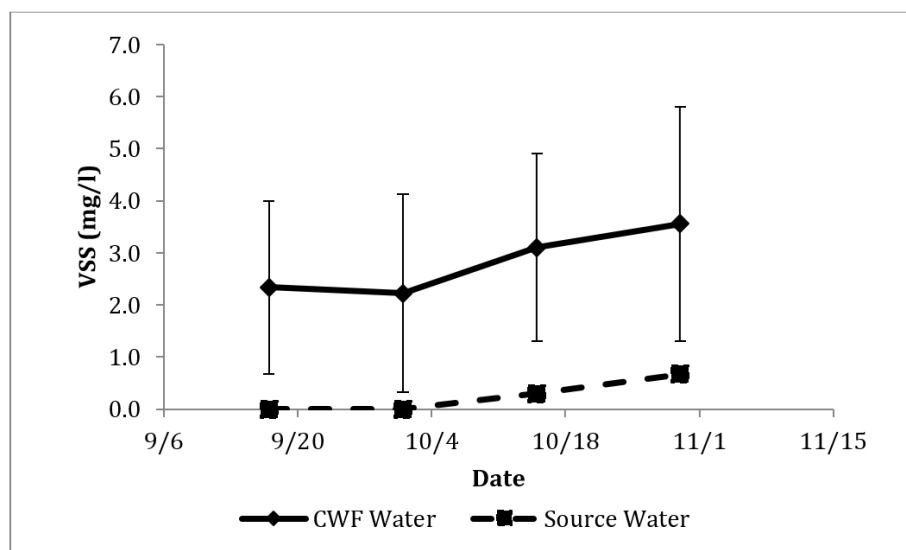


Figure 5.20. Volatile Suspended Solids for the CWF water (solid lines) and source water (dashed lines).

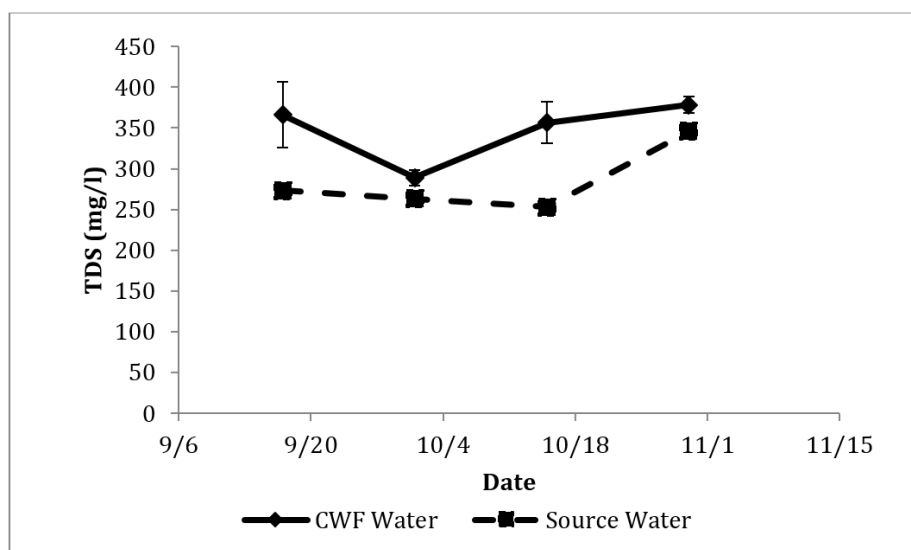


Figure 5.21. Total Dissolved Solids for the CWF water (solid lines) and source water (dashed lines).

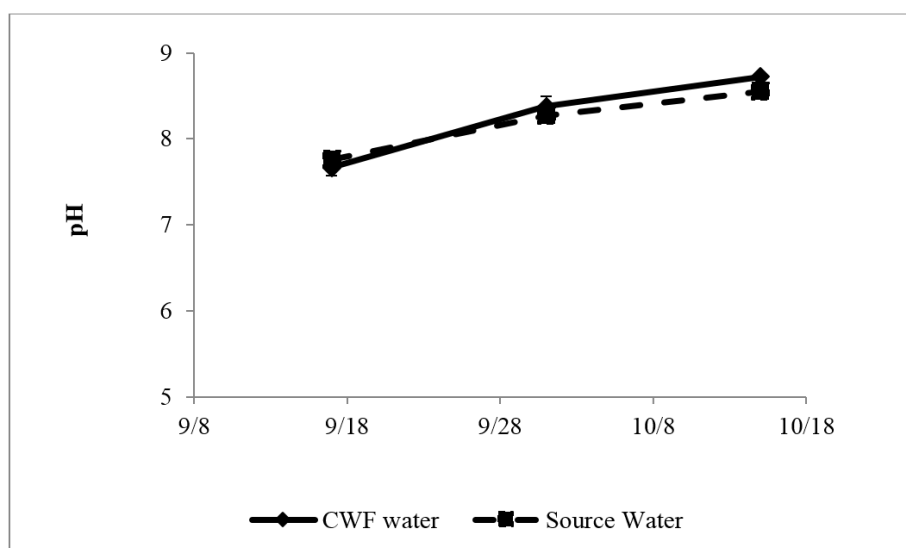


Figure 5.22. pH for the FDR Memorial CWF water (solid lines) and source water (dashed lines).

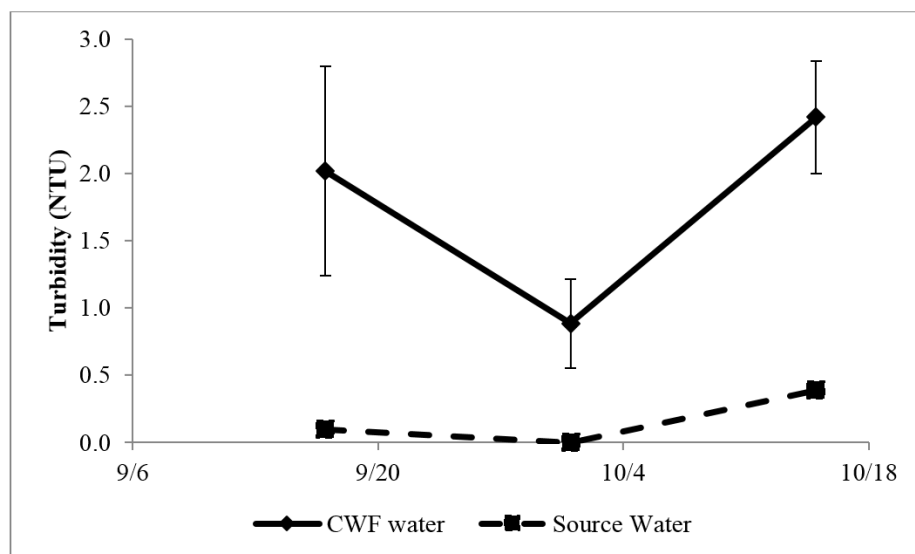
pH of the source water are more difficult to pinpoint. One possibility is that the drop in atmospheric temperatures at the beginning of fall increased the pH as predicted by simple equilibrium kinetics. On the other hand, the similarity between the pH of the CWF and source water over a one-month period could have several explanations. In addition to the temperature effect, another possibility could be that the CWF pH was increased by algae photosynthesis at the same rate that the municipal water supply plant was increasing due to temperature. A third reason could be that the CWF water was being replenished with source water on such a high frequency that it was controlling the pH level. However, the differences in TDS and turbidity (Figure 5.23) between the two waters do not support this notion.

5.3.11 TURBIDITY

Turbidity was fairly low during the sample period (Figure 5.23) and did not suggest any algal growth. This contrasts with the visual assessment data on the water-colors observed during the study. If turbidity had been measured during the summer, when algae were clearly present in large numbers, one would expect much higher turbidity measurements.

se CWFs, one would expect rapid algal growth. During a bloom in suspended algae, TSS, VSS, and turbidity levels would be expected to be much higher than reported for FDR. However, the visual assessment and increasing pH provides support that algae production and therefore growth, was present. This suggests that the water-sampling period occurred when algal growth was restricted to the benthos and at a minimum in the water column (i.e., planktonic). In contrast the

Figure 5.23. Turbidity for the FDR Memorial CWF water (solid lines) and source water (dashed lines).



visual assessment showed quite clearly that algae were a re-occurring phenomenon (Table 5.6).

It is plausible that the existing sand filters were working properly to remove suspended algae in some of the FDR basins during the sampling period but failing to do so in other basins and during the visual assessment in the summer. Attached (benthic) and suspended (planktonic) algae were present in multiple basins of the FDR CWF during the summer (Table 5.6), indicating that the sand filter was not capable of removing algae sufficiently when a bloom occurs, or that it was not working properly. The UMD Team was never informed that the sand filters were not working, which indicates that the algal bloom simply overwhelmed the capacity of the sand filter.

5.3.12 WATER DISCHARGE ESTIMATES AND WATER BUDGET

The fountains at the FDR Memorial collectively have an estimated volume of nearly 45,000 gallons. They consume over five times this amount during a typical year (320,000 gal; Figure 5.24). Its use of municipal water was 3 times more than the rainwater it receives naturally each year. Discharge estimates, which account for 56% of water loss each year, are approximately 184,000 gal due to intentional

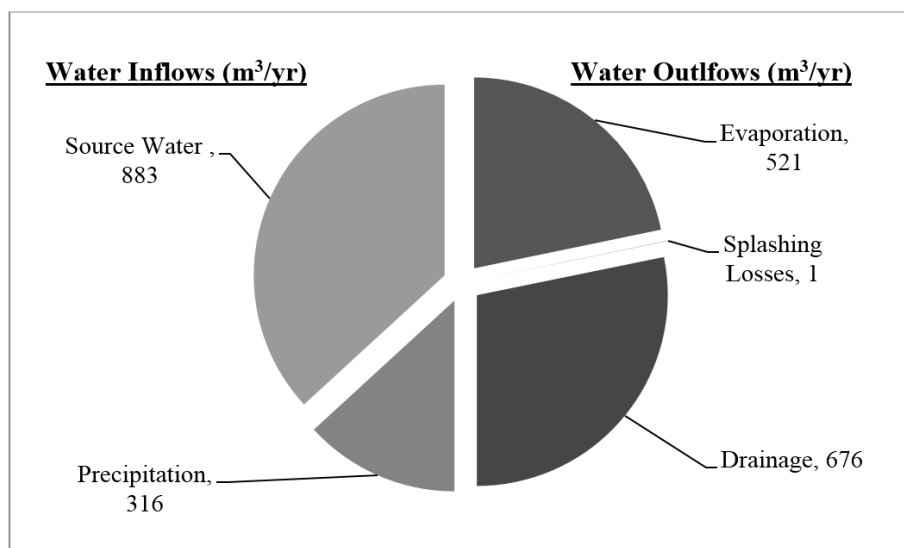


Figure 5.24. Annual water budget (m³/yr) for FDR Memorial. Inflows are on the left side of the pie chart, outflows are on the right.

FOOTNOTES:

Evaporative Losses = Evaporation rate (m/yr) * Surface area (m²/yr) = 1.04 m/yr * 501 m² = 521 m³/yr

Splashing Losses = Estimated rate (m³/hr) * Hours of operation (hrs/yr) = 0.0002 m³/hr * 5136 hrs/yr = 1 m³/yr

Drainage = Storage volume lost/event * # of times drained/yr = (169 m³/event) * (4 event/yr) = 676 m³/yr

Precipitation = Surface area (m²) * Precipitation rate (m/yr) = 501.21 m² * 0.63 m/yr = 316 m³/yr

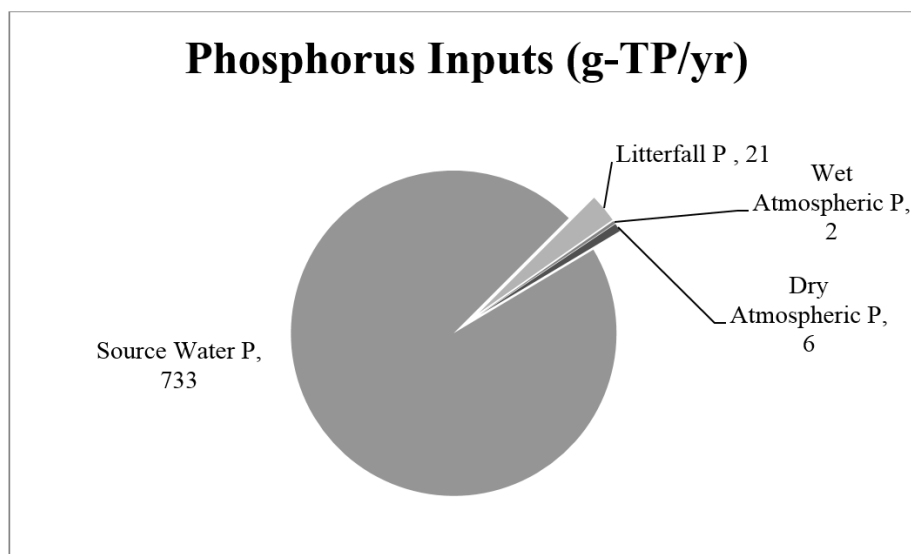
Source Water = Evaporative losses (m³/yr) + Drainage (m³/yr) + Splashing losses (m³/yr) + Leaks (m³/yr) - Precipitation (m³/yr) - Overland flow (m³/yr) = 521 m³/yr + 1.02 m³/yr + 0 m³/yr + 676 m³/yr - 315.8 m³/yr - 0 m³/yr = 883 m³/yr

draining to rid the feature of green water. By comparison it lost 139,000 gal via evaporation (44% of water loss each year). Thus, if algal blooms did not occur, 139,000 gal could be saved at FDR (assuming that 45,000 gal are drained when the CWF is shut down for winter), which amounts to a 43% savings of municipal water.

5.3.13 PHOSPHORUS INPUT ESTIMATES

As discussed earlier (Sect. 5.3.8), phosphorus and nitrogen are critical nutrients for algae and other photosynthesizing organisms. The water analysis showed that source water drawn from the municipal supply contained high concentrations of phosphorus; however phosphorus can be supplied by other sources, such as, dust, rainwater, leaf litter from nearby trees, and other debris that enters the water feature and begins to decompose. The mass balance analysis for phosphorus inputs confirmed this (Figure 3.24). It showed that 96% of the phosphorus came

Figure 5.25. Phosphorus inputs of FDR Memorial CWF during 2014.



FOOTNOTES:

Bird Deposited P = Assumed no input from birds.

Litterfall P = Estimated rate (g/m²/d) * Surface area (m²) * Annual days of operation (214 days/yr)
 * P released after 24 hrs of decomposition (mg-P/g-leaf litter)=1 g-leaf/m²/day (data source: Bell et al, 1978) * 501.2 m²* 214 days/yr * 0.2 mg-P/g (Data source: Duan et al, 2014; Hobbies et al, 2014) *1e-3 g/mg = 21 g-P/yr.

Wet Atmospheric Deposited P = Concentration of P in rainfall (µg/l) * Conversion to grams (1e-6 g/µg) * annual precipitation inputs (m³/yr) * conversion to liters (1000 l/m³) = 7.1 µg-P/l (Data source: Koelliker et al 2004) * 1e-6 g/µg * 315.8 m³/yr * 1000 l/m³ = 2 g-P/yr.

Dry Atmospheric Deposited P = Rate of deposition (kg-P/m²/yr) * surface area (m²) * 8 months/12 months/yr = 18.4 mg-P/m²/yr (Data sources: Ahn and James, 2000; Chen et al, 2008; Delumyea and Petel, 1978; Sun et al, 2013) * 1e-3 g/mg * 501.2 m²*8 months of operation /12 months/yr = 6 g-P/yr.

Source Water P = Concentration of P in Source Water (mg/l) * Annual source water inputs (l) * Conversion to grams (g/mg) = 0.83 mg-TP/l (Data source: this study) * 1e-3 g/mg * 883 m³/yr * 1000 l/m³ = 733 g-P/yr.

from the municipal source water (730 g-P/yr; Figure 5.25), while a much smaller percentage (4%) came from rain, dust and litterfall (30 g-P/yr, Figure 5.24).

With such a large amount of phosphorus added every time make-up water is added from municipal source water, or re-filled after draining, algal growth has more than enough phosphorus to initiate and sustain a bloom. The management implications of this inflow are that some sort of nutrient removal or reduction method must be employed for algal growth to be minimized.

The use of alternate source water with lower amounts of phosphorus could be employed, such as rain water harvesting or the collection of rainwater. Another option is to pre-treat the municipal water with a phosphorus removal technology prior to its use. If pre-treatment is impractical, technologies that target phosphorus removal should be used as the water cycles and recycles through the system.

Finally, the phosphorus budget also shows that simply avoiding the use of municipal water does not stop phosphorus because the other three major inflows (i.e., rainfall, dry fall, and litterfall) add appreciable amounts of phosphorus to the water. In other words, P from other sources could build up in a CWF and allow algae to flourish, although likely at a slower rate.

While the TN levels measured at FDR were high enough to contribute to algal blooms, the phosphorus levels measured were many times greater than the threshold for algal blooms. Nonetheless, inflows and build-up of nitrogen may need to be addressed by any upgrades in treatment technology.

5.3.14 ENERGY USE ESTIMATES

Records of electricity use were not available for the FDR Memorial. Based on calculations, the CWFs were estimated to collectively use approximately 1.5 million kWh of electricity per year for moving water in the systems. This amount of electricity is approximately equal to the amount consumed by 125 average households annually in the US, thus it is a large amount of energy use. This assumes that pumps run continuously from April 1 to October 31 and that pumps run at 80% of their maximum efficiency due to age. This does not include any lighting in the CWFs, or any other electrical use on site, such as at the Visitor's Center.

Our estimates for energy use have a high degree of uncertainty because they were calculated based on a number of assumptions. If accurate, they show that the waterfalls and other attribute flows consume a considerable amount of electricity to function. This may constitute an acceptable rate of consumption because of the narrative they convey about President Roosevelt's cultural legacy.

5.4 CONCLUSION

During the summer, algal blooms were visible in most of the CWFs at FDR, and occurred as both planktonic, suspended algae that discolored water, and as benthic algae settled on or attached to the basin floors and walls. Unfortunately, water sampling occurred after this period and did not reflect the levels of algae that were visible earlier in the season. It could be that the PSF had been cleared and began working to remove algae, or that the season shift in climate reduced algal growth within the capability of the sand filters to remove them, or finally that the CWFs were being cleaned prior to sampling visits. Regardless, water analysis showed that there are sufficient nutrients in source water (municipal water from the Washington Aqueduct) for rapid and intense growth of algae, as witnessed earlier in the season.

Upgrades to the system focusing on nutrient management are needed in order to reduce the intensity, frequency, and rapid growth of algal blooms in the system. In addition, repair or redesign of the main vessel to complete the liner and reduce the bottom roughness would help in maintenance and reduce water loss. Repairing the PSFs and replacing the sand may help, but PSFs with standard #20 filter sand do not remove nutrients and may not work well to reduce intense algal blooms. Additional investigations into optimizing the PSF operation focusing on the media (sand) and potential chemical additives (lanthanum chloride or flocculants) is recommended

Many of the problems that exist at the FDR Memorial have to do with the persistent algal blooms that are fed by large inputs of phosphorus and nitrogen from the municipal water supply. That is, since the municipal water is the primary source of nutrients, it is the ultimate cause of the algal blooms. The algal blooms also discolor the water, which tarnishes its immediate visual effect. Algal blooms can be odorous and may adversely impact the visitor experience. Algal blooms also raise the pH to alkaline levels, which may cause permanent staining of the basin's materials.

Automated chemical treatment assemblages are no longer operating and no nutrient management systems are currently employed in the CWFs at the FDR Memorial. In place of an effective nutrient management plan, the UMD Team observed that an informal operating procedure employed at FDR in which CWFs are intentionally drained and refilled, when the basin water turns green from an algal bloom. While this practice temporarily improves the water-color, it increases the consumption of municipal water and is not a sustainable practice.

This study was not able to determine the cause of foaming in the CWFs. Further investigations are needed to determine from where the foaming agents are added to the water.

CHAPTER 6. CHESAPEAKE AND OHIO (CHOH) CANAL HISTORIC PARK – CUMBERLAND TERMINUS BASIN



Figure 6.1. The CHOH Canal Basin at the Terminus in Cumberland, MD.

6.1 BACKGROUND

The CHOH Canal Basin or Cumberland Terminus Basin is a reconstructed portion of the historic CHOH Canal Terminus. It is the end of the canal that was used to load cargo (mainly coal) and rotate canal boats for the journey to Georgetown in Washington, DC. The basin was reconstructed in 2006 to resemble the historic terminus, but it was not connected to the remainder of the canal and instead was constructed as a basin, rather than a canal (Figure 6.1). Some of the original infrastructure remains, but much of the basin and surrounding structures are not historical, such as the visitor center, paths, and footbridge.

The Cumberland Terminus Basin was selected for study because of frequent algal blooms and difficulty maintaining water levels. Additionally, the basin is representative of earthen lined basins and canals that use untreated water from nearby rivers or streams, unlike the other sites in this study.

6.2 METHODS

6.2.1 WATER FLOW AND PLUMBING LAYOUT

A site tour of the park and pump station was held on May 6, 2014 and served to familiarize the UMD Team with the layout of the CWF and the plumbing system.

No engineering diagrams or plumbing diagrams were available for the Cumberland Terminus Basin. Basin surface area and volume were provided by NPS Staff (Michelle Carter, personal communication).

Figure 6.2. Aerial view of the Cumberland Terminus Basin adjacent to the Potomac River in Cumberland, MD. Yellow circles in the photograph mark the water sampling locations. Photo Source: Google Maps, 2014.



6.2.2 VISUAL ASSESSMENT AND WATER QUALITY SAMPLING

Research permits for water sample collection were obtained on June 1, 2014. Water samples and visual assessments were taken from 11:30 am to 12:30 pm on the dates listed in Table 6.1 in 2014. Three (3) water samples were taken from the water feature during each site visit at three locations; the rotation area, the middle of the canal section, and near the ramp on the far side (Figure 6.2). Source water samples were taken from the Potomac River adjacent to the pump station (Figure 6.3). See Chapter 2 for details of the water analysis methods used in this study.



Figure 6.3. Overhead view of the Cumberland area. The yellow circle marks the sampling point. Photo source: Google Earth, 2015.

Table 6.1. Water Sampling and Visual Observation Dates

DATE	WATER SAMPLES TAKEN	VISUAL OBSERVATIONS
7/8/14	X	X
7/23/14	X	X
8/7/14	X	X
8/26/14	X	

6.2.3 ENERGY USE ESTIMATES

Energy use from the pump station was provided by NPS for the years 2012, 2013, and 2014. Electricity use was provided in kilowatt-hours per month.

6.2.4 DISCHARGE ESTIMATES AND WATER BUDGET ANALYSIS

To obtain discharge estimates and water budgets, site managers and supervisors were interviewed to estimate how often the CWF was completely drained and re-filled during a year of operation to determine discharge estimates. Estimated rates for evaporation were taken from pan evaporation rates for Savage River Reservoir, MD from April through October (NOAA, 1982) in the absence of recent local data. Estimated precipitation rates were taken from NOAA (2015). The data presented here should be considered approximate estimates of discharge and water use, rather than observed data. Leakage estimates were provided by NPS Staff.

6.2.5 PHOSPHORUS INPUTS

Phosphorus inputs were estimated as outlined in Chapter 2. Since waterfowl were often observed at the water feature, we assumed that 20 waterfowl per day contributed phosphorus at a rate determined from literature (Post et al, 1998). The CHOH Canal Basin does not have significant tree vegetation the surrounding area, but inputs of grass clippings from lawn maintenance around the basin were observed several times during the study. These were considered as leaf litter inputs with input rates from estimates of a typical deciduous forest (Bell et al, 1978) and rates of phosphorus release were taken from previous studies (Duan et al, 2014; Hobbies et al, 2014). Rates of phosphorus flow into the system from source water were calculated from observed concentrations of phosphorus in this study. Rates of atmospheric deposition of phosphorus were averaged from Koelliker et al (2004), Ahn and James, (2000); Chen et al, (2008), Delumyea and Petel (1978) and Sun et al (2013).

6.3 RESULTS AND DISCUSSION

6.3.1 PLUMBING LAYOUT AND SYSTEM DIAGRAM

The Cumberland Terminus Basin is a pond-like water feature that is located in Cumberland, Maryland. The basin is has a surface area of 1.58 acres (68,825 ft²) with an estimated depth of 4.5 ft., and an estimated volume of 2,316,000 gallons. A

conceptual diagram of the Cumberland Terminus Basin is given in Figure 6.4. The source water for the basin is drawn from the Potomac River, upstream of a dam at Cumberland before the river converges with Wills Creek. A pump station houses two centrifugal pumps, which send water to the basin through a 10-inch pipeline. When the water level in the basin drops below a certain point, a float switch in the basin signals the pumps to deliver water. The pump switches off when the float switch reaches a determined water level. Therefore the pump is intermittently idle until sufficient water drains out of the basin and the cycle is repeated. Unlike the other sites in this study, there is no water treatment system for managing water quality in the Cumberland Terminus Basin.

The basin is lined with a synthetic liner that was installed when the system was constructed in 2006. When the UMD Team observed the system it was obvious that the basin leaked badly as water could be seen discharging from weep holes along Wills creek. This leak was higher when the basin was completely filled and diminished as the basin water level dropped. The basin is perched some 15 to 20 feet above the water level in Wills Creek and the Potomac River. This difference provided hydraulic head to drive the water from the basin to the river. The water level changes are shown in Figure 6.5 and 6.6.

Since water was draining out of the basin constantly, the pumps were being used intermittently throughout the day to re-fill the basin. NPS staff on-site often had to service the pumps because of their overuse and electricity use was higher than normal. Further compounding the problem, one pump failed in 2013 and another failed in 2014. This is why the UMD Team recommended very early on in the study that these hydraulic issues be repaired.

The staff at CHOH repaired the liner and leaks in the spring of 2015. At the present time (summer 2015) Cumberland Terminus Basin holds water with greater integrity. The data for this study was collected in the summer of 2014 thus some of the observations have now changed. The basic conclusions are valid and the need for further upgrades is still relevant to the existing operation of the system.

6.3.2 ALGAE COVERAGE

Thick mats of algae were present during each site visit for the visual assessment with estimates of water surface coverage presented in Table 6.2. Algae was distributed across the main basin surface and along the canal portion (Figure 6.7), but tended to collect in the northernmost corner of the basin, pushed there by prevailing wind (Figures 6.8 and 6.9). During July and August, it appeared that the coverage of algae on the surface did not change and remained relatively stable. The UMD Team observed a complex ecosystem associated with the feature that

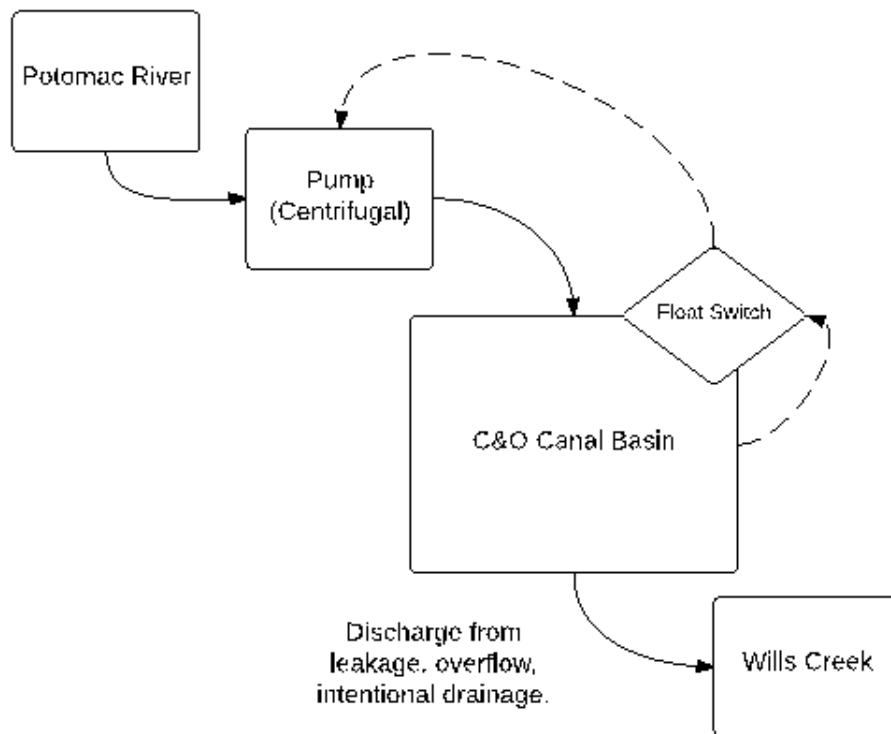


Figure 6.4. Conceptual diagram of the CHOH Canal Basin system. Solid lines represent water flows and dashed lines represent signals (information).



Figure 6.5. Water level in the CHOH Canal Basin. Photo taken July 8, 2014.



Figure 6.6. Water level in the CHOH Canal Basin. Photo taken August 26, 2014.

Figure 6.7. Thick mats of algae distributed across the water surface. Photo taken July 8, 2015.



Figure 6.8. Floating algae collected in the corners of the basin. Photo taken July 8, 2014.



Figure 6.9. Algal mats in the basin. Photo taken July 8, 2014.

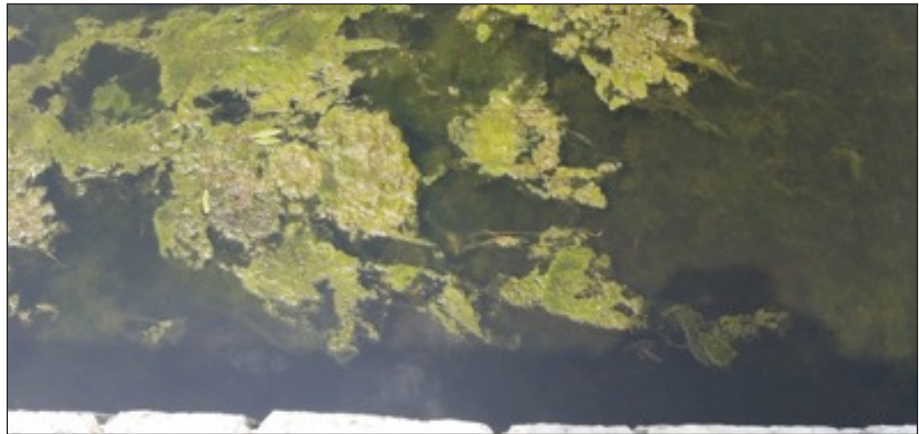


Figure 6.10. A snapping turtle along the shore of the basin. Photo taken July 8, 2014.



included many species of fish, Canada geese, several species of submerged and floating aquatic plants, aquatic insects, and snapping turtles (Figure 6.10).

Table 6.2. Percentage of water surface covered in algae.

DATE	% COVERAGE	DESCRIPTION
7/8/14	38%	Algae mats covering the surface with a foamy texture. Some algae co-mingling with aquatic plants on the floor of the basin.
7/23/14	38%	Algae mats covering the surface with a foamy texture. Some algae co-mingling with aquatic plants on the floor of the basin.
8/7/14	40%	Water level was extremely low so large mats of algae (dead and alive) were covering much of the surface of the water and exposed mud.

6.3.3 WATER-COLOR

Although thick mats of algae covered the surface, the water column was clear and not discolored (Table 6.3). As the thick mats of algae developed, they were able to tie up nutrients and outcompete smaller planktonic algae that tend to discolor water. Measurements of turbidity also confirm that the water was clear (Figure 6.11), more so than source water (Potomac River water).

Table 6.3. Water color observations during summer 2014.

DATE	WATER COLOR
7/8/14	Clear water but green algae mats are covering some parts of the surface.
7/23/14	Clear water but green algae mats are covering some parts of the surface.
8/7/14	Clear (Water level extremely low so the water appears darker than it is).

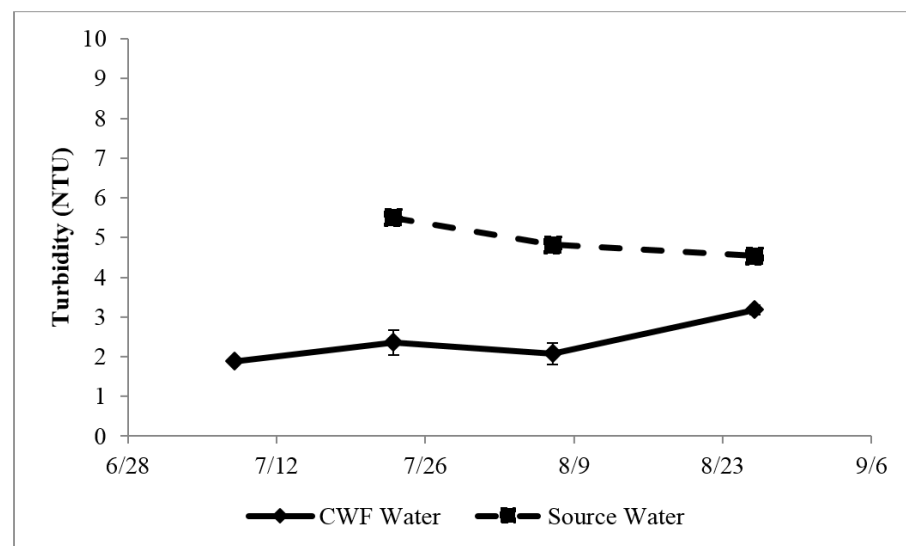


Figure 6.11. Turbidity of CWF water (solid lines) and source water (Potomac River water; dashed lines).

6.3.4 FOAM

Foaming in the CWF during the study was largely absent because the basin is devoid of attribute flows such as sprays, waterfalls or water spouts.

6.3.5 ODOR

Odor was only moderate in July but was noticeably worse in August when the water level was at its lowest (Table 6.4). During this time, dead algae and mud were exposed to the open air and the organic matter was clearly decomposing. The smell was unpleasant but not overbearing.

Table 6.4. Odor ratings and descriptions for the CHOH Canal Basin in Cumberland, MD.

DATE	ODOR RATING	DESCRIPTION
7/8/14	5	Algae and goose droppings
7/23/14	4	Algae and goose droppings
8/7/14	6.5	Strong dead algal and aquatic vegetation

6.3.6 PLANT DEBRIS

Plant debris was often present and it consisted of leaves, grass clippings and aquatic plants (Table 6.5).

Table 6.5. Plant debris coverage (%) on water surface of the CHOH Canal Basin.

DATE	PERCENTAGE	DESCRIPTION
7/8/14	15%	Grass clipping, aquatic plants, small leaf deposits
7/23/14	8%	Branches, leaves, aquatic plants
8/7/14	20%	Leaves and dead aquatic plants

6.3.7 LITTER

Litter was a noticeable problem in the CHOH Canal basin water (Table 6.6). Some of the litter was quite large such as traffic cones, articles of clothing, but most of it was small plastic waste, such as wrappers, bottles, plastic bags and other items. The basin lies adjacent to a highway overpass and much of the litter could come from passing cars and other vehicles. The basin is adjacent to a bicycle terminus and has a multiuse park area that is shared and partnered with the Canal Place Authority of Cumberland that holds events that are not under direct NPS supervision.

Table 6.6. Litter and descriptions at the CHOH Canal basin.

DATE	NUMBER OF ITEMS	DESCRIPTION
7/8/14	20	Glass and plastic bottles, wrappers, plastic bags, food product packaging
7/23/14	80	Glass and plastic bottles, wrappers, plastic bags, food product packaging, pillow, traffic cone, clothing, paper, zip lock bags, etc.
8/7/14	30	Glass and plastic bottles, soccer ball, Frisbee, aluminum cans, wrappers, plastic bags, food product packaging, traffic cone, clothing, paper, zip lock bags, etc.

6.3.8 NUTRIENT ANALYSIS

TP in the CWF water of the CHOH Canal basin were similar to source water with concentrations below 0.08 mg/l. (Figure 6.12). Source water TP tended to increase

in concentration during the study. The CWF water TP increased but then decreased when the pump failed and no new water was added. The CWF water TP then decreased, this could have been due to uptake by algae and vegetation. PO_4^{3-} concentrations were very low (less than 0.01mg/l) during this time, but did not show the same trend toward increased concentration as observed with TP (Figure 6.13). Concentrations were lower than source water and had decreased by the end of August. Aquatic plant and algae uptake could be responsible for this decrease in concentration in the water column. .

TN followed the trend of increasing concentration into August (Figure 6.14). NH_3 was steadily low in concentration until late August when there was a spike in NH_3 concentrations (Figure 6.15). This may be due to the decomposing matter in the system, as sediment, algae, and aquatic plants were exposed to the open air. When water samples were collected on August 26, there were several dead fish in the

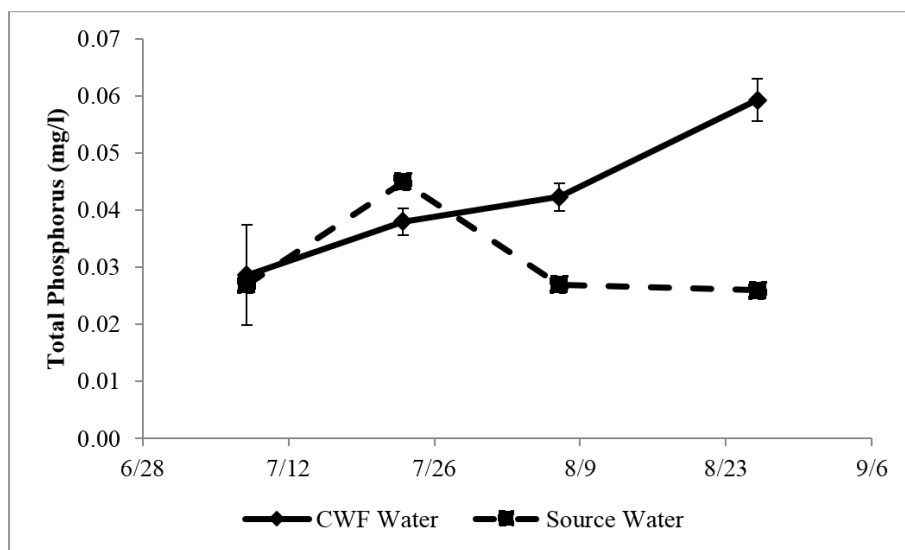


Figure 6.12. TP concentrations for CWF water (solid lines) and source water (Potomac River water; dashed lines).

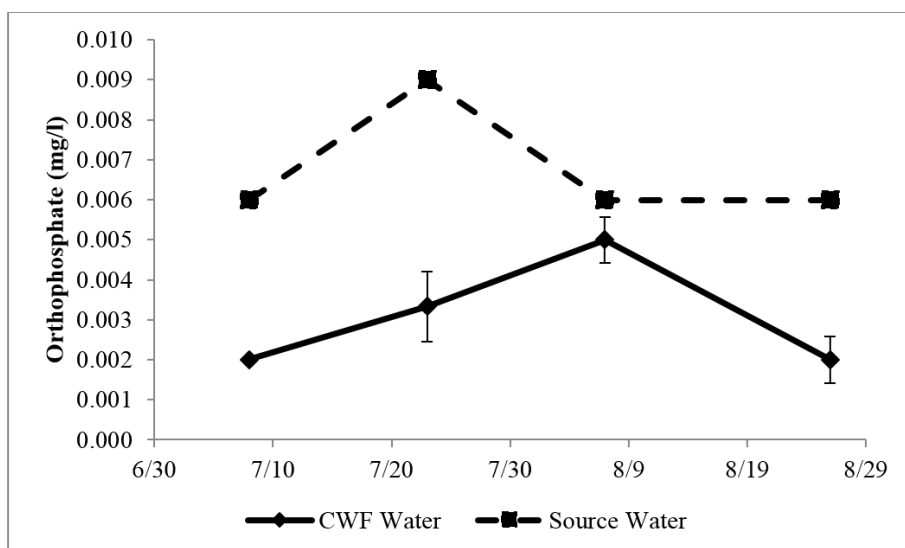


Figure 6.13. PO_4^{3-} concentrations for CWF water (solid lines) and source water (Potomac River water; dashed lines).

Figure 6.14. TN concentrations for CWF water (solid lines) and source water (Potomac River water; dashed lines).

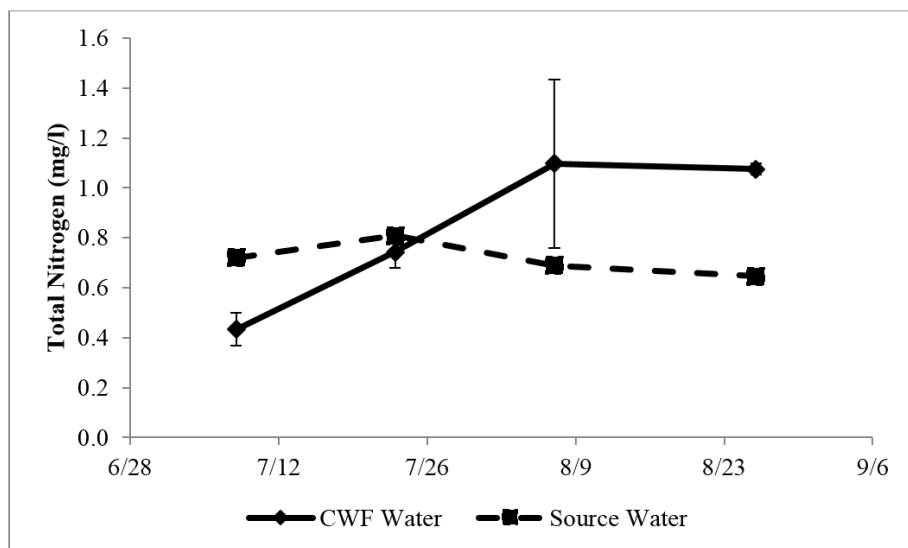


Figure 6.15. NH_3 concentrations for CWF water (solid lines) and source water (Potomac River water; dashed lines).

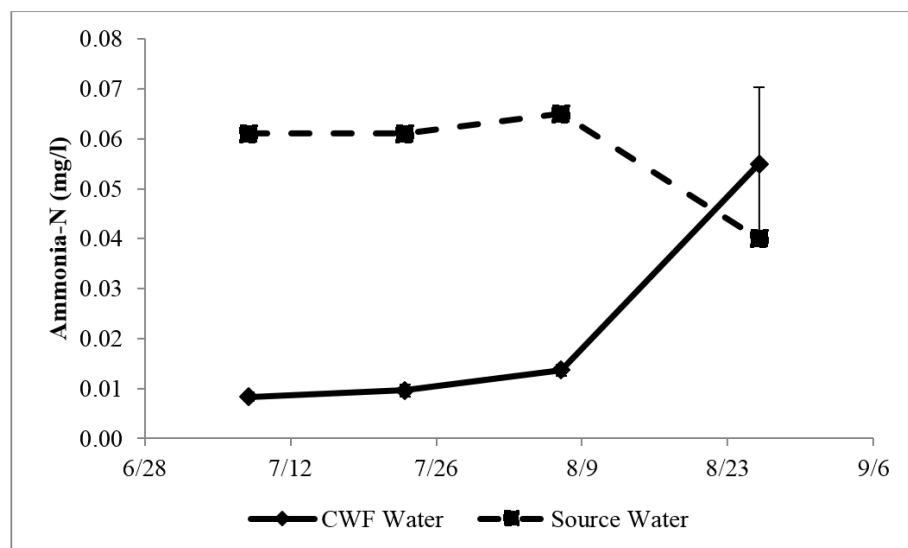


Figure 6.16. Dead fish in the CHOH Canal basin that may have caused a spike in NH_3 concentrations on August 26, 2014.



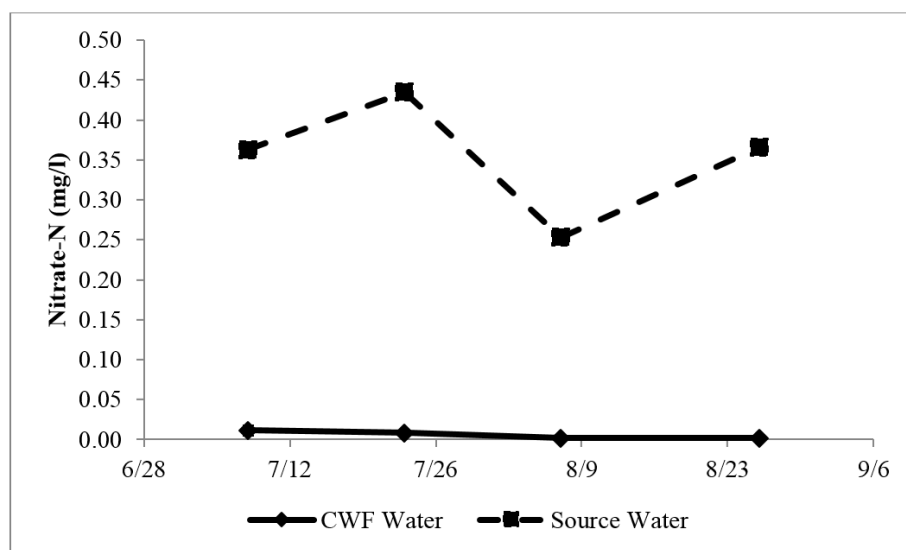


Figure 6.17. NO_3^- -N concentrations for CWF water (solid lines) and source water (Potomac River water; dashed lines).

water (Figure 6.16) and this may account for the rapid increase in NH_3 concentrations reported that day.

In contrast, NO_3^- was minimal in the CWF water (Figure 6.17). It may be that the earthen lined basin and associated aquatic plants are functioning like a wetland by undergoing denitrification processes (the conversion of NO_3^- to N_2 gasses) in the sediments. Some wetland vegetation was visible such as *typha* species (cattails) as well as some submerged aquatic vegetation.

These data might suggest that nutrient enrichment is not a concern in the CHOH Canal basin; however, it is important to note that thick algae mats had already developed in the water feature at the start of the study (Figure 6.7) and that algae coverage on the water surface did not increase greatly during the study (Table 6.1) suggesting that algal growth had climaxed and stabilized in the basins. The mats of algae must have taken advantage of available nutrients earlier in the summer and spring, before the water sampling began. Nutrient levels in natural river water are typically higher in the first 6 months of the year (Jaworski et al., 1992) when the basin would have been filled and replenished before the pump had failed. Therefore it may be that the water sampling data only shows what nutrients remained in the water column after the growth of the algae earlier in the season. If this is so, then there may internal cycling of phosphorus occurring among the algae, or that new nutrients might be sourced from the sediment.

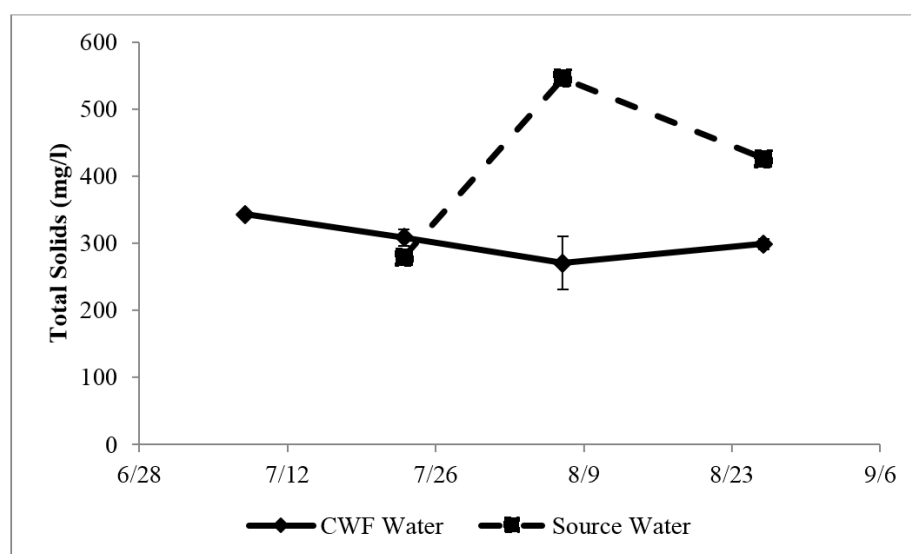
Nutrients in sediment can be released to the water column under certain conditions (anoxia, fluctuating pH) as often observed in natural systems (Van Luijn et al., 1995; Rozan et al, 2002). The storage of phosphorus in sediment means that algal blooms can continue even after incoming phosphorus is reduced as occurs in the Chesapeake Bay (Joshi et al., 2015) and the Baltic Sea (Viktorsson et al.,

2013; Puttonen et al., 2014). Given these factors, controlling release of nutrients from sediments may be an important part of mitigating algal blooms in the CHOH Canal basin.

6.3.9 SOLIDS ANALYSIS

Results of the solids analysis show that total solids (TS) content of CWF water are high (mean and SE, 306 ± 15 mg/l; Figure 6.18). Potomac River source water was initially similar, but was much higher later in the season. Most of these solids were dissolved solids (TDS; Figure 6.19) with only a small portion as suspended solid matter (Figure 6.20). Total suspended solids (TSS) were a mean ($\pm$ SE) of 21 ± 6 mg/l with more than a half consisting of suspended algae (volatile suspended solids; VSS; Figure 6.19). The water that was sampled does not include any portion of the concentrated algae mats floating on the surface. These were excluded from the sample collection. As such, the results indicate that suspended algae are present in the water alongside the floating algae mats, even in the clear water that was observed during the study. However it is likely that some of this volatile material was particulate organic matter (POM) that had sloughed off of algae mats and aquatic vegetation.

Figure 6.18. Total solids concentrations for CWF water (solid lines) and source water (Potomac River water; dashed lines).



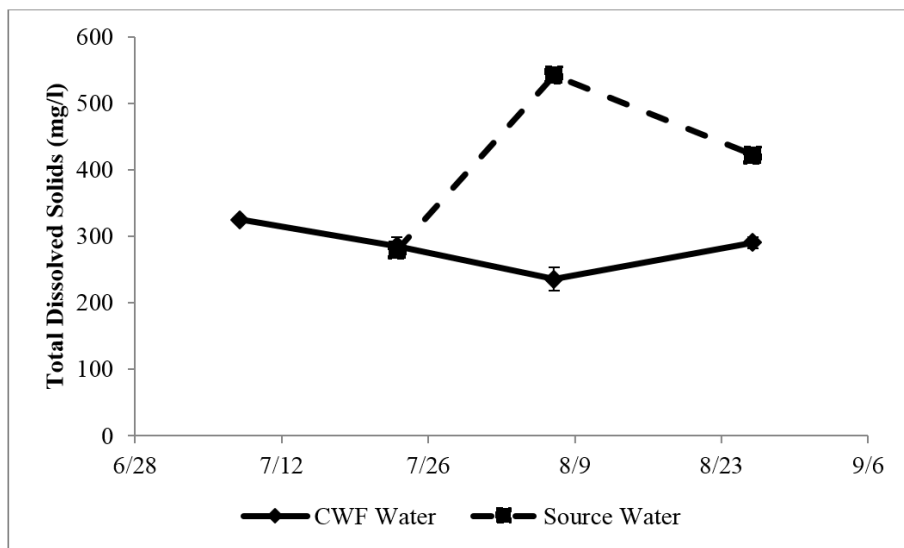


Figure 6.19. Total dissolved solids concentrations for CWF water (solid lines) and source water (Potomac River water; dashed lines).

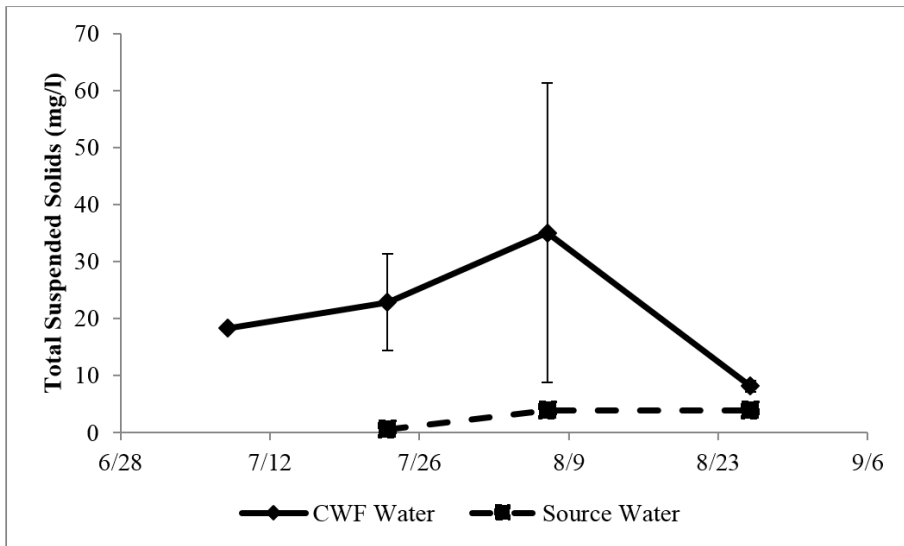


Figure 6.20. Total suspended solids concentrations for CWF water (solid lines) and source water (Potomac River water; dashed lines).

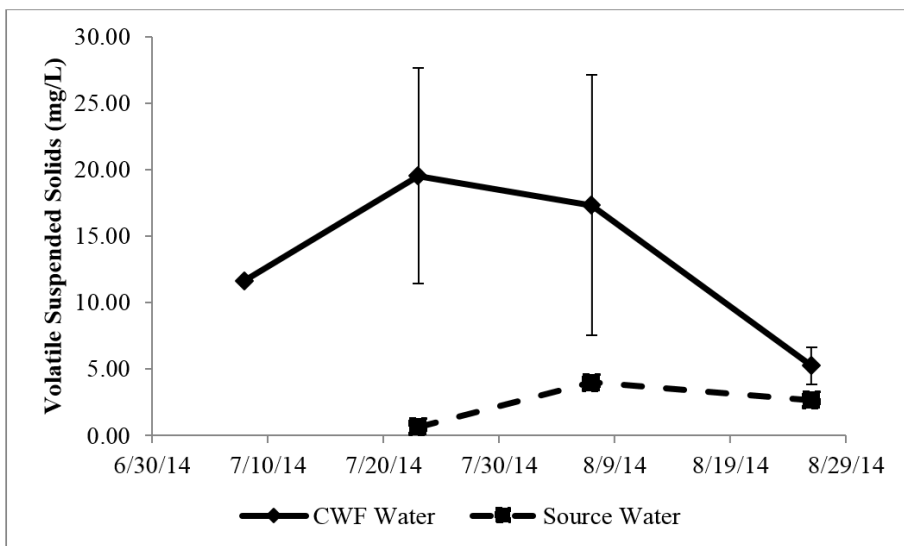


Figure 6.21. Volatile suspended solids concentrations for CWF water (solid lines) and source water (Potomac River water; dashed lines).

Figure 6.22. pH levels for CWF water (solid lines) and source water (Potomac River water; dashed lines).

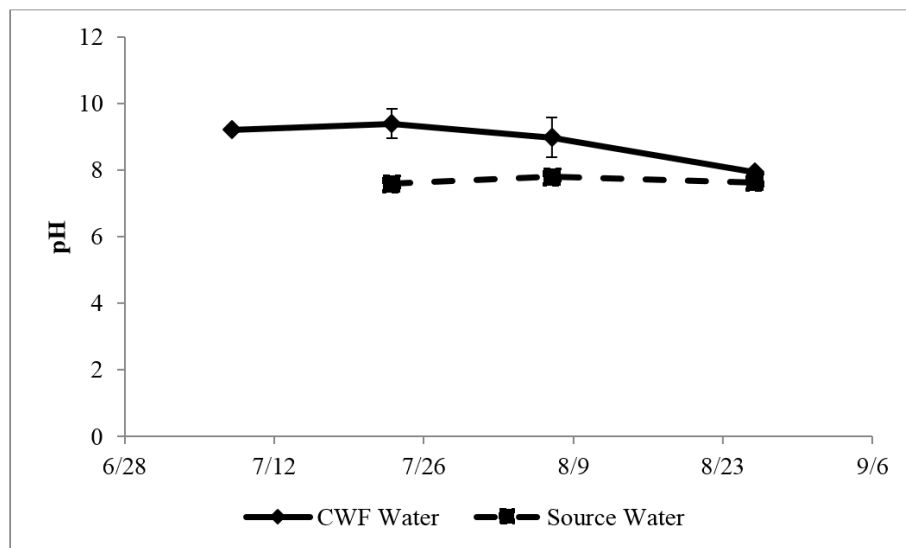


Figure 6.23. Dissolved oxygen concentrations for CWF water (solid lines) and source water (Potomac River water; dashed lines).

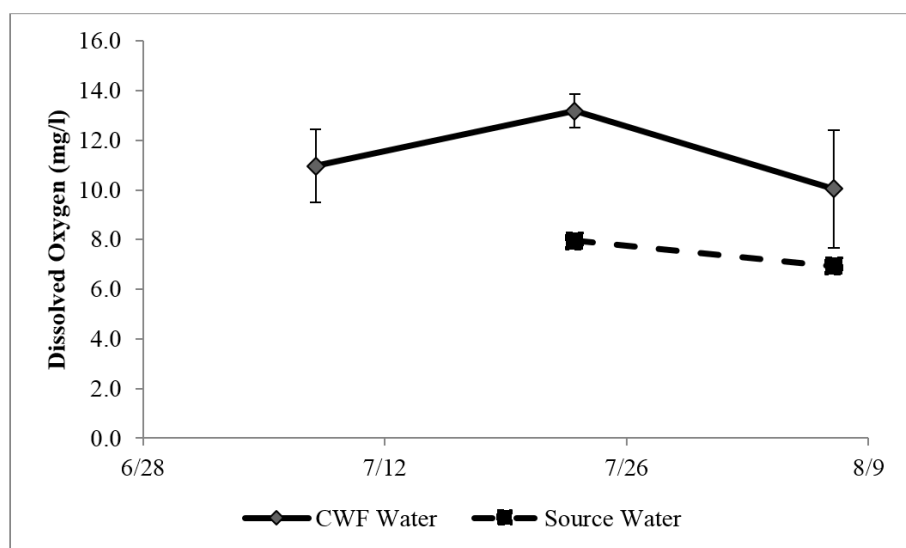
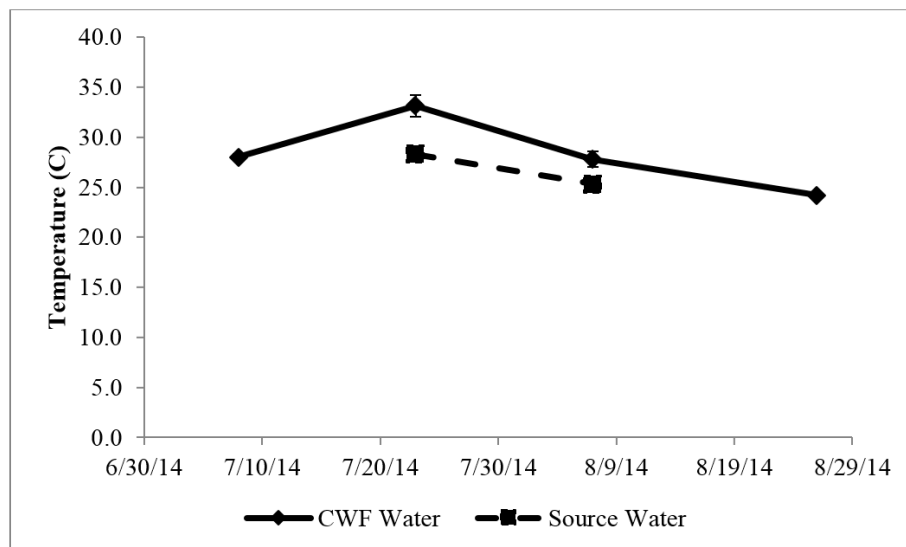


Figure 6.24. Water temperature for CWF water (solid lines) and source water (Potomac River water; dashed lines).



6.3.10 PH, DISSOLVED OXYGEN AND TEMPERATURE

pH levels were more basic than Potomac River water most of the time (Figure 6.22).

As mentioned in earlier chapters, this is likely the result of high rates of photosynthesis in algae laden waters. Dissolved oxygen measurements corroborated this, since the water was super saturated with oxygen (Figure 6.23). Water temperature was quite warm as well (mean of 28 ± 3 °C; Figure 6.24).

6.3.11 WATER DISCHARGE ESTIMATES AND WATER BUDGET

The Cumberland Basin had a volume of 2,316,000 gallons. In the summer 2014, the basin lost most of its water to a leak in the lining of the basin (Figure 6.25). Every time the water dropped below a certain point, pumps re-fill the basin from the Potomac River. This leak accounted for 99% of the water loss in the CWF. Since the leak was so quick, the basin acted more like a flow-through system, rather than a pond that retains water. As water moves through the basin, the water velocity slows once the water enters the basin, allowing particulates to settle as sediment, containing essential nutrients for plant and algal growth. Even though amounts of nutrients are quite low in river water, the basin effectively traps nutrients and concentrates them in the basin sediments, providing a source for algae and plants in the system.

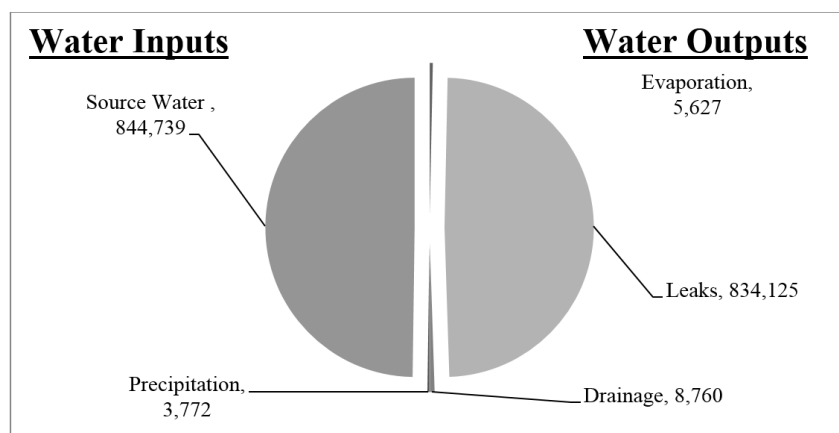


Figure 6.25. Water budget (m³/yr) for the CHOH Canal basin during the leak scenario in 2014.

FOOTNOTES:

Evaporative Losses = Surface area (m²) * Evaporation (m/yr; data source: NOAA, 1982) = 8759.88 m² * 0.88 m/yr = 5,627 m³/yr

Drainage = storage volume lost/event (m³/events) * # of times drained/yr (events/yr) = 8759.78 m³/event * (1 event/yr) = 8,760 m³/yr

Leaks = Leakage rate (m/hr; data source: NPS, 2014) Conversion hours to years (hrs/yr) = 0.0254 m/hr * 24 hrs/day * 214 days/year * 6394 m² = 834,125 m³/yr

Precipitation = surface area (m²) * precipitation rate (m/yr; data source: NOAA, 2015) = 6394 m² * 0.59 m/yr = 3,772 m³/yr

Source Water = Evaporation (m³/yr) + Drainage (m³/yr) + Splashing losses (m³/yr) – Precipitation (m³/yr) – overland flow (m³/yr) = 844,739 m³/yr

Another concern is the high-energy use of the pump, which must continually replace the water lost to leak. Energy use by the pumps was recorded as an average of 42,624 kWh per year. If the leak were repaired, this would result in a significant reduction in energy use and make the system overall more sustainable.

With a repaired leak and a watertight basin, the water budget looks very different (Figure 6.26). With lower flows of source water through the basin, the inputs of nutrients to the system should be reduced. This would aid in the reduction of noxious algal growth, but technology or management efforts to further control growth could be needed.

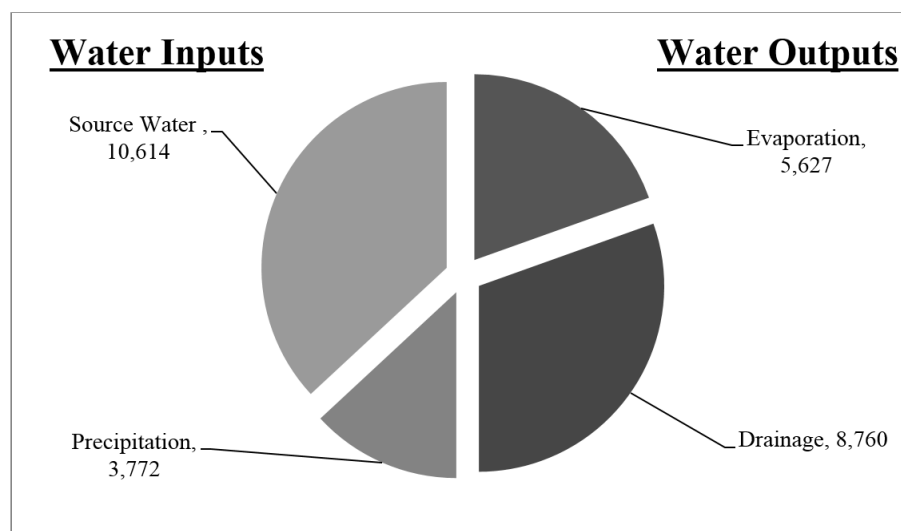


Figure 6.26. Water budget (m³/yr) for the CHOH Canal basin in a no-leak scenario.

FOOTNOTES:

Evaporative Losses (m³/yr) = Surface area (m²) * Evaporation (m/yr; data source: NOAA, 1982) = 8759.88 m² * 0.88 m/yr = 5,627 m³/yr

Drainage (m³/yr) = storage volume lost/event (m³/events) * # of times drained/yr (events/yr) = 8759.78 m³/event * (1 event/yr) = 8,760 m³/yr

Leaks (m³/yr) = 0 m³/yr

Precipitation (m³/yr) = surface area (m²) * precipitation rate (m/yr; data source: NOAA, 2015) = 6394 m² * 0.59 m/yr = 3,772 m³/yr

Source Water (m³/yr) = Evaporation (m³/yr) + Drainage (m³/yr) + Splashing losses (m³/yr) – Precipitation (m³/yr) – overland flow (m³/yr) = 10614 m³/yr

6.3.12 PHOSPHORUS SOURCES

The mass balance for the Cumberland Basin presented in this study occurred during an atypical year when either source water was added in continuous basis or it wasn't added at all and the basin water level was very low. Concentrations of phosphorus and nitrogen in CWF water were not typical where water inputs were controlled and leakage was minimal. Source water data does indicate low levels of nutrients and thus appears to be good source of makeup for the basin.

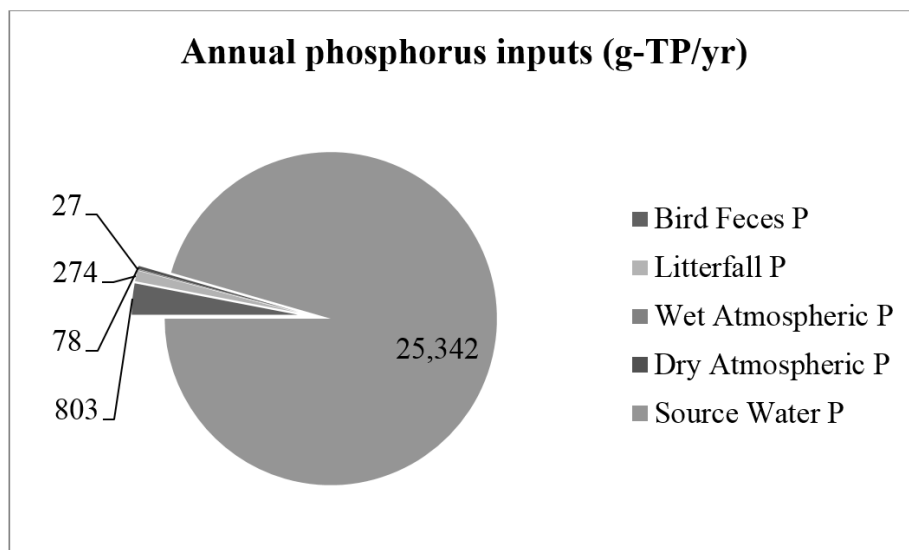


Figure 6.27. Annual phosphorus inputs (g-TP/yr) for a leak scenario in the CHO Canal basin.

FOOTNOTES:

Bird Deposited P (g/yr) = Rate of bird input (g-P/bird/day) * number of visiting birds (birds/day) * length of CWF operation (days per year) = 0.45 g-P/day/bird * 8 hours/24 hours/day * 25 birds * 214 days/year = 803 g/yr

Litterfall P (g/yr) = Rate of litterfall (g/m²/day) * Surface area (m²) * Annual days of operation (214 days/yr) * P released after 24 hrs of decomposition (mg-P/g-leaf litter) * conversion to grams (g/mg) = 1 g-leaf/m²/day * 6,394 m² * 214 days/yr * 0.2 mg-P/g * 1e-3 g/mg = 274 g/yr

Wet Atmospheric Deposited P (g/yr) = Concentration of P in rainfall (µg/l) * Conversion to g (1e-6 g/µg) * Annual precipitation inputs (m³/yr) * conversion to grams (mg/g) * conversion to liters (l/m³) = 7.1 µg/l * 3772.5 m³/yr * 1e-6 g/µg * 1000 l/m³ = 27 g/yr

Dry Atmospheric Deposited P (g/yr) = Rate of deposition (kg-P/m²/yr * surface area (m²) * 1 year/12 months * 8 months/yr = 18.4 mg-P * 1e-3 g/mg * 6,394.00 m² * 8/12 (month of operation per year) = 78 g/yr

Source Water P (g/yr) = Concentration of P in Source Water (mg/l) * Annual source water inputs (l) * Conversion to grams * conversion to cubic meters (l/m³) = 0.03 mg-TP/l * 1e-3 g/mg * 844739.5 m³/yr * 1000 l/m³ = 25,342 g/yr

Finally measurements of nutrients in the sediments were not collected and could constitute a nutrient source that could recycle back into the overlying water. Two mass balance scenarios are presented to estimate phosphorus inputs: leak scenario that existed during the study and the minimal leak scenario that existed after the leaks were repaired.

In a leak scenario where water is constantly re-filled with an automated pump system (Figure 6.27), the Cumberland Basin would have the highest annual TP loading than any of the other study sites. Nearly all of the phosphorus would come from source water (i.e. the Potomac River), which has lower concentrations of nutrients than municipal source water but when re-filled a nearly continuous basis constitutes a very large flow of phosphorus into the basin. All other inputs such as grass cutting or waterfowl are minimal in comparison. This constant supply of phosphorus would be more than sufficient for algal blooms.

In the minimal leak scenario that now exists with basin leaks repaired, the phosphorus loading would be reduced by 96.8 percent with the major input coming waterfowl. Waterfowl feces tend to settle in the sediments and could contribute a significant amount of phosphorus recycled back to the water column (Figure 6.28). We found that fecal coliform bacteria were quite high (2,419.6 CFUs/100ml) indicating inputs of bird droppings and other feces. We also witnessed waterfowl droppings in large amounts (Figure 6.29) on several of the site visits. Using data from literature (Post et al, 1998), we estimated that waterfowl could contribute as much or more phosphorus as was observed coming into the FDR memorial CWF system in a single year (802.5 g-P/yr). This highlights that repairing the leak will help reduce flows, but may not solve the problem of nutrient pollution in the basin. Further treatment or management is needed to control water quality in the Cumberland Terminus Basin.

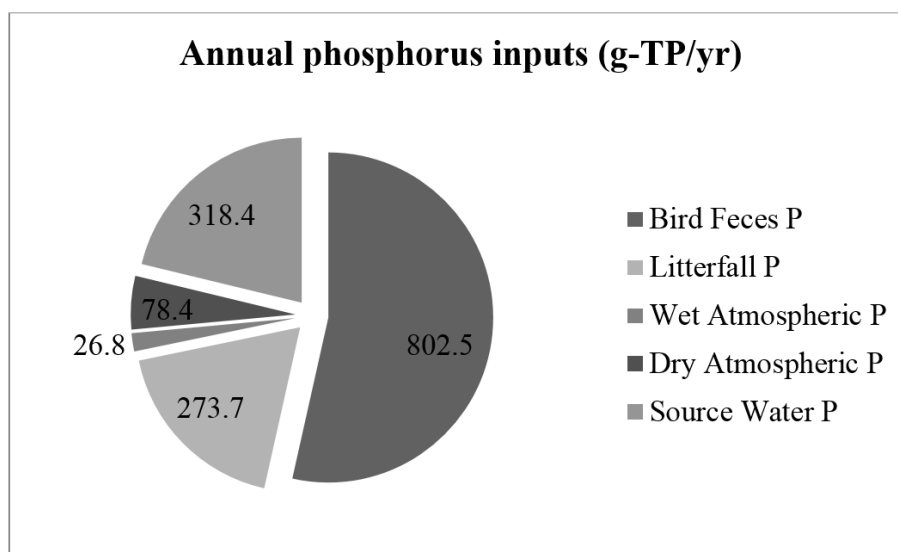


Figure 6.28. Annual phosphorus inputs (g-TP/yr) for a non-leak scenario in the CHOH Canal basin.

FOOTNOTES:

Bird Deposited P (g/yr) = Rate of bird input (g-P/bird/day) * number of visiting birds (birds/day) * length of CWF operation (days per year) = 0.45 g-P/day/bird * 8 hours/24 hours/day * 25 birds * 214 days/year = 803 g/yr

Litterfall P (g/yr) = Rate of litterfall (g/m²/day) * Surface area (m²) * Annual days of operation (214 days/yr) * P released after 24 hrs of decomposition (mg-P/g-leaf litter) * conversion to grams (g/mg) = 1 g-leaf/m²/day * 6,394 m² * 214 days/yr * 0.2 mg-P/g * 1e-3 g/mg = 274 g/yr

Wet Atmospheric Deposited P (g/yr) = Concentration of P in rainfall (µg/l) * Conversion to g (1e-6 g/µg) * Annual precipitation inputs (m³/yr) * conversion to grams (mg/g) * conversion to liters (l/m³) = 7.1 µg/l * 3772.5 m³/yr * 1e-6 g/µg * 1000 l/m³ = 27 g/yr

Dry Atmospheric Deposited P (g/yr) = Rate of deposition (kg-P/m²/yr * surface area (m²) * 1 year/12 months * 8 months/yr = 18.4 mg-P * 1e-3 g/mg * 6,394.00 m² * 8/12 (month of operation per year) = 78 g/yr

Source Water P (g/yr) = Concentration of P in Source Water (mg/l) * Annual source water inputs (l) * Conversion to grams * conversion to cubic meters (l/m³) = 0.03 mg-TP/l * 1e-3g/mg * 10614 m³/yr * 1000 l/m³ = 318 g/yr



Figure 6.29. Bird droppings along the walkways along the CHOH Canal basin. Photo taken July 7, 2014.

6.4 CONCLUSION

Algal growth is clearly excessive in the CHOH Terminus Basin, but concentrations in the source water and the CWF water were low; however, during the study period the basin was not receiving any source water to make up for leaks and evaporation. This means that the basin was only receiving nutrients from other sources, such as bird dropping and from the sediment layer. Nutrient concentrations in the water were low since algae were likely taking them up as soon as they became available. Instead of being present in the water, the phosphorus had been taken up and stored in algae biomass, or stored in sediments. Collecting and testing sediment samples for phosphorus concentration will help to confirm these conclusions.

Beyond the removal of NO_3^- by the wetland-like environment and associated microbes, there is no nutrient management system in place to reduce the floating mats of algae. The phosphorus mass balance showed that, during normal operation, uncontrolled phosphorus input from source water and bird feces is large enough to cause the growth of a large amount of algae. As algae decays, the sediment layer can absorb phosphorus and store it until conditions cause its release (fluctuations in pH and oxygen levels). In effect, the basin and its sediment later act as a phosphorus trap, storing and concentrating phosphorus from various sources, without any vector for removal.

Finding a solution for controlling algae growth should include nutrient removal that targets phosphorus. Biocides are not feasible at this site, since the basin has a community of fish, turtles, birds and other organism that are desirable for the semi-natural setting. Additionally, filtration systems are not currently feasible at this site because it has no water movement or attribute flows that could be redirected through a filter or disinfection unit (such as UV units or ozone genera-

tors). These systems including wetlands or PSFs with phosphorus removal could be added and adjacent land is available. Without these upgrades controlling algal blooms will have to rely on benign nutrient removal systems and a reduction in stored nutrients on the basin bottom. Furthermore, reducing nutrient inputs by plugging leaks and deterring waterfowl will be necessary. Any significant nutrient inputs will accumulate overtime to cause blooms of algae repeatedly unless they reduced or eliminated.

Some variety of algae will always be present in the basin, but the control of nutrients can minimize the unsightly floating mats of algae and improve water clarity to an acceptable turbidity level. This will improve the visual quality and odor, while supporting fish and other aquatic wildlife typically found in the basin.



TECHNOLOGIES & RECOMMENDATIONS

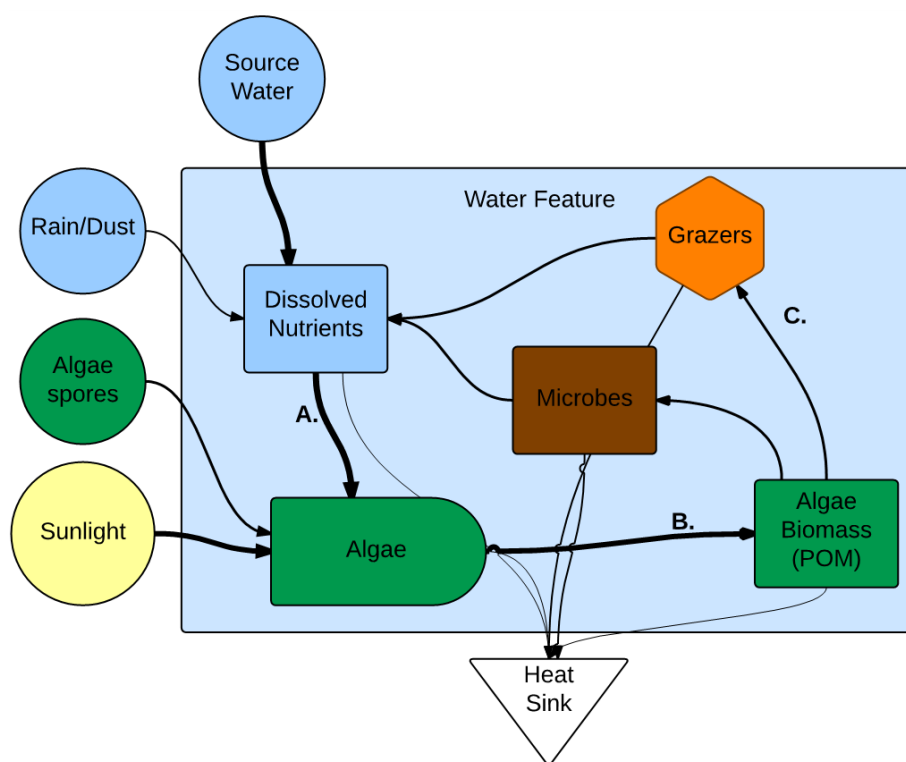


Figure 7.1. Energy diagram of algal growth in a water feature. Pathway A. is the nutrient flow pathway to algae. Pathway B. is biomass production. Pathway C. is grazing by animals.

CHAPTER 7. REVIEW OF TECHNOLOGIES FOR SUSTAINABLE WATER MANAGEMENT.

7.1 INTRODUCTION

A common theme was the re-occurrence of algal blooms and eutrophic conditions. Dealing with algal blooms is not a simple task and will require technologies to kill algae, prevent growth and/or reduce nutrient concentrations. The wide breadth of scientific data makes it clear that algae production and biomass is, in most fresh-water systems, controlled by the amount of P available for uptake (Schindler, 1977; Guildford & Hecky, 2000; Anderson et al, 2002; Steffan, 2014; Kane et al, 2014).

Figure 7.1 is a simplified conceptual diagram of a CWF ecosystem. In the diagram, P originates primarily from source waters but also originates from rain, dust and terrestrial ecosystems. Algae use solar energy and dissolved nutrients to produce biomass. Biomass is either eaten by grazers or sinks as particulate organic matter (POM) that is broken down by microbes, and recycled back into dissolved nutrients¹. The heat sink represents losses of energy to entropy.

In order to reduce algae, manipulation of the CWF water renders the aquatic environment inhospitable to algae, by adding toxic compounds, reducing available nutrients, or other method. Reducing sunlight is impractical as is reducing incoming algae spores since these are nearly impossible to control. The wind, birds and other mobile vectors that may be unknown or very small can carry algae spores. As such, water management should focus on reducing the nutrient flows (pathway A.), the biomass production (pathway B.) or the enhancing grazing (pathway C.).

For natural systems, Hudnell (2008) outlined the three main strategies for reducing algal growth:

1. Nutrient input reduction and manipulation to reduce the availability of essential nutrients for algal growth;
2. The use of biocides and algaecides to kill existing algae or;

¹ It is important to note that algal species also have micronutrient requirements, such as a need for Fe, Si, Mg, Ca, and others. These types of micronutrients are abundant in river waters and generally not removed in large amounts by the drinking water treatment, with the exception of Fe and other harmful metals (US Army Corp of Engineers, 2013). Therefore we can assume that CWFs fed by either municipal water in the Capital Region or by Potomac River water have a sufficient supply of micronutrients for algal growth.

3. Biological manipulation (i.e. enhancing grazing or the microbial community).

In this way, most, if not all, water treatment technologies operate by the manipulation of nutrient, energy or biomass flows. In this chapter we review biocides and algaecides, solids filtration, nutrient reduction techniques, and biological manipulation. Selecting an appropriate, effective technology requires a review of how the technologies function, their ability to handle excessive algae concentrations, and their overall resource intensity (cost, amount of effort to maintain, use of refined materials, etc.). Moreover, the NPS is tasked with the stewardship of important cultural sites that must be preserved for future generations. Ensuring that these sites and any new technologies are environmentally sustainable, socially acceptable and compatible with the materials and equipment in CWFs is of critical importance.

This chapter reviews how different water treatment technologies work, and provide values for sustainability using the rating system outlined in Chapter 2.

7.2 BIOCIDES AND ALGAECIDES

7.2.1 CHLORINATION

The use of chlorine as a disinfectant is well established in drinking water treatment, waste water treatment, recreational swimming pools and outdoor water features. Chlorination was developed in the early 20th century and has significantly increased public health in many countries. It is generally viewed as one of the most important developments in water treatment.

Chlorine is a strong oxidizing agent that kills microbes and algae. Chlorine gas is dissolved in water and rapidly hydrolyzes to form free chlorine (Cl_2) and hypochlorous acid (HOCl). HOCl is a weak acid that undergoes partial disassociation in water to form hypochlorite ions (OCl^-). Therefore chlorine exists in water as Cl_2 , HOCl , and OCl^- . The proportion of these compounds is controlled by pH. Below pH 7.5, the active ingredient, HOCl , predominates. By regulating the proportion of HOCl and OCl^- , pH controls chlorination efficacy (Kemmer 1979). Low pH generally increases disinfection rates, while a pH above 8 slows disinfection rates and reduces the efficacy of the treatment (Ward et al. 1984). Considering pH levels of source water in the study often showed a pH above 8 and some cases reaching a pH of 9, CWFs with high-pH municipal water may require greater doses of chlorine or pH adjustment prior to chlorination.

To remove algae in water systems, chlorine is used in combination with a coagulant that aggregates the dead algal cells so that they can be easily removed. Shen

and colleagues (Shen et al. 2010) studied the pilot use of chlorine and potassium coagulation at a drinking water treatment plant in China. Raw water was high in algal cells, ranging from 10×10^6 cells/l to 40×10^6 cells/l, and required an efficient algal removal process. The use of chlorine as a pre-oxidant and potassium permanganate as a coagulant yielded removal efficiencies above 98% when water temperatures were favorable ($18 - 22^\circ \text{C}$). Coagulation was needed because the dead algae often remained in suspension and required removal by coagulation. In swimming pools, chlorination prevents algae from developing in the first instance, rather than dealing with existing algae.

Other constituents commonly found in natural water react with chlorine; these include free ions and natural organic matter, such as proteins and lipids, NH_3 , and amino acids. As chlorine reacts with other compounds and chlorine gas comes into equilibrium with the atmosphere, more chlorine must be added over time to replenish the active ingredient. Therefore it is important that chlorine and pH levels are monitored daily and that chlorine is dosed as needed.

Another method of chlorinating pools and water features is the use of electrolysis and dissolved salts to produce chlorine on site, often referred to as “salt water pools.” A device is fitted in line with the water circulation system and salt (usually sodium chloride) is added to the water at concentrations between 3 parts per thousand (ppt) and 5 ppt. The device then passes an electrical current across an electrode that causes internal pressure to build up and discharge free chlorine gas to the water. In essence, the device converts electricity and salt into free chlorine for disinfection (Rabson and Richards, 1971).

Salt-water chlorination is an automated system that constantly discharges chlorine to maintain sufficient levels of free chlorine at all times when the device is sized appropriately and well maintained. An additional benefit is that chlorine converts to chloride once again, so is recycled by the system; only periodic additions of salt are needed to replace losses from splashing, and intentional draining and refilling.

The systems are not maintenance-free, however. Since the pH is elevated by the salt water (because the carbonate system is altered), scaling is likely to occur and operators must monitor the buildup of scale on the plumbing system and pool. If scale develops on the electrode, there is reduced contact between the electrode and water yielding less free chlorine and allowing a slight buildup of heat (water contact cools the electrode) and the device can be damaged. Additionally, super-chlorination (“shocking the system”) and/or algaecides may still be needed when using electrolytic chlorine generation, since chlorine levels rarely fluctuate, allow-

ing for some algae and bacterial blooms to occur when biofilms build up (APSP Recreational Water Quality Committee, 2011).

Corrosion from salts is a serious risk to the materials in a CWF. Corrosion may take years to develop into noticeable problems, but the risk is too high for historical CWFs that are intended as part of the United States' cultural heritage. Corrosion of stone on ancient CWFs was analyzed in Italy and the buildup of sodium chloride degraded stone substantially (Bersani et al, 2008). Though initial concentrations in the water are low, salts could pose a significant threat to the quality of the stone basins in water features and is not recommended.

Preservation of Design Intent: 4.

Chlorination does not discolor water, nor does it require any construction or infrastructure to use, other than monitoring equipment, and a location to house a store of solid chlorine.

Human Safety: 1.

Sodium hypochlorite and calcium hypochlorite are corrosive and can severely harm eyes and skin on contact. Appropriate safety training and precautions are needed if chlorination is to be employed to manage CWF water quality.

Environmental Impact: 1.

Chlorine, chlorinated organic compounds, and other forms of chlorine cause environmental harm even at low levels. Chlorine has toxic effects on fish and wildlife in aquatic systems and its discharge to the environment is allowed only under permits by the National Pollution Discharge Elimination System (NPDES) of the US Environmental Protection Agency.

Since the 1980s, scientists have been aware that the chemical reactions between chlorine and natural organic matter produce harmful disinfection by-products. More than 600 disinfection by-products have been identified (Richardson, 2003; Sharma et al, 2014) and 20 are regulated due to human health risks such as urinary bladder cancer. Exposure to these substances occurs during ingestion, direct contact with skin and inhalation (Richardson, 2003). While scientists have gathered evidence on the human health risks, little is known about the effects of these compounds in the environment (Farré et al, 2008).

The chief precursors to disinfection by-products are compounds from algae and humic substances in water (Lui et al, 2010). Small hydrophobic compounds are the most potent producers of disinfection by-products, but also the most difficult to remove from a water source (Chang et al, 2001).

For these reasons, chlorination posed a risk to local ecosystems when discharged and receive a poor rating (1) for environmental impact.

Energy Use and Greenhouse Gas (GHG) emissions: 2.

Regular use of chlorine does not increase an on-site energy use, but the production and delivery of chlorine products does. Sodium hypochlorite is an industrially produced chemical, converted from brines into a useable chemical by electrolysis or other intense industrial processes. Approximately 2 g-CO₂-equivalents are emitted for every 1 m³ of water treated with chlorine at drinking water treatment plants (Vince et al, 2008). For example, if used to treat water at Meridian Hill Park that consumes ~2,000 m³ per year, then 4,000 g-CO₂-eq would be emitted for the production of the sodium hypochlorite. It receives a low rating (2) for energy use.

Water Use: 3.

Theoretically, chlorination does not increase or decrease water use. It receives a good rating (3) rating for water use.

Resource Intensity: 3.

Chlorine is made from brine, which abundant in many areas of the world. Chlorine receives a good rating (3) for resource intensity.

Labor Intensity: 1.

Chlorination requires frequent monitoring of chlorine levels and the frequent dosing of chlorine during the operation of a water feature.

Efficacy: 3.

Chlorination is a disinfectant that does not alter the underlying nutrient concentrations that cause algal blooms. Additionally it has a tendency to volatilize and disperse to the atmosphere. Therefore, if there is any lapse in chlorination, or if dosages are not sufficient, one can expect the rapid growth of algae to occur.

Chlorine is very effective as a disinfectant when dosages meet or exceed the solution's chlorine demand but repeated use of chlorine is needed to effectively prevent microbial and algal growth in recirculating systems. As mentioned above, testing for pH is needed to determine dosages, as chlorine is less effective at pH above 8—as is often the case with the municipal water supply.

Since it is very effective at preventing algal growth when applied properly, chlorination receives a good rating (3) for efficacy.

Cost Estimates: 2.

Chlorination does not require any installation of new infrastructure, so there are no capital costs. When used for municipal drinking water production is generally thought as low cost (Sedlak, 2014). However, chlorination requires that a trained operator is available on a weekly basis to test and apply dosages of chlorine as needed. Labor costs need to be evaluated along with chemical costs, as this may become a more costly long-term expense. Chlorination receives a fair rating (2) for cost.

Summary

Chlorination received a 2.2 on the sustainability rating scale. Chlorination is not considered a sustainable process because it uses toxic chemicals—dry hypochlorite—produced by using non-renewable fuels. There are safety and health risks involved with chlorination. Environmental impacts may affect aquatic environments if discharged into natural water bodies. Though it is effective when used properly, it does not have a lasting effect on water quality and must be monitored daily. This means that operators must understand the appropriate doses that are needed, have the capacity to measure chlorine concentrations in water, and have the time to repeatedly dose systems. If chlorine is to be used, then sufficient time, training, safety measures, and testing equipment are needed.

7.2.2. OZONE (O₃)

Ozonation is an effective water treatment method used in various applications; most commonly in drinking water treatment and aquaculture. Ozonation is the mixing of ozone gas (O₃) with water for disinfection and other benefits. Ozone gas is a strong disinfectant; bacteria, viruses, and protozoans are all deactivated by exposure to ozone. Additionally, ozone gas breaks down to benign oxygen (O₂) that fish or other animals can use in respiration.

The use of ozone requires the establishment of contact between target organisms and ozone gas (O₃). Its killing efficiency is therefore related to contact time and how much ozone gas is present, but temperature and pH the killing efficiency and solubility of ozone in water (thus allowing for higher dosages of ozone; Camel and Bermond, 1998).

Systems are set up so that the ozone generator pumps ozone gas into a chamber where it mixes with water and comes into contact with target organisms. The construction and design of such a chamber depends on the dosages needed and the flow rates of water through it. The dosages needed vary with target organisms, their concentration (how many are present in the water) and water quality – as

other constituents in water will exert an ozone demand like leaf litter, organic particles and some inorganic particles.

Preservation of Design Intent: 3.

Ozone generator could be housed in CWF pump rooms without affecting the overall appearance of the CWF. However, ozone is very reactive and corrosive, so before it is adopted, its compatibility with materials in the CWF must be assessed.

Human Safety: 2.

Ozone is a corrosive gas that can cause extensive damage to respiratory systems when inhaled, even in small concentrations. Generally, ozone is contained with the contact chamber and rapidly degrades as it works on the water column. Risks of ozone exposure occur when there is a leak in the ozone gas generator and delivery system. Exposure is serious and can be fatal to humans' however once degraded ozone has no harmful effects. It receives a fair rating (2) for safety.

Environmental Impact: 4.

Environmental impacts from ozone are minimal, because ozone breaks down to benign oxygen rapidly in water. Ozone receives an excellent rating (4) for environmental impacts.

Energy Use and Greenhouse Gas (GHG) emissions: 0.

However, production of ozone is an energy-intensive process and therefore entails a considerable carbon footprint when under continuous operation. Vance and colleagues (Vance et al., 2008) reported that approximately 10 g-CO₂-equivalents are released for every 1 m³ of water treated. If used at Meridian Hill Park, ozonation would increase the carbon footprint by 20,000 g-CO₂-equivalents per year. Therefore ozonation receives a very poor rating (0) for energy use

Water Use: 3.

Ozonation does not increase or decrease water use. It receives a good rating (3) rating for water use.

Resource Intensity: 3.

Once constructed from material able to withstand contact with ozone, ozone generators do not require intensive materials for operation.

Labor Intensity: 2.

Ozone generators are often automated, but at times require a trained operator to adjust dosages and maintain the sophisticated equipment. Because of this, ozone generators receive a fair labor intensity rating (2).

Efficacy: 2.

In a well-circulated CWF, an ozone generator should be very effective at killing suspended algae while providing other benefits such as the degradation of organic matter, disinfection without residual disinfection by-products like chlorine (Camel and Bermond, 1998). It is excellent for aquaculture is well controlled (Wheaton, 1993) and is often used to produce potable water in municipal systems in many parts of Europe (Glaze, 1987; Loeb et al, 2012). Ozone is also effectively used in swimming pools in place of chlorine (Loeb et al, 2012).

Some inorganic substances are transformed by exposure to ozone, including certain forms of nitrogen—an essential nutrient for algae. NH_3 is converted to nitrite (NO_2^-) and then to NO_3^- by ozonation, rendering it more soluble in water. Additionally, ozonation of organic matter releases soluble phosphorus—another essential nutrient—to the water column (Saktaywin et al, 2005; Lehtelo et al, 2001) even though complete degradation of organic matter rarely occurs (Camel and Bermond, 1998). Therefore ozonation of water features may make nutrients more soluble and available for growth, if algae can escape ozonation.

Algae could escape ozonation by attaching to the walls of the CWF, or by forming algal mats that float and do not flow through drains and other piping that leads to an ozone generator. This type of algae might even be enhanced because ozonation makes nutrients more available, as mentioned above. Additionally, such types of algae would have no competition for light or nutrients from suspended algae.

Ozone generation receives a fair rating (2) for efficacy.

Cost estimates: 1.

Ozone generators are typically expensive systems to build and operate because of large energy requirements. In comparison with other methods, ozonation is more expensive than UV disinfection or chlorination (Hoibye, et al., 2008). Operating costs of ozone will be largely related to the cost of energy, and the maintenance requirements of the system. Some skilled labor is also required in order to determine dosages and adjust as needed. Ozone receives a poor rating (1) for cost.

Summary

Ozonation received an average rating of 2.2 rating (out of 4) in the assessment. It is a powerful disinfectant and there are few downstream environmental effects: but it has a substantial energy footprint and may not be effective if water basins contain any stagnant areas of water or do not circulate well.

7.2.3. BARLEY STRAW

Barley straw (*Hordeum vulgare*) has been used to control algae in some applications and has received attention in the UK and elsewhere. It's been identified as having algae static properties rather than algaecidal, but the mechanisms are poorly understood. It is thought that an oxidized polyphenolic compound is released from barley straw during decomposition. This compound is thought to have an oxidizing effect on algae and can cause fatal reaction to algae that are already under notable oxidative stress (Al Place, pers. com). Aerobic conditions and a rich micro flora that can enhance decomposition are needed for best results (Ridge and Phillips, 1996; Martin and Ridge, 1999; Ball et al, 2001; Iredale et al, 2012). Suggested field applications range from 20 g-dw straw m⁻³ to over 100 g-dw m⁻³ (Ridge and Phillips, 1996; Martin and Ridge, 1999; Caffery and Monahan, 1999).

Preservation of Design Intent: 0.

Bails of barley straw are loaded in contact with the CWF water at the surface. The straw then breaks down over time, releasing active compounds that stress cyanobacteria. While this may not be a visual concern at earthen lined basins, exposed bails of barley straw would not be appropriate for other CWFs. They receive a very poor rating (0) for preservation of design intent.

Human Safety: 4.

There are no human safety risks for using barley straw for water treatment.

Environmental Impact: 4.

There is little to no risk from using barley straw to control toxic algae. It is a natural product and breaks down in the environment to benign materials.

Energy Use and Greenhouse Gas (GHG) emissions: 3.

Production and delivery of barley straw entails energy use and GHG emissions comparable to other forms of agricultural products.

Water Use: 3.

The use of barley straw does not increase or reduce water use.

Resource Intensity: 4.

Barley straw is readily available, affordable, and abundant.

Labor Intensity: 2

As barley straw decomposes in a water body, it must be replaced every two to three months. Because of this, there are some periodic labor requirements of monitoring and re-stocking the straw. Barley straw receives a fair rating for labor intensity (2).

Efficacy: 0

Evaluating the efficacy of barley straw has only been attempted in a few scientific studies with conflicting results. Caffery and Monahan (1999) anchored barley straw bales (113 g – barley straw m⁻³) in a slow flowing canal in Ireland and re-applied bales every 4-5 months. It reduced the amount of filamentous algae, mainly *Cladophora glomerata*, leading instead to the growth of higher plants such as *Myriophyllum* spp. During the study, barley needed to be replenished and was not, allowing filamentous algae to quickly recolonize the canal in large amounts. Place and Sellner (unpublished data) from the Institute of Marine and Environmental Technology in Baltimore tested barley straw for its ability to reduce growth of toxic blue-green algae (cyanobacteria) in Lake Williston in Maryland. They observed a shift in algae away from toxic strain and toward non-toxic ones.

Others researchers have identified algae species that are resistant and/or immune to the effect, such as some strains of cyanobacteria and green algae (Martin and Ridge, 1999; Ferrier et al, 2005; Gill et al, 2010). It has been suggested that barley straw be used as a control for specific strains of algae like *Microcystis aeruginosa*, rather than used in broad applications (Ferrier et al, 2005; Gill et al, 2010; Purcell et al, 2013; Lim et al, 2014).

Because of inconsistent results and that barley straw appears to only affect certain strains of algae, it will not likely be effective at treating algal blooms in CWFs. It receives a very poor rating for efficacy (0).

Cost Estimate: 1.

Barley straw is a low-cost material; but its efficacy is in question (see above). Purchases of barley straw would not likely produce the desired affect and therefore resource are better allocated elsewhere. Because of this, barley straw receives a low rating (1) for cost.

Summary

Barley Straw receives a 2.3 rating on the rating scale. It is sustainable for use, but research suggests that it is only effective in reducing certain strains of cyanobacteria. In that sense, this rating may be misleading, because barley straw is not recommended for use in CWFs due to its limited role.

If toxic cyanobacteria are present in earthen water features, such as the canals or Cumberland Basin, barley straw could be an affordable and sustainable way to mitigate public health risks, but will not reduce overall concentrations of algae biomass.

7.2.4 COPPER SULFATE

Copper sulfate (CuSO_4) was developed as an algaecide more than 100 years ago (Moore & Kellerman, 1905) and has been extensively used to eradicate harmful algal blooms in reservoirs because of its effectiveness and low cost (McKnight et al, 1983; McGuire et al, 1984). Chunks or granules of CuSO_4 are dispersed by boat in compromised reservoirs when algal blooms threaten drinking water supplies. The active ingredient is the ionic form of copper (Cu^{2+}) that is particularly toxic to blue-green algae, although some strains are resistant to copper toxicity and survive copper sulfate treatment (Wu et al, 2007).

Dosages are often related to concentrations of algae, although pH and total alkalinity of waters plays a factor as well (McKnight et al, 1983). CuSO_4 is only recommended when algae are in low concentrations, because full blooms are more likely to include Cu-resistant strains that survive treatment (McKnight et al, 1983). Copper sulfate requires the EPA's Pesticide General Permit (PGP) is available for its use (EPA, 2015).

Preservation of Design Intent: 1.

If CuSO_4 were added to CWF waters, dissolved Cu concentrations would increase, and Cu and dead algae biomass would be deposited on the CWF floor as sludge. This may lead to discoloration of surfaces and would alter the visual quality of the CWF. While it might be effective in killing algae, the resultant sludge would alter the appearance of the CWF greatly.

Human Safety: 3.

CuSO_4 can cause skin and eye irritation if one makes dermal contact with the chemical, but is harmless once applied to a water body.

Environmental Impact: 1.

Long term environmental effects of copper sulfate use in lake systems are: 1) accumulation of copper in sediment, 2) elevated concentrations of dissolved copper in the water column, 3) development of copper-resistant algal populations, 4) disappearance of aquatic plants, 5) shifting species composition toward tolerant species and 6) declining benthic invertebrate populations (Hanson & Stefan, 1984; Han et al, 2001; Van Hullebusch et al, 2003; Song et al, 2010).

Energy Use and Greenhouse Gas (GHG) emissions: 4.

Using CuSO_4 would not increase on-site energy use.

Water Use: 3.

CuSO_4 would not increase water use, nor reduce it.

Resource Intensity: 0.

CuSO_4 is produced by treating mined or recycled Cu with concentrated sulfuric acid. It is affordable at present, but would need to be continuously applied to control algae throughout the year.

Labor Intensity: 1.

Copper sulfate is used in drinking water reservoirs because it is extremely effective at killing algae, is relatively affordable, and does not pose a public health risk. Drinking water reservoirs are much larger systems that allow dead algal biomass and copper to settle to the sediment to decompose or to be buried. Many CWFs do not have a sediment layer where biomass and copper can be stored indefinitely. Instead sludge would have to be removed after each use, which renders copper sulfate impractical for use in water features.

Efficacy: 1.

CuSO_4 restores water clarity, reduces odors associated with algae shortly after use. These effects are short-lived, as the Cu settles to the bottom. Once algae are killed, their biomass settles as well and depletes dissolved oxygen as it decomposes. The resultant anoxia is known to accelerate phosphorus recycling from sediment (Hansen and Stefan, 1984; Song et al, 2010). Therefore, additions of copper sulfate are never sufficient to reduce future blooms as recovery of algae occurs within days to months (Hullebusch et al, 2002). CWFs typically do not have a sediment layer where algae biomass can collect and decompose. Instead, the dead biomass would settle at the bottom, visible to the viewer under clear water conditions.

CuSO_4 receives a poor rating (1) for efficacy because it is not a long-term solution to algal blooms in CWFs.

Cost Estimates: 2.

Copper Sulfate is not exceedingly expensive. Online retailers price the product from \$1.50 to \$3.00 for 500 grams, which treats roughly 250 gallons of water (Wurts, 2013). As an example, treating the Meridian Hill Park CWF with copper sulfate would cost approximately \$1,500, for a single dosage. Further costs would be incurred by removing the resultant sludge from the CWF basins and repeated

dosages used to control subsequent algal blooms. Therefore copper sulfate treatment is given a low rating (2) on cost.

Summary

Copper Sulfate receives a poor rating (1.75) on the rating scale. It is very effective at killing algae but because repeated dosages of copper sulfate would be needed, it becomes a resource intensive process that only provides a temporary effect. It is also labor intensive since once it has been used, clean-up is needed to remove the dead biomass and copper. Therefore simply draining the features and cleaning them without any algacide applications may be just as effective.

7.2.5 UV DISINFECTION

Specific wavelengths of UV radiation destroy the DNA of microorganisms, including algae, causing them to die. UV disinfection units for aquaculture and swimming pools are often composed of a length of pipe that includes a UV bulb encased in quartz to protect the bulb from the corrosive effects of the waters. Water is disinfected as it passes through the UV unit without any residual effects.

Preservation of Design Intent: 4.

UV disinfection units are small and compact and can be housed in pump rooms without any alterations of the visual appearance of CWFs. Another advantage is that it does not have any corrosive effects and is compatible with most materials used in a CWF.

Human Safety: 4.

UV disinfection units are generally safe, although UV light can be dangerous to human eyes and skin. However, most units are made such that human contact is not likely. It receives an excellent rating for safety.

Environmental Impact: 3.

UV disinfection units have no long lasting effects that would damage local ecosystems when water is discharged. Fabrication and operation of UV disinfection units has other effects, typical of other technologies.

Energy Use and Greenhouse Gas (GHG) emissions: 2.

UV disinfection requires electrical power to run and hence entails an increase carbon footprint. The electrical power required relates to how large the unit is, which is related to the quality of water to be disinfected. In a life cycle assessment for UV disinfection at wastewater treatment plants, UV disinfection had a comparable carbon footprint as chlorine disinfection (Das, 2002). As with chlorination, it receives a fair rating (2) for GHG emissions.

Water Use: 3.

UV disinfection does not increase or reduce water use.

Resource Intensity: 1.

UV disinfection bulbs are intensive to produce and must be replaced frequently. Therefore UV units receive a poor rating (1) for resource intensity.

Labor Intensity: 2.

During operation, UV disinfection units must be cleaned regularly and checked often to see if the bulb is still functioning. Because of this, the labor intensity is high, as a CWF operator must check it frequently.

Efficacy: 2.

254 nm is the most effective wavelength against all waterborne pathogens (Wheaton, 1993), but its efficacy is influenced by both water quality and characteristics of the target microorganisms (Hijnen et al., 2006). Certain organisms have greater UV sensitivity than others and suspended particles can inhibit light penetration so that attached microorganisms escape eradication (LeChevallier et al., 1988; Walters et al., 2013). Similarly, turbidity and coloration inhibit the ability of UV radiation to inactivate microorganisms by reducing light intensity. Gullian et al. (2012) discovered that the killing effect functions best at turbidities below 11.2 nephelometric turbidity units (NTUs) in aquaculture operations.

Since only the water is disinfected as it moves through the UV unit, any algae that are attached to walls of CWFs, or floating in mats that do not move through pipes are unaffected. This could lead to a situation where attached algae are allowed to proliferate in the CWF.

Cost Estimates: 2.

UV disinfection is rated at moderately priced in comparison to ozonation and chlorination (Hoibye et al., 2008). UV- disinfect units incur upfront costs, but are not excessively expensive. UV disinfection unit comprise of a length of pipe, a UV bulb, and a quartz sleeve for the bulb, which prevents water from coming into direct contact with the bulb. The bulb needs to be replaced annually when it is used continuously. Most bulbs come with recommended time period of replacement. Operational costs include energy costs, annual bulb replacement, and maintenance of the bulb, which must be cleaned often to prevent declining disinfection rates (i.e. bulbs can accumulate biofilms and other debris that reduces light intensity and must be cleaned regularly). UV disinfection units receive a low rating for cost (2).

Summary

UV disinfection units receive a rating of 2.6 on the rating scale. They only treat suspended algae, require regular care, and are resource intensive water treatment systems for a CWF.

7.2.6 CHEMICAL ALGAECIDES

Many private companies have developed products and chemical substances that can be used to disinfect water and kill off algae. Many of these products kill algae in ways outlined above, by strong oxidation of organic matter. Most are temporary solutions that rely on a single kill event, but do not affect the underlying causes of algal blooms—nutrient inputs and conditions conducive to growth (ample sunlight, lack of grazer populations, etc.). Therefore, any chemical algaecide should be re-applied manually or by an automated feed system. Given that the automated feed system at FDR is inoperable and repairs are not being considered at this time, chemical algaecides are unlikely to be effective for the long term.

Another drawback to the use of chemical algaecides is the potential safety concerns for both staff that must administer the treatment and visitors to the monuments that interface with the CWF and are exposed to algaecides, either by inhalation or by dermal contact with the water. With treatments such as ozone and copper sulfate, this is not a major concern, but with chlorine, and other chemicals it warrants consideration.

There is a wide variety of chemical algaecides so it would be length and impractical to evaluate each one here. Overall they function similar to chlorine or copper sulfate, in that they either require repeated dosages, or cause a single kill event whose effects are short-lived and allow for algae recovery.

7.3 PRESSURIZED SAND FILTERS (PSFs)

Sand filters consist of a bed of sand or other granular media through which water is forced either by gravity or pressure. Sand filters are used for the removal of suspended solids that are difficult to remove during gravitational separation (settling tanks). Particles larger than the spaces between the media are caught in the filter. Therefore the size of grains determines the size of particles removed. Typically, sand filters have sand particles between 2.0 and 0.02 mm (Wheaton, 1993). Other important factors include the physical and chemical properties of the suspended solids and the influent water, and the frequency of backwash cycles (Naghavi and Malone, 1986). PSFs are more widely favored in industrial and commercial water-conditioning applications such as aquariums, sea parks, industrial water conditioning or other operations. These units have an advantage in that they may be

placed in the line under pressure, eliminating the need to repump the water. This especially the case for many of the NPS water features in the NCR.

The design of PSFs is similar to that of a gravity filter with respect to the filter medium, gravel bed, underdrain system, and control devices. PSF are typically sized based on the manufacturer's allowable hydraulic loading rate usually between 4 and 8 gpm/ft² of filter surface. Higher flow rates as shown in Figure 7.2 can be used but this may result in higher system operating pressure and some components including the PSF vessel may not tolerate these higher pressures. Higher filter rates can result in poor filtering efficiency and increased backwash rates. The filter vessel is usually a cylindrical steel tank or fiberglass.

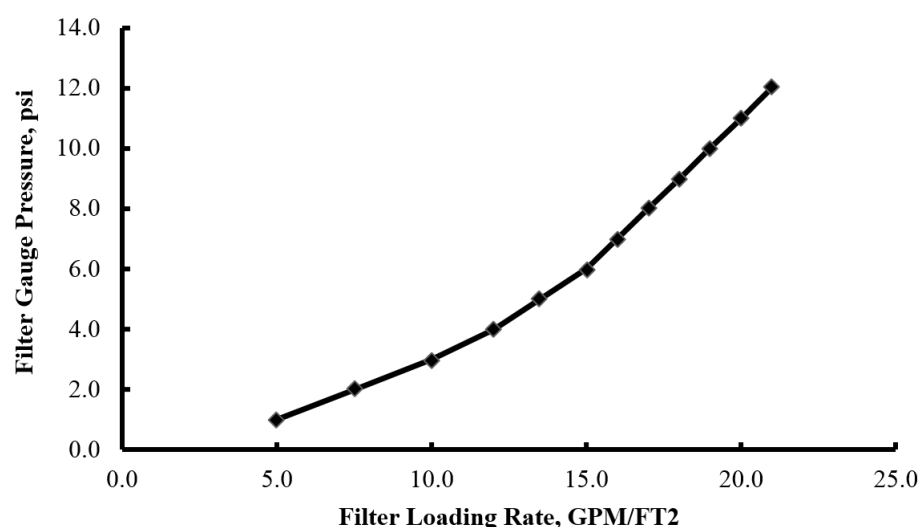


Figure 7.2. Filter head loss versus filter loading rate or flow rates (Astral PSF Manual).

When used to filter *Scenedesmus* sp., a common green alga, rapid sand filtration was 97% effective when sand grain size was below 0.2 mm; however, rapid clogging lead to frequent backwashes (Naghavi and Malone, 1986; Sabiri et al, 2011). Backwashing is a critical process of maintaining a functioning PSF. A hypothetical pressure curve for the backwash of PSF is shown in Figure 7.3. The gauge pressure of the PSF will rise as material is entrapped and pore spaces are clogged. When the pressure rises about 6 to 10 psi over normal operating pressure the need for back washing is indicated. The water flow is reversed at sufficient flow to fluidize the filter bed and allow collected particles to dislodge from the sand media. This water, now laden with suspended solids, must be discharged as waste from the system. Once complete, the flow is reduced and the filter bed once again settles, with the largest and heaviest sand grain at the bottom and the finest, lightest at the top of the filter bed.

Depending on the concentrations and sizes of suspended solids in the incoming water, it is common for rapid sand filters to require as many as 1-3 backwashes

daily (Arndt and Wagner, 2004). Without frequent backwashing, filters can become completely clogged, or their filter beds can become compressed so greatly that cracks and fissures form, allowing particles to pass through the filter (Arndt and Wagner, 2004). This may explain why the sand filters at the WIMSA were clogged solid. It may be that the filter bed and trapped particles had become too compressed that they formed a very dense mixture through which no water was able to flow. Automated backwash cycles may be needed in such systems, but without sufficient nutrient management to mitigate algal growth, backwash cycles will need to be frequent (1-3 times daily) such that water use from backwashing is greatly increased.

During backwash, some sand particles may accumulate attached biological growth or experience particle-to-particle abrasion that results in formation of lighter material and loss of sand bed depth. The settled sand bed depth must occasionally be inspected to assure that a sufficient bed volume is maintained.

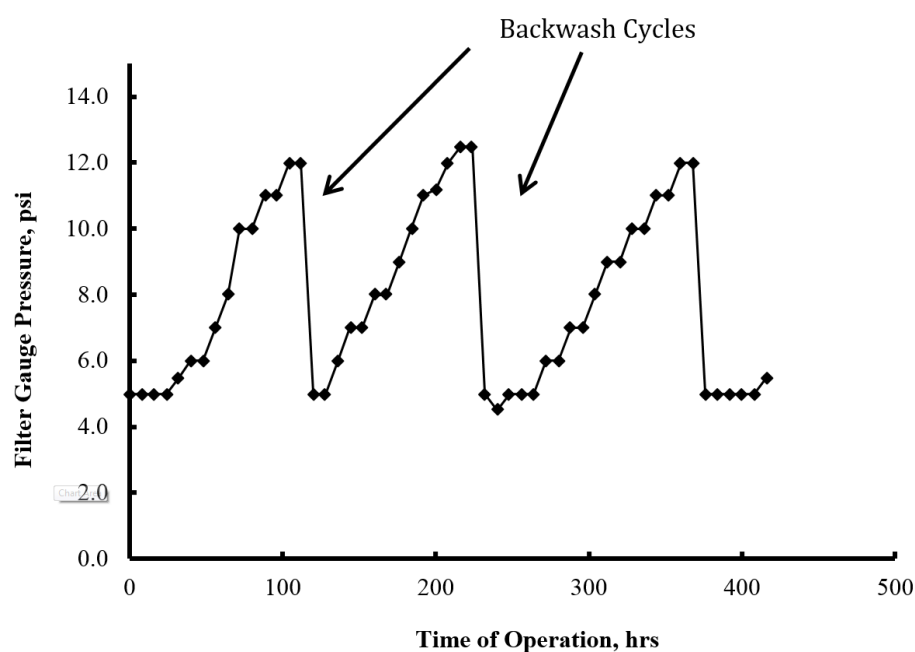


Figure 7.3. Hypothetical PSF backwash curve over a five-day period of operation.

If properly operated and maintained PSFs can be effective for the removal of various sized particles in aquatic systems including water features. Removal of TSS can be improved by proper sand size selection, use of alternative media such as anthracite or mixed sand grain sizes, or by the addition of chemical coagulants to aid the entrapment process in the sand. This all depends on greater operator attention and regular maintenance to work at optimal levels.

PSFs have the potential to remove nutrients such as phosphorus and nitrogen by using tailored media in the sand bed. Vohla et al. (2011) conducted a thorough review of P-binding materials and categorized the various materials as natural

products, which were often types of rock; industrial by-products, such as fly-ash and slag; and man-made products, such as Filtralite P (see below) and other specially formulated media. Vohla et al (2011) argued that saturation time (i.e. how often the material must be replaced), availability at a local level, content of heavy metals, and the recyclability of saturated filter media should be considered before a compatible material is chosen. In terms of P-binding capacity, a common theme among the most effective P-binding materials was a high pH (>7), and high calcium (in the form of CaO) content.

Arias and Brix (2005) conducted research on various media for P-adsorption. The intention was to identify media that could be used in constructed wetlands for enhanced P-removal, but such media could easily be used in a PSF since the same factors that make them acceptable for wetland media (hydraulic conductivity, and sustained and consistent P-binding capacity), would make them acceptable for retrofitting PSFs. Arias and Brix (2005) identified a calcite material referred to as 'new Damolin' produced by the company Damolin A/S and marketed as cat litter as having the highest P-binding capacities (~30 mg-P/g), and confirmed results from an earlier study (Brix et al, 2001). One product, Filtralite P® may be an option for retrofitting PSFs, although this had a lower capacity for P-binding (~6 mg-P/g). In contrast, untreated calcium-rich rocks and seashells had very low P-binding capacities and are not recommended, unless specifically treated for enhanced P-removal.

Overall, Arias and Brix (2005) concluded that calcite could adsorb 2 kg-P m^{-3} . The largest PSF at the FDR Memorial (48 inch diameter) contained roughly 0.7 m^3 of sand, therefore theoretically when loaded with calcium-rich media, could remove 1.4 kg-P before it would need to be removed and replaced with fresh media. This means that such a filter would need to be replenished every 2 years at current P-loadings (0.714 kg-P/yr). Smaller sand filters would need more frequent replenishment.

Material rich in Fe and Al oxides also bind P and show promise for retrofitting PSFs for P-removal. Sibrell et al. (2009) reported results from a dried, granulated product from acid mine drainage sludge, called Ferroxysorb. P-adsorption by Ferroxysorb showed varied results—from 0.18 g-P/kg to 23.9 g-P/kg . The wide range of P adsorption capacities was attributed to varying sludge composition with the highest capacities observed when sludge had high concentrations of both Al and Fe oxides. One notable benefit to Ferroxysorb is that once P is absorbed to the media, P can be stripped from the media and processed into fertilizer, while the remaining Ferroxysorb can be re-used for further P adsorption.

Lanthanum is a rare earth element that has a strong affinity for phosphorus. Like calcite, alum, and iron compounds, lanthanum binds phosphorus and removes it from the water column but at a wider pH range (4.5–8.5; Chen et al., 2012). Interest in lanthanum to phosphorus pollution has grown in the last 10 years. It has been used in ceramic granular form to remove 89% to 98% of P from extremely rich water (10mg-P/l) with no adverse effects to water quality (Chen et al., 2012). It is also the active ingredient in P-capping agents discussed later in this report. Fortunately, lanthanum has a low toxicity and has been studied as a potential treatment for hyperphosphatemia for medical patients (Sprague et al., 2009).

Lanthanum Chloride (LaCl) has recently been used as the active ingredient in a pool-maintenance product called Phosfree™, readily available to the general public. The product is added in a high initial dose to clean sand filters, where it coats sand particles of the filter. The pool water is then allowed to cycle through the filter for 48 hours. Once complete, the sand filters are once again backwashed to remove the excess phosphorus that has attached to the LaCl. From this point on, a smaller dose of Phosfree™ is added weekly to keep phosphorus levels close to zero.

PSFs amended with P-binding materials was evaluated for sustainability and applicability with CWFs.

Preservation of Design Intent: 4.

Since most CWFs feature PSFs already, amending these filters with P-binding media requires no alteration of the CWF design or plumbing system. On the other hand, P-binding materials should be evaluated for their potential to stain the features by leaching oxidized compounds to the water column. Therefore, amended PSFs receive a good rating (3) for preservation of design intent.

Human Safety: 4.

Amending PSFs with P-binding media has not inherent human safety risks and is given an excellent rating (4).

Environmental Impact: 4.

Considering that eutrophication is a serious environmental issue, the removal of phosphorus from water positively affects local ecosystems and receiving waters. Assuming that only non-toxic media like calcite, lanthanum chloride, and iron are used, amended PSFs receive an excellent rating (4) for environmental impact.

Energy Use and Greenhouse Gas (GHG) emissions: 3.

Sand filtration requires intensive pumping of water and is one of the most energy intensive processes during water treatment (Hoibye, et al., 2008). This energy cost is already factored into the operation of CWFs so amended PSFs should not increase or reduce energy use. It receives a good rating (3) for energy use and GHG emissions.

Water Use: 1.

Frequent backwashing of PSF entails a substantial water footprint. Because of this, PSFs receive a poor rating (1) for water use.

Resource Intensity: 3.

Depending on the media used, resource intensity varies widely. Lanthanum is typically found as bastnesite in the Earth. To extract lanthanum, bastnesite is mined and then heated to high temperatures to remove carbonate minerals before leaching with either hydrochloric or sulfuric acid (Xie et al., 2014). Therefore lanthanum should be considered a resource-intense product, regardless of its market affordability. Other media are less intensive, such as calcite, but overall the process of producing these media should be considered intense. Some media have potential to be made from reclaimed acid mine drainage sludge and would therefore have a much higher rating. P-binding media are therefore given a good rating (3) for resource intensity.

Labor Intensity: 2.

General maintenance of any PSF involves frequent backwashing and replacement of sand every 5 to 7 years. If backwash cycles are not automated, then the overall maintenance and care of a PSF involves high labor requirements. PSFs receive a moderate rating (2) for labor intensity.

Efficacy: 4.

As noted earlier in this report, nutrient pollution is the primary cause of water quality impairments in CWFs. By removing phosphorus with P-binding media, the root causes of the algal blooms and other impairments can be prevented. Such media should be stocked in the PSFs when they are first filled with water in the spring, before algal blooms occur. If done properly, amended PSFs could be very effective and receive an excellent rating (4) for efficacy.

Cost Estimates: 4.

Purchased in the quantities needed for CWFs, P-binding media should not be overly expensive. No additional capital costs would be required. Amended PSFs receive an excellent rating (4) for cost.

Summary

Amended PSFs received a 3.2 on the rating scale, which was heavily influenced by the use of rare earth minerals such as lanthanum which are resource intense materials to extract and concentrate into a useable form. But the potential to use more sustainable materials is high. Regardless, retrofitting PSF with P adsorbing media is a promising idea for CWF since most are fitted with PSFs at present, because of their low cost and their compatibility with existing infrastructure in CWFs. The actual use of P adsorbing media in PSFs has not been validated by any scientific studies and the concept has been validated. Further study is warranted, as there are many unknown factors. Whether calcite, Ferroxysorb or any other P-binding media would leach staining compounds that would alter the appearance of CWFs is uncertain as coloration of effluents is not reported in literature. Initial trials with Phosfree™ are recommended because it is readily available, effective, and no adverse effects are expected. Since the product is made to be used in swimming pools, Phosfree™ is appropriate for CWFs which have much in common with pools.

7.4 NUTRIENT INPUT REDUCTION AND MANIPULATION**7.4.1 CONSTRUCTED WETLANDS**

Natural wetlands are swamps, marshes, bogs, fens, and peat lands that serve a variety of important ecological functions. They are sources of foods and biodiversity, and improve water quality through filtration and biogeochemical processes. Some refer to them as the kidneys of ecosystems because of their ability to regulate water quality while others refer to them as “factories in the landscape” because they are extremely productive systems with a large amount of plants, fish, birds and other animals (Keddy, 2000).

Humans have learned to construct wetlands for their own purposes, like wastewater treatment, agricultural systems, or for the restoration of critical habitat. When used for water treatment, wetlands utilize solar-driven plant communities, naturally occurring microbes, specific hydrological conditions, and properties of soils to filter pollutants in water, remove nutrients and reduce flood damage (by the storage of water during storm events). Constructed wetlands have been used for municipal and agricultural wastewater treatment, mine drainage and landfill leachate treatment, storm water control, and to reduce non-point source pollution (Mitch & Gosselink, 2000).

There are two kinds of constructed wetlands; *surface flow wetlands* and *sub-surface flow wetlands*. Surface flow wetlands are classified by the presence of standing water. Water flows above ground during regular conditions and the constructed

wetland will appear similar to a natural wetland (Figure 7.4). Sub-surface flow wetlands are different in that water flows through a porous medium such as small gravel or rock below the ground surface, so that water is not visible (Figure 7.5).

Preservation of Design Intent: 3.

Since wetlands are living systems, they cannot be housed in pump rooms and the like. Instead they must be placed outdoors, which may mean an alternation of the landscape or park layout. Some parks may have limited available space meaning that some park elements must be removed or altered before installing a wetland. Other parks may have a specific narrative intended that may be disrupted by a wetland. Design shapes are highly flexible and can be integrated into the landscape and many plant varieties can be adapted for use in these systems. Evaluating the impact on the design intent must be site-specific.

At sites with less available space or with restricted vegetation options in the surrounding areas, constructed wetlands could be incorporated within the footprint of the CWF themselves as long as the hydraulics are built to send water through aerobic and anaerobic zones of the wetland.

Human Safety: 4.

Wetlands are generally safe and do not pose any risk to visitors or managers of water features. This particularly true of the use of submerged surface wetlands do not have exposed water surfaces or ponded water.

Environmental Impact: 4.

Beyond initial construction, environmental impact of a constructed wetland is minimal and can be considered restorative since they are special habitats that are in decline worldwide. Plaques can be placed by the wetlands to inform residents about their use and function, the importance of natural wetlands, and general issues of water quality. In this way, constructed wetlands can act as ambassadors for their natural counterparts.

Energy Use and Greenhouse Gas (GHG) emissions: 4.

In order to function properly, a wetland must have water actively moving through it, in a special sequence of aerobic and anaerobic processes. As such, constructed wetlands require pumping to function properly. Because CWFs already use pumps to move water, the use of a constructed wetland should only require additional pumping if existing pumps do not suffice.

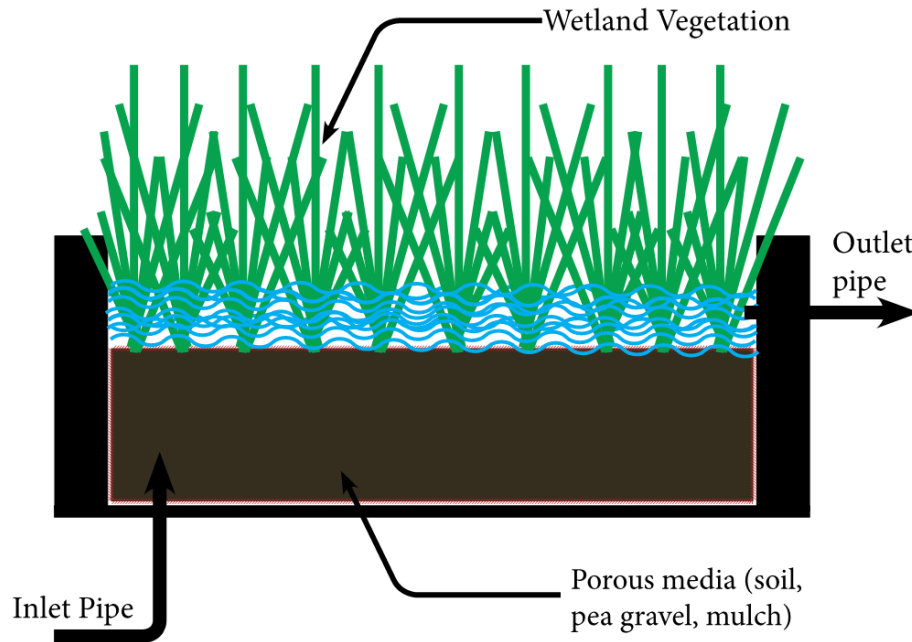


Figure 7.4. Surface flow wetland diagram.

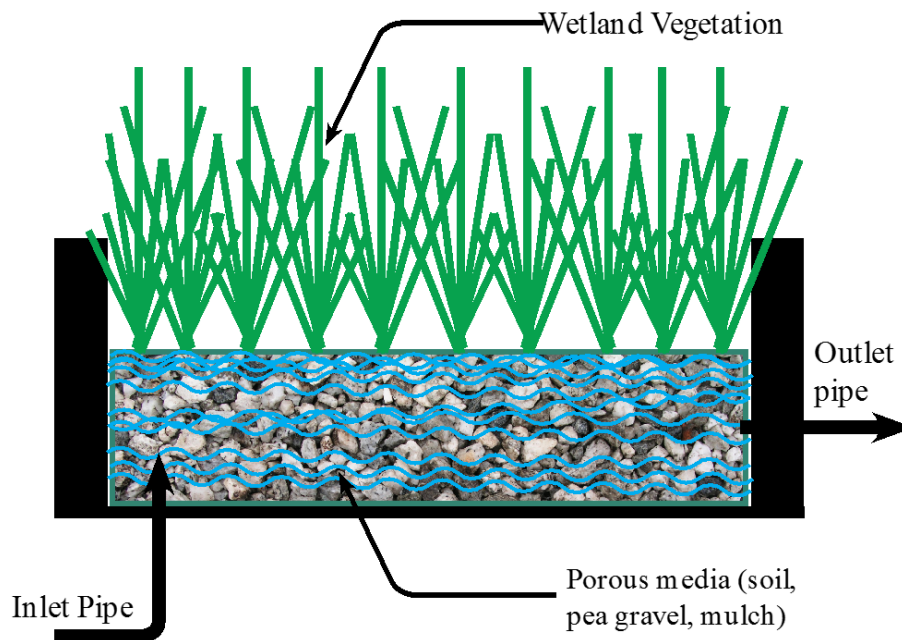


Figure 7.5. Sub-surface flow wetland diagram.

Water Use: 3.

Constructed wetlands may marginally increase water demand through the increased evapotranspiration by the wetland plants.

Resource Intensity: 3.

Moderate to low intensity materials are needed for construction. Operation does not require any additional inputs or materials.

Labor Intensity: 3.

As living systems, constructed wetlands are self-regulating. They will require maintenance typical of other vegetation and gardens, such as clearing of litter, weeds, and invasive plants.

Efficacy: 4.

Constructed wetlands are one of the few technologies that deal with the underlying causes of algal blooms; excessive nutrients. Wetlands act like nutrient sinks and deal with eutrophication through plant uptake and through the conversion of nutrients into gaseous forms that disperse to the atmosphere. Plant uptake is generally considered minor in wetlands but under moderate loading of nutrients, plant uptake and subsequent harvest can have a greater effect (Brix, 1997; Langergraber, 2005). The majority of nutrient removal comes from the microbial processes that occur in wetlands. These processes, while common in many ecosystems, are enhanced in wetlands because of waterlogged soils that have strong gradients of oxygen concentrations. There is a layer of oxygenated water and sediment along the surface (aerobic zone) that interfaces with a deeper sediment layer devoid of oxygen (the anoxic zone). Specially adapted wetland plants enhance this interface by pumping oxygen to the water logged soils via their root system. Many elements become oxidized and then reduced as microbes utilize them in their various metabolisms. These processes are excellent at converting nitrogen to a gas that escapes to the atmosphere.

Above the sediment layer, plant stems, branches and leaves filter solids by slowing water velocities to allow for particles to settle out of the water. Since phosphorus is often bound to particles, this helps deposit phosphorus to the sediment layer, where it can be incorporated in plant biomass, attached to immobile sediments, or buried. Some constructed wetlands are built with enhanced adsorbent material, such as limestone or gypsum, which binds to phosphorus to immobilize it.

Wetlands receive a very good rating (4) for efficacy because they treat the underlying causes of algal blooms instead of attempting to kill existing algae. It follows then that through nutrient removal alone, wetlands should be able to reduce suspended and attached algae indiscriminately.

Cost Estimates: 2.

Constructed wetlands are considered to be less expensive than conventional wastewater treatment systems (Mitch and Gosselink, 2000). The cost of a wetland varies widely and is influenced by the engineering plan, needed site preparation, construction costs, and cost of the land to be used.

Operational costs also vary and are influenced by pumping, plumbing and any mechanical maintenance. These costs are already included in regular use of CWFs to some degree, but the construction of a wetland may require more plumbing, but would not likely increase electrical costs of pumping. Constructed wetland would likely a moderate to expensive capital cost with minimal on-going operational costs. They receive a fair rating (2) for cost.

Summary

Constructed wetlands received a 3.3 rating. Wetlands are self-sustaining, run on sunlight, and provide the needed water treatment (solids filtration and nutrient removal) to manage algal growth, but alterations are needed to install them in water features.

7.4.2 ALGAL TURF SCRUBBERS

Algal Turf Scrubbers™ (ATS), invented by Walter Adey of the Smithsonian Institute, are constructed ecosystems modeled after the productive algal communities in reef ecosystems (Adey and Loveland, 1998). ATSs create a contained environment where attached algae can flourish, taking in large quantities of nutrients. As the algal community reaches a climax, the algae and assimilated nutrients are removed, thereby reducing overall concentrations of nutrients in the water body.

ATSs consist of a mesh substrate harboring a periphyton community in a shallow raceway trough (Figure 7.4). Untreated water is delivered to a tipping bucket that spills over when full to create a wave effect across the algal turf. The wave allows sufficient gas exchange for photosynthesis (Adey et al., 2011) and creates turbulence that prevents self-shading and increases mixing, reducing the diffusive layer around algal filaments and making nitrogen more available for algae uptake (Blersch et al, 2013).

Preservation of Design Intent: 2.

Unlike constructed wetlands, ATSs are two-dimensional and as such require more surface area. ATSs differ from wetlands in appearance as well. While wetlands can be incorporated into a park as part of the landscaping and park design, ATSs are obvious water treatment systems that could be unsightly to some park visitors.

Human Safety: 4.

ATSs are completely safe for users and the environment. There are no toxic chemicals used and they generally do not contain toxic algae.

Environmental Impact: 4.

ATSs have no negative environmental impacts when installed outdoors.

Energy Use and Greenhouse Gas (GHG) emissions: 4.

When artificial lighting is needed, these systems would have a carbon footprint beyond the cost of their fabrication. Like other treatment systems, they require water to be pumped through the system. In most cases, CWFs already have the pumping needed to run an ATS so incorporating an ATS should not entail a greater carbon footprint.

Water Use: 3.

ATS systems do not increase or reduce water use.

Resource Intensity: 3.

Many ATSs are built with moderately intensive materials such as PVC and other plastics.

Labor Intensity: 2.

Algal biomass is periodically harvested to stimulate production and remove nutrients from the system. The biomass can then be used as a compost fertilizer (Mulbry et al., 2006), as a biofuel feedstock (Adey et al., 2011), or other natural product. Under moderate to high nutrient loading rates, algae is typically scraped off the substrate and removed every 7 days in order to maximize removal. Other maintenance is ensuring that the wave bucket is functioning properly (i.e. it continually produces waves, rather than a continuous stream of water) is important to maximizing production of algae and removal of nutrients from the water column.

Efficacy: 4.

When properly sized to handle accurately estimated nutrient loads, ATSs provide excellent water treatment and should reduce the ability for suspended algae and attached algae in other parts of the CWF to grow. Like wetlands, ATS efficiently deal with the underlying problems that cause algal growth.

Cost Estimates: 3.

The major costs associated with ATS are related to pumping costs, and maintenance. There are mechanical parts (i.e. the tipping bucket and axil) that may break or may become misaligned. Pumping is already an accepted cost to running a CWF but implementing an algal turf scrubber would require new plumbing in order to bring water to the ATS. Beyond this, an ATS would not require any additional energy costs, water use, or other expensive components. However, an ATS require that an operator be present weekly to harvest algal biomass and dispose of it. The algae could be composted on site, but there would be increased labor costs for harvesting. ATSs receive a good rating (3) for cost.



Figure 7.6. A small algal turf scrubber in use at an oyster aquaculture facility for nutrient removal. Algal biomass grows in the trough and locks up nutrients. The biomass is periodically harvested in order to remove nutrients from the system. Photo Credit: Nicholas Ray.

Summary

Algal turf scrubbers received a 2.7 on the rating scale. They are safe systems that provide excellent water treatment, but entail a heavy labor requirement and may alter CWF sites in an unappealing way.

7.4.3 P-CAPPING AGENTS

P-capping agents are formulated clays that are applied to the sediment layer of a pond or lake in order to block the flow of sediment-bound phosphorus (P) to the water column. Lanthanum is the active ingredient that immobilizes phosphorus and prevents algae from accessing it for growth. Since they only deal with existing nutrients in the sediments, it is important that nutrient inputs are reduced as well.

P-capping agents can be applied by a spray manifold as thick slurry or dispersed in a granular form. During dispersal, P-capping agents adsorb dissolved phosphorus from the water column and settle to the bottom to form a layer of clay over the sediment.

Preservation of Design Intent: 1.

P-capping agents are not appropriate for all sites. Their main purpose is to “cap” the sediment of a lake or pond. If a site has a mud layer on the bottom, and there is evidence that the mud is source of nutrients, then P-capping agents are appropriate. Otherwise, P-capping agents should not be used. Adding a P-capping agent to a stone lined CWF, like a fountain, would alter its appearance significantly.

P-capping agents receive a poor rating (1) for preservation of design intent because they can only be used in earthen-lined basins.

Human Safety: 4.

P-capping agents pose no risk to humans, but when being applied as slurry, workers should wear facemasks to prevent dust inhalation.

Environmental Impact: 4.

Bentonite and lanthanum are benign materials when used as a cap for phosphorus on lake bottoms. There may be some effect on benthic communities since the clay creates a layer over the sediment, but no current studies have investigated or reported any negative impacts.

Energy Use and Greenhouse Gas (GHG) emissions: 4.

Applying p-capping agents to a CWF does not entail significant GHG emissions.

Water Use: 3.

P-capping agents do not reduce or increase water use.

Resource Intensity: 1.

Lanthanum is a rare earth metal that requires an intensive process of mining, acid-separation, and ion exchange to isolate it from rock and other minerals. It receives a poor rating (1) for resource intensity.

Labor Intensity: 3.

The amount of labor required depends on the size of the water body being applied with P-capping agents; however it is a one-time labor commitment. Once applied, there is no upkeep of the p-capping agents.

Efficacy: 1.

P-capping agents are situational. P-capping agents locked 87% of available phosphorus in the sediment at 25° C water temperature in the lab (Zamparas et al, 2015) and were able to greatly reduce phosphorus release from sediment in the field (Robb et al, 2003; Liu et al 2012). In studies where P-capping agents were ineffective, algal blooms resulted from incomplete coverage of sediment and ineffective nutrient input controls (Robb et al, 2003; Lürling & van Oosterhout, 2013). Literature shows that p-capping agents are only applicable in CWFs with a sediment layer that provides nutrients to algal growth and only when incoming nutrients from other sources are reduced.

Because they are very effective in limited applications, p-capping agents receive a poor rating (1) for efficacy in CWFs; however, they may be very effective in earthen-lined basins and canals.

Cost Estimates: 3.

P-Capping agents is estimated to cost \$2,800 per ton, with 2.5 tons required per hectare. For the CHOH Canal Terminus basin, one application would cost over \$6,000; however it does not require any operating costs because the technology requires no maintenance. If nutrient inputs are reduced by sealing leaks, then a single application could last several years before needing replacement. Since no operating costs are entailed but capital costs are high, P-capping agents are given a fair rating (2) for cost.

Summary

P-Capping Agents earned a 2.6 rating on the rating scale. Its use is situational and the active ingredient, lanthanum, is a rare earth metal that must be mined and isolated using industrial processes; however beyond mining and processing its use has few environmental impacts on the local area and does require labor to maintain once applied.

7.5 ALTERNATIVE WATER SOURCES**7.5.1 RAINWATER HARVESTING**

Since source water was the primary source of nutrients at the four sites, one way to reduce incoming nutrients is to harvest and use rain as make-up water. In contrast with nutrient-rich municipal water, rainwater has negligible amounts of phosphorus (0.007 mg-P/l; Koelliker et al, 2004), but requires additional infrastructure to collect and store. A catchment area (roof or other hard surface) collects and funnels rainwater to gutters and downspouts. As water runs off catchment areas, it may collect and transport leaves, twigs and other debris. Screens and first flush filters are designed in the system to filter out this debris before it enters the cistern. A cistern is a large rain barrel that is used to store water to be used later as needed. They vary in size depending on the frequency of rain, and demand for water. If there is a high demand, and frequent rain events, cisterns can be smaller. If there is a high demand but infrequent rain, both catchment areas and cisterns must be larger. Once collected and stored, a delivery system (pump and piping) is used to re-fill the CWF.

The sites we studied have little available roof area that could be used as catchment area. It is possible that impervious surfacing of walkways could be used as the catchment area.

The biggest challenge when designing a rainwater harvesting system is to understand the water demand, how frequent it rains, and how much storage is needed

per rain event. Once this information is obtained, the size of catchment areas and storage volume of the cistern can be estimated.

Preservation of Design Intent: 2.

The installation of a rainwater harvesting system does not necessarily obstruct the narrative elements and design intent of CWFs. Cisterns can be stored in pump rooms and other equipment spaces out of sight. The catchment area could include existing roofs or other structures. When an option for a catchment area does not exist, one would have to be installed. Often times these are quite large and might alter the physical appearance of a park landscape or setting. Catchment areas could be existing ground cover or impervious surfacing if appropriate filtration is included (such as an area where debris is removed from the water stream before it enters the cistern). Rainwater also tends to be acidic and could materials in the CWFs. Limestone or other buffering system may be needed. Because site alterations will likely be needed but could be sited away from the CWF, rainwater collection systems received a fair rating (2) for preservation of design intent.

Human Safety: 4.

There is no risk to humans with the use of rainwater, but it should be noted that rainwater harvesting systems are only for non-potable uses.

Environmental Impact: 4.

Other than the fabrication and installation of rainwater harvesting infrastructure, collecting rainwater does not entail negative environmental impacts.

Energy Use and Greenhouse Gas (GHG) emissions: 3.

A rainwater collection system with an underground cistern or one housed in a pump room may require the use of a pump to deliver water to the CWF reservoir. An additional pump that delivers water from the cistern to the CWF will increase energy use of a CWF and therefore increase the GHG emissions of the feature. Since the pump is only operated intermittently this may be negligible in comparison to the energy use of the main CWF pumps.

Rainwater harvesting systems receive a good rating (3) on energy use and GHG emissions.

Water Use: 4.

Harvesting and using rainwater reduces a CWF's water footprint and therefore receives an excellent rating (4) for water use.

Resource Intensity: 3

The materials used to construct rainwater harvesting systems are moderately intensive materials, such as plastics, PVC piping and the concrete for housing cisterns.

Labor Intensity: 2.

Rainwater harvesting systems will require maintenance and upkeep, such as clearing the filters and catchment area of debris and bird droppings. Rainwater harvesting systems get a fair rating (2) for labor intensity. Rainwater is low in nutrients but is often noted for its low pH and concentrations of corrosive pollutants (such as SO₂) (Sarro et al, 2006). Therefore, although nutrient concentrations are several orders of magnitude smaller, expanding the use of rainwater may lead to more problems caused by corrosion of the basin and plumbing systems, unless it is pre-treated or carefully monitored.

Efficacy: 2.

Rainwater harvesting provides nutrient reduction proportional to how much rainwater can be collected and stored, but the infrastructure to provide a large water feature with 100% rainwater use may be prohibitive. Few of the sites we surveyed had significant roof area, and none of them had any notable storage capacity for rainwater. This infrastructure would need to be constructed and installed before it can be relied upon for use. The main drawback to sustainability is the lack of control. Since rain is an intermittent resource, it is highly likely that nutrient-rich municipal source water will still need to be used in large amounts. Therefore rainwater harvesting alone cannot solve the problems of algal blooms in water features. Because of this, rainwater harvesting received only a fair rating (2) for efficacy.

Cost Estimate: 2.

A rainwater harvesting system would entail both moderate capital costs for installation and some operating costs for holding tanks, pump systems and monitoring, but would reduce nutrient inputs. Rainwater harvesting is given a fair rating (2) for costs.

Summary

Rainwater collection systems received a 3.2 for sustainability. Offsetting water use can help reduce overall nutrient loads and helps reduce environmental impacts associated with water use. There is no negative affect to the local environment, but fabrication of the system and possible increased pumping may increase a global environmental impact. Lastly, rainwater collection alone will not prevent algal blooms.

7.6 BIOLOGICAL MANIPULATION

7.6.1 BIOLOGICAL PHOSPHATE REMOVAL

The use of microbial communities for nutrient transformation and removal is a foundation of wastewater treatment processes. Microbes are used to convert NH_3 to benign forms of nitrogen, to digest and liquefy organics, and to produce methane (the chief component of natural gas) from organic material for energy. Biological phosphate removal is less common process of nutrient removal from wastewaters.

The process involves the manipulation of oxygen levels to enhance “luxury” uptake of phosphorus from wastewater. Luxury uptake refers to the accumulation of phosphorus in stressed bacteria cells, beyond levels that are needed for basic cell function and metabolism. Specialized bacteria, when stressed, take in 10 times more phosphorus than typical microbes, such that approximately 12% of their biomass (dry weight) is composed of phosphorus (Loosdrecht et al, 1997). This only occurs when conditions are conducive to life with ample dissolved oxygen, the absence of poisonous toxins, and optimal temperatures and pH levels.

Biological phosphate removal takes place in activated sludge chambers present at most wastewater treatment plants. The bacteria need a supply of degradable carbon as food in order to uptake phosphorus so the process does not function properly in diluted waters (Mulkerrins et al. 2004). Because water features do not have the amounts of degradable carbon sources needed, biological phosphate removal will not work properly.

One company produces a microbial culture that is used to digest sludge that accumulates in ponds at golf courses and other parks. The company does not have any published research to show the effectiveness of the product and does not provide details as to what type of bacteria is used and how the bacteria reduce nutrients in ponds. Presumably, the product only works when ponds have an accumulation of sludge at the bottom, which provides the bacteria with the needed food to uptake phosphorus. The company suggests aeration of ponds, reduction of incoming nutrients and the introduction of both their bacterial culture and algae-eating fish in order to control algal growth.

Microbial control of nutrients cannot be fully recommended because the technology requires the manipulation of water conditions that are not present in water features or ponds and can only really be implemented in activated sludge found in wastewater treatment plants. Because of this, the technique is not evaluated in full in this chapter.

7.6.2 ENHANCING GRAZER POPULATIONS

The introduction of grazer species is occasionally suggested as a method of nutrient removal. In theory, adding grazers like zooplankton and filter feeders (such as clams or oysters) control algal growth by feeding on it, thereby manipulating the food web so that the ecosystem favors grazers that control algae biomass.

Grazer enhancement is done by adding a large stock of grazers, or by removing fish and other animals that prey on grazers. In literature, the restoration of oysters as grazers in the Chesapeake bay has been proposed as an important component of nutrient reduction (Bricker et al, 2014) and many of the worst aspects of eutrophication of the bay may have resulted from a decline in oyster grazing (Newell, 1988).

Yet when nutrients are excessive, the strategy is less effective because grazers only suppress the growth of edible algae, while inedible algae continue to grow (Carpenter et al, 1995). Grazers preferentially feed on high-quality species, and reject inedible or toxic strains of algae. In that way, grazing actually wipes out the competition to inedible strains, allowing them to proliferate, as seen in Lake Erie where the accidental introduction of zebra mussels left the toxic strain with ample nutrients, space, and light to proliferate unimpeded by competitors (Vanderploeg et al, 2001). Most CWFs were never intended to function as habitat so adding grazers is highly inappropriate. This is the main reason why enhancing grazer populations in water features is not recommended and will not be evaluated for sustainability.

7.7 CONCLUSIONS

Figure 7.7 summarizes the results of the sustainability assessments of each technology. Existing PSFs, rainwater harvesting and submerged surface constructed wetlands were the most sustainable options for CWFs. The PSFs have built infrastructure and can provide good nutrient removal. Some optimization and testing is needed to assure the proper selection of media additives. The wetlands use local renewable energies (rain, sunlight, biodiversity) to prevent algal blooms by reducing nutrient flows to algae. UV disinfection, P-capping agents, rainwater use and barley also had high scores for sustainability but were situational and would not be suited for CWFs. Copper sulfate, chlorination and ozone had sustainability scores below 3. This is because they rely on industrial processes for fabrication, are toxic or have a high labor and/or electrical cost.

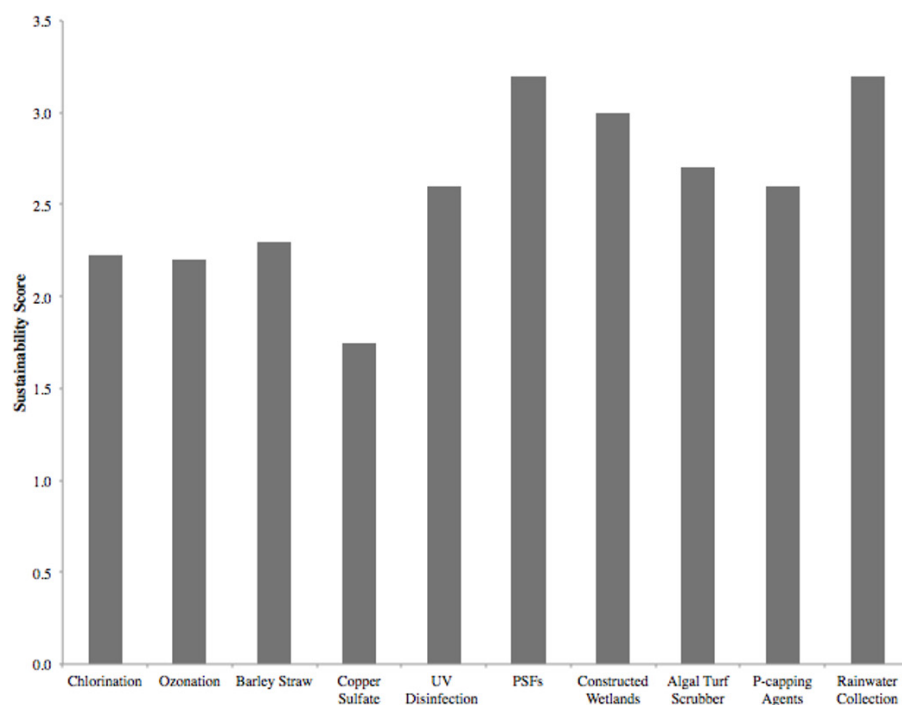


Figure 7.7. Sustainability ratings for the water treatment technologies for CWFs.

Because algae can grow attached to surfaces and suspended in the water column, it is unlikely that technologies that kill algae in separate chamber, such as UV disinfection units and ozone generators, will be effective. Additionally, the use of chlorine to eliminate algae, while effective, cannot be used at many CWFs because they discharge to natural water bodies. Instead, nutrient management is recommended as a method to starve algae and prevent blooms. Constructed wetlands are an effective and proven technology that can be incorporated in park settings without disruption to the overall landscape. For sites with a layer of sediment, such as canals, wetlands may be accompanied with a p-capping agent to prevent release of nutrients from the sediment layer.

CHAPTER 8. RECOMMENDATIONS

CWFs often vary in a number of ways, which means recommendations should ideally be made on a site-specific basis; however, the four CWFs examined in this report serve as valuable case studies for understanding the problems with CWFs in other locations. Based on information gathered from these sites, three broad recommendations are put forth below.

8.1. TECHNOLOGIES AND PRACTICES TO REDUCE OR ELIMINATE NUTRIENTS.

The sites examined in this study each had problems associated with elevated levels of nutrients, such as algal blooms, malodors, and staining. Other water quality impairments were evident, such as the accumulation of foam and plant debris, but algal blooms caused by nutrient pollution were the most significant. At CWFs at Meridian Hill, the FDR Memorial, and the WIMSA Memorial, the primary source of nutrients was the municipal water supply. Municipal water, drawn from the Washington Aqueduct system, was found to have high amounts of phosphorus and sufficient levels of nitrogen to cause rapid algal growth and indeed this is what was observed. For the CHOH Terminus Basin, which is not fed by municipal water, overuse of river water from the Potomac River, gradual accumulation of nutrients in the basin, and bird droppings all contributed to high amounts of floating mats of algae.

Because chemical treatment is incompatible with discharge regimes, efforts should be placed towards the reduction of nutrients inputs and removing accumulated nutrients from sediments or the water column. This can be achieved by reducing source water use, and by incorporating constructed wetlands that remove nutrients, specifically nitrogen and phosphorus. Nutrient control also affects the entire water body. Treatment technologies that eliminate algae in a separate chamber, such as in a UV disinfection unit or in an ozone contact chamber, will only be effective in removing suspended algae, leaving attached algae and biofilms unharmed and are therefore not recommended. Some of these technologies also increase electricity-use and should be avoided in order to enhance sustainability.

Constructed wetlands are a nutrient removal technology that is recommended and currently available for CWFs. These systems can use existing water flow to deliver water flow through anaerobic and aerobic zones of wetland soils, converting and

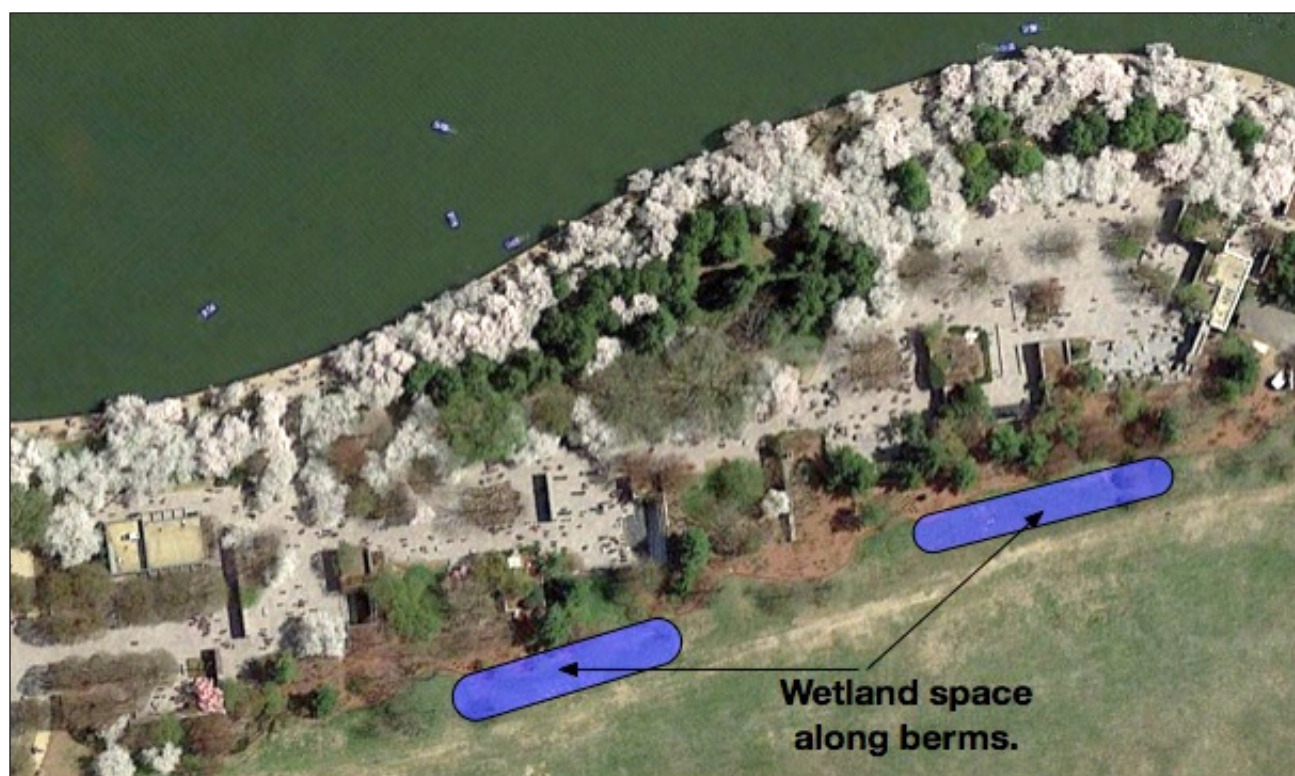


Figure 8.1. Possible wetland space shaded in blue for the Franklin Delano Roosevelt Memorial.

removing nutrients. As an added benefit, they can be incorporated into the park environment seamlessly and may add to educational value of such sites.

At the FDR Memorial, surface-flow wetlands can be built along the edge of the park, along the opposite side of the berm as shown in Figure 8.1. In this example, two wetland areas are constructed and linked to each of the Equipment Space Rooms. Each water feature would need its own flow through the wetland systems, so ideally the two wetlands would have separate pathways for each water feature. Positioning these wetland areas behind the berms allows them to be connected to the equipment space rooms without obstructing the memorial during construction or regular operation.

In contrast, Meridian Hill Park does not have additional unused space for locating wetland area. Here it may be more feasible to construct wetlands within the existing footprints of the water feature, as in Figure 8.2. Sections of the reflecting pool on the lower plaza could be converted to wetland space, utilizing existing plumbing systems for water flow. Doing so may also fit into the original designs that incorporated lilies and other wetland plants. Additional wetland area could be found in the planters that flank the cascades. These planters have already become waterlogged due to overflow, and wetland plants have taken root. By installing

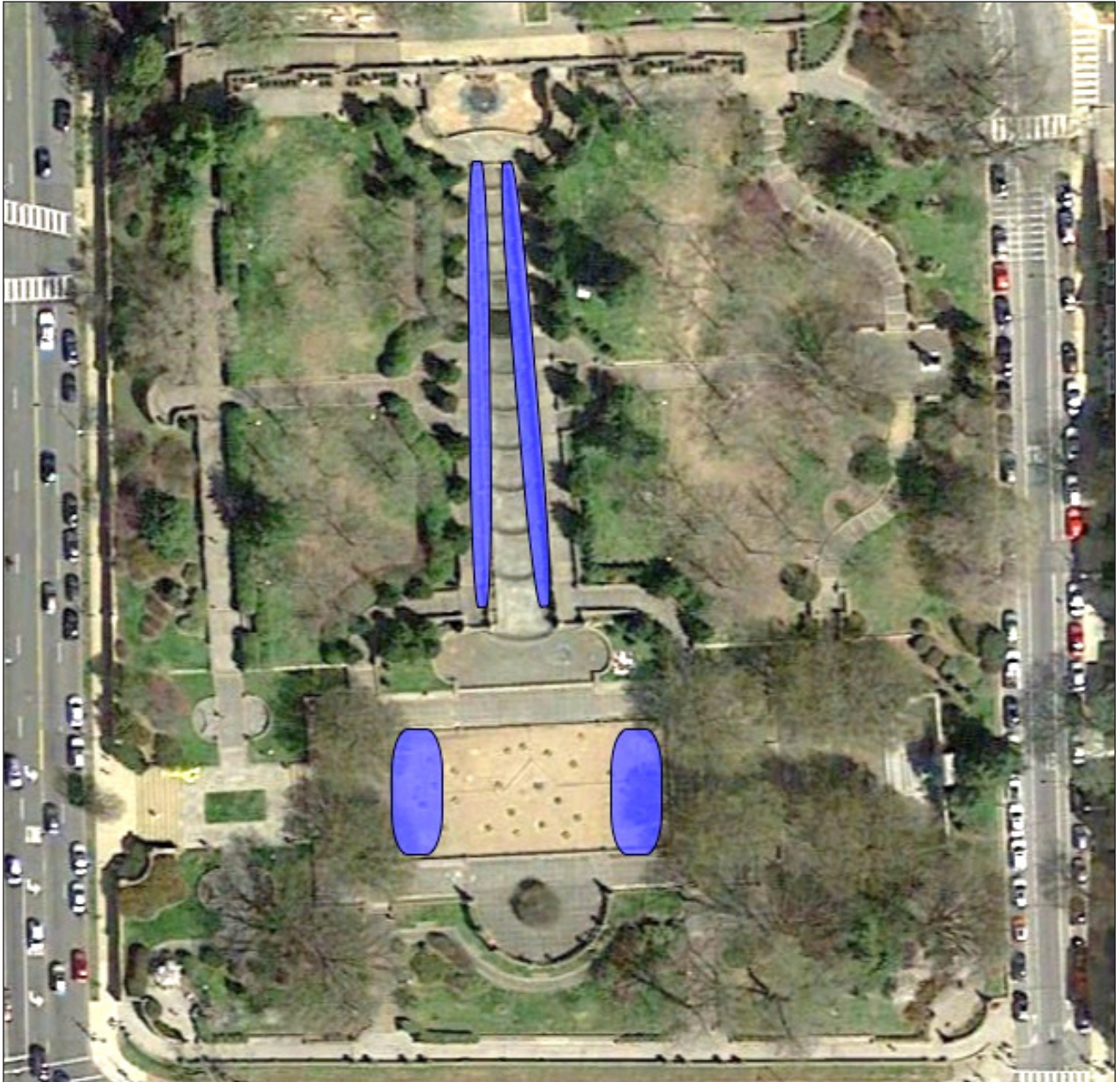


Figure 8.2. Wetland space is shown shaded in blue at Meridian Hill Park. The spaces proposed here are all within the existing footprint of the water feature.

pipes to route water through the planters, the existing wetland-like environment could be focused toward water treatment.

The WIMSA Memorial presents a challenge in that there is no space within the water feature's footprint for a wetland, so it must be incorporated in the landscaping of the overall site. In Figure 8.3, sub-surface wetlands are located in the grassy areas of the hemicycle. Sub-surface wetlands would need to be constructed, connected to the existing plumbing system and planted with plants that will not alter the overall appearance of the site. By installing sub-surface flow wetlands,

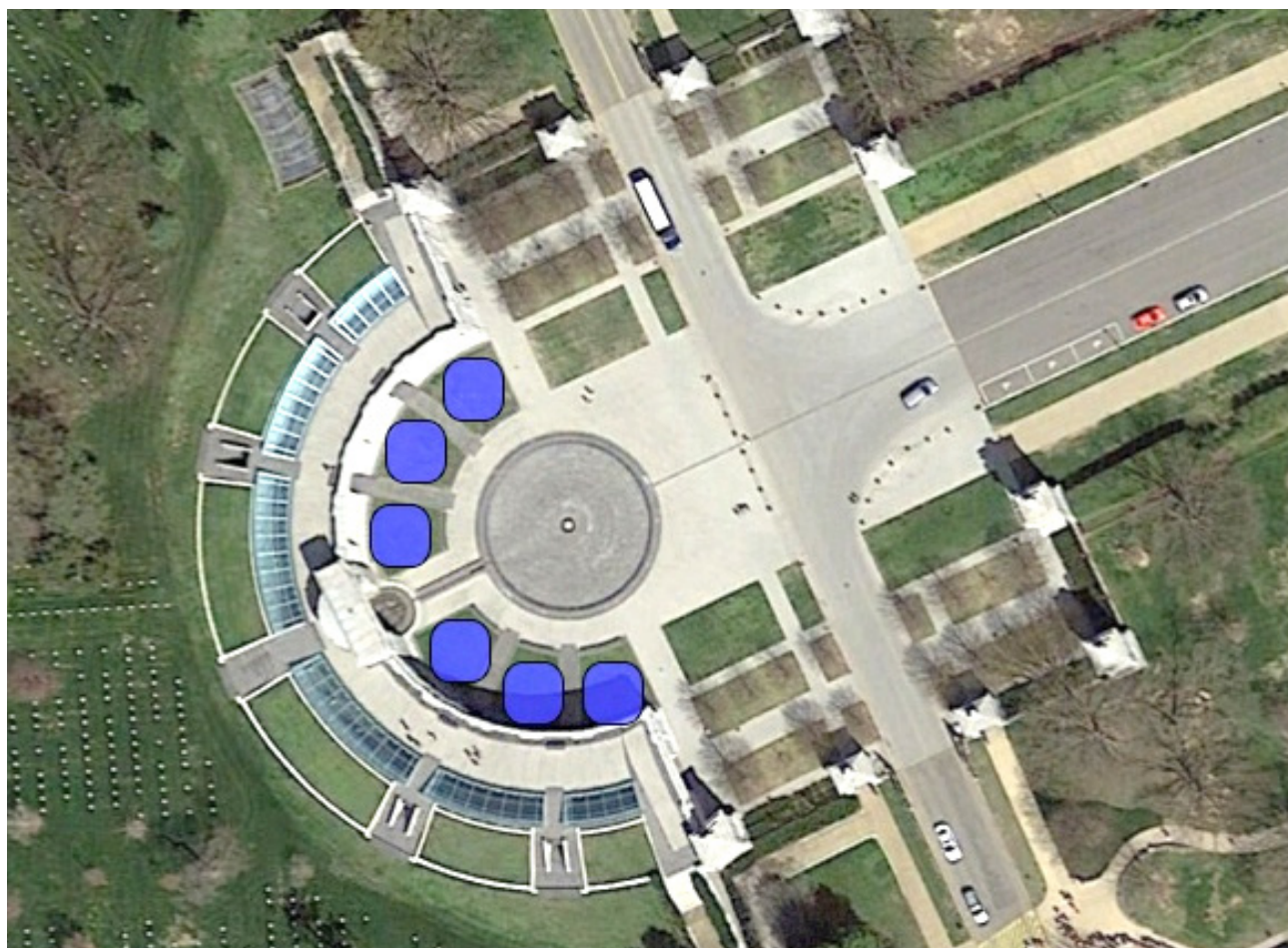


Figure 8.3. Wetland space is shown shaded in blue at the WIMSA Memorial.

no water would be visible to visitors and the wetland treatment system would be effectively hidden from sight altogether.

The CHOH Canal Terminus Basin poses less of the challenge in terms of appearance and siting wetlands because parts of the CWF already have wetlands naturally forming. However, water would need to flow through the constructed wetlands and thus would require pumps and plumbing to be installed in the CWF, which does not currently have flowing water. Locations for the wetland systems are shown in 8.4.

Nutrients can gradually accumulate in sediment layers of canals and ponds. Once accumulated, sediments can release nutrients to cause algal blooms even after nutrient inputs have been reduced. In these cases, P-capping agents can seal the sediment layer, and prevent nutrients from being released. Combining this with a constructed wetland shows great promise for reducing algal blooms. To reduce further nutrient inputs, methods to deter waterfowl from visiting the CWF may be needed.

As discussed in section 7.3.1, retrofitting PSF with P-adsorbing media could be an affordable and promising method of removing phosphorus from CWF water. P-adsorbing materials like calcite, Phosfree™, ‘new Damolin,’ Filtralite P®, and Ferroxysorb (see section 7.3.1 for further details) could replace the sand media in the PSFs to create P-adsorbing filter.

Retrofitting PSFs should be considered experimental, but the concept has been validated by scientific studies (Arias and Brix, 2005; Sibrell et al., 2009; Vohla et al., 2011). There may be the potential for staining, especially for media that contains high amounts of Fe. Additionally, NPS would need to determine whether the existing PSFs are large enough to contain enough P-adsorbing media in order to remove sufficient amounts of P, without frequent media replacement.

This recommendation assumes that maintenance of the PSFs is improved so that the retrofit is successful long-term. Media will need to be backwashed as solids build up and occasionally replacement of media will be required as the media becomes saturated with P.

Figure 8.4. Wetland space is shown shaded in blue at the CHOH Canal Terminus Basin in Cumberland, MD



8.2. REPAIR AND MAINTAIN HYDRAULIC INTEGRITY

Three of the four sites we studied had observed problems associated with poor hydraulic integrity (i.e. the CWFs had leaks). The WIMSA site had a large leak due to a gap in the bottom liner around the edge of the main basin, the Meridian Hill Park feature had small leaks in piping and basins and the Cumberland Basin had a very large leak that drains water rapidly, but has since been repair. Leaks lead to greater water use and higher nutrient loads that promote the growth of algae. Therefore it is strongly recommended to prevent leaks and preserve the physical structure where possible.

Growth of biofilms on surface promotes degradation of materials through the build-up of organic acids, carbonic acid, and the “wedge effect.” Additionally the build-up of salts may degrade stone by chemical weathering. Further effort should be given to preventing biofilms through nutrient removal, and preventing salt and mineral accumulations reducing splashing over surfaces and preventing water from running directly over stone surfaces. This is not entirely possible in all cases, but fountain spouts can be fitted with plastic tubing that directs water flow away from surfaces and prevents unwanted splashing. Existing stains caused by the build-up of salts and minerals can be cleaned with deionized water.

Attached algae can be killed by slightly diluted alcohol as described in Krueger (2010). To do so, the problem area is covered in plastic sheeting to form a vapor chamber. Then cloths saturated with 90% alcohol solution are on the target area and left to sit. After 24 hours, the plastic sheeting and cloths are removed and the area is then vacuumed thoroughly to remove the dead algae.

Another common phenomenon was equipment failure. At three of the sites examined here (WIMSA, FDR, and Meridian Hill), sand filters did not appear to be operating properly. They either were not able to manage the loading of algae, or had clogged, due to inadequate maintenance. In other cases, equipment was not compatible with discharge regimes, such as the chemical treatment assemblage at the FDR Memorial, which had fortunately been shut down prior to this study. Other equipment could not handle the loads of algae present in the CWFs. Screen filters and PSFs are not made to filter high amounts of suspended algae, and instead are intended to remove large and lower concentrations of fine solids, respectively, not large amounts of unicellular organisms. Repair of water treatment equipment is recommended, along with a greater focus on the proper maintenance and routine inspection of equipment.

A final recommendation regarding the preservation of structures and equipment is to carefully monitor cracks, stains, attached algal growth, and other degradation

so that problems can be dealt with before they require extensive reconstruction work. Being able to identify the potential for structural damage may help enhance overall sustainability of CWFs.

8.3. FORMATION OF A WATER FEATURES WORKGROUP

During the study period, plant debris accumulated in the CWFs, PSFs appeared to be deteriorating from poor maintenance, chemical treatments may have been administered improperly, allowing for blooms to occur, and there appeared to be plumbing problems at the FDR Memorial (evidenced by the lack of waterfalls in the Niche Fountains; see Chapter 5). It is clear that CWFs are complex systems that need more frequent maintenance work, monitoring and properly trained staff solely dedicated to CWFs.

This report acknowledges that there is a limited pool of NPS staff and individuals that are available for the enhanced maintenance called for in this report. One possibility is the formation of a work group that meets annually and shares knowledge about maintenance may help alleviate some of the knowledge gaps surrounding the complex task of managing water quality and maintaining equipment. Additionally, there may be opportunities for the community involvement in the upkeep of CWFs. The Friends of Meridian Hill Park were instrumental in the recovery of Meridian Hill Park from criminal elements and it may require further involvement of such groups to assist in identifying problems, removing debris, and other necessary activities. An expansion of this type of involvement could include a summer internship program with local universities. Students of science (environmental science, chemistry, civil engineering, etc.) could learn valuable skills by monitoring water quality, maintaining constructed wetlands, or developing new ideas for sustaining CWFs. Utilization of university research partners and student interns to investigate on-going issues and optimize processes will be crucial to sustaining high-quality CWFs for the future.

8.4. CONCLUDING REMARKS

As mentioned earlier, developing actions to take for CWFs should be based on a site-specific basis. Appendix A-2 is a sample checklist for the rapid assessment of a CWF. Once an understanding of the root causes of the problems is reached, a management plan can be put in place. Generally speaking technologies for nutrient management are important; but other actions can help, such as removing plant debris daily, preventing waterfowl from visiting CWFs. The water quality problems and their associated affects are not simple to solve and managing them is difficult especially when source water has a tendency to develop algal blooms.

Other than chlorination, no technology has a history of treating nutrient pollution in CWFs. Instead, the problem will require a combination of appropriate technology, repair and maintenance of existing treatment systems, and human effort to maintain water features for future use and enjoyment.



REFERENCES

GLOSSARY OF TERMS

AEROBIC

Denotes the presence of oxygen.

ALGAE (ALGAL)

Algae are a large group of photosynthesizing organisms that lack the vascular tissue of higher plants. They range from unicellular organisms, to cell colonies, to multicellular organisms.

ALGAECIDE

A chemical compound used to kill and prevent the growth of algae.

ALGAL BLOOMS

A rapid accumulation of algae populations in an aquatic system.

ALGISTATIC

A property of a substance that prevents the growth of algae without killing it.

ALKALINITY

The quantitative capacity of water to buffer (or neutralize) an acid that is added to the water.

AMMONIA

A gaseous, colorless, pungent compound of nitrogen and hydrogen (NH_3).
Can be used as a nutrient for plant and algal growth.

ANAEROBIC

Denotes the absence of oxygen.

APSE

A semicircular recess covered with a semi-dome structure. Often found in churches.

ATTRIBUTE FLOW

A waterfall, cascade, fountain or other ornamental water flow within a water feature.

BIOMASS

Organic material derived from living organisms.

CALCIUM HYPOCHLORITE

A calcium salt that is used for bleaching and water treatment by disinfection.

CHLORAMINES

Disinfectants used to treat drinking water composed of derivatives of ammonia and chlorine.

CHLORINATION

The use of chlorine to disinfect waters.

COAGULATION

The process of thickening a liquid substance to a gel-like substance.

DISSOLVED OXYGEN

Oxygen (O₂) that is dissolved in water and available for respiration by fish and other organisms.

EUTROPHICATION

The over-enrichment of an aquatic ecosystem, often by fertilizer run-off.

EVAPORATION

The conversion of a liquid to a gaseous state that is accelerated by high temperatures, air movement and low humidity levels.

FLOCCULATION

The process of aggregating particles into larger lumps so that the lumps can settle out of the water column.

HARDNESS

The amount of dissolved calcium and magnesium in water.

HARMFUL ALGAL BLOOMS (HAB'S)

A rapid accumulation of algae populations that degrades water quality causes harm to other organisms and humans either directly through the production of toxins or indirectly through the depletion of oxygen.

LITTERFALL

Any plant and/or tree debris such as leaves, small branches, flowers, pollen or any other plant material that falls or is blown into a CWF.

MALODOR

An unpleasant smell.

MURIATIC ACID

Hypochloric acid that is used to adjust the pH of water systems.

NIGROSIN DYE

A mixture of black dyes that is used to change the color of water.

NITRATE

An ionic compound that contains oxygen and nitrogen (NO_3) that is often used as a fertilizer.

NITROGEN

A chemical element that is essential for life and many industrial uses.

NUTRIENTS

Any element, compound or substance that nourishes organisms for life.

ORTHOPHOSPHATES

The form of phosphate that can be taken in by photosynthesizing organisms like algae.

OZONATION

The use of ozone gas to disinfect waters.

pH

The negative log of the hydrogen ion concentration in an aqueous solution. PH below 7 is considered an acid, and those greater than 7 are considered basic.

PHOSPHORUS

A chemical element that is required in large amounts by photosynthesizing organisms.

SEDIMENT

Any solid material, usually dust, rocks, gravel or organic material, which is deposited in a new location.

SLUDGE

A thick, wet mud that is often a by-product of an industrial process. In CWFs, sludge is muck composed of decomposing algal biomass and sediment.

TOTAL DISSOLVED SOLIDS

A measure of the amount of solids that are dissolved in a water sample. Determined by first filtering out suspended solids and then vaporizing the water content, leaving the dissolved solids to be weighed.

TOTAL SUSPENDED SOLIDS

A measure of the amount of solid material that is suspended in a water sample.

TURBIDITY

A measure of water clarity in nephelometric turbidity units (NTUs). A higher NTU value indicates cloudier water. Clear water has a turbidity of 0 NTUs.

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APPENDICES

APPENDIX A-1: VISUAL STUDY RECORD SHEET

VISUAL ASSESSMENT

Park: _____ Water Feature: _____

Date: _____ Name of Assessor: _____

WATER QUALITY ASSESSMENT

TEST		
FOAM	% COVERAGE:	HEIGHT OF FOAM:
COLOR		
ODOR	1 (NO ODOR) - 10 (STRONG ODOR):	TYPE OF ODOR:

OUTSIDE FACTOR ASSESSMENT

TEST		DESCRIPTION
PLANT LITTER	% COVERAGE OF WATER SURFACE:	
HUMAN LITTER	# OF ITEMS:	
FILAMENTOUS ALGAE	% COVERAGE OF WATER SURFACE:	
VISIBILITY (SECCHI DISC)	CM:	

APPENDIX A-2: CWF TROUBLESHOOTING CHECKLIST

Since problems are site specific, assessing problems at other CWFs will require managers to take the following actions:

1. Determine the nitrogen and phosphorus concentrations in source water. Concentrations of phosphorus above 0.05 mg/l should alert managers to nutrient-related problems such as algae and biofilm growth.
2. Inspect pump rooms and sand filtration systems. Determine when the most recent replacement of sand occurred, what are the operating pressures, and how often the filters are backwashed.
3. Make note of splashing and any staining, the colors of stains, and where moist areas of the structures and surfaces.
4. At start of season, make note of water meter readings and compare to readings at the end of the season. Determine the discharge regime, i.e. how much water is being discharged and where it being discharged.
5. Make note of any cracks in stone structure and puddles around the CWF that indicate leakage.

