

National Park Service
U.S. Department of the Interior

National Capital Region
Washington, DC



National Capital Region Network 2009 Water Resources Monitoring Data Report

*Water Chemistry, Nutrient Dynamics, and Surface Water Dynamics
Vital Signs*

Natural Resource Data Series NPS/NCR/NCRN/NRDS-2010/095



ON THE COVER

Water laboratory at the Center for Urban Ecology
Photograph by: I&M field technicians

National Capital Region Network 2009 Water Resources Monitoring Data Report

Water Chemistry, Nutrient Dynamics, and Surface Water Dynamics Vital Signs

Natural Resource Data Series NPS/NCR/NCRN/NRDS—2010/095

Marian Norris

James Pieper

National Park Service
Inventory and Monitoring Program
National Capital Region Network
4598 MacArthur Blvd., NW
Washington, DC 20007

September 2010

U.S. Department of the Interior
National Park Service
Natural Resources Program Center
Fort Collins, Colorado

The National Park Service, Natural Resource Program Center publishes a range of reports that address natural resource topics of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Data Series is intended for the timely release of basic data sets and data summaries. Care has been taken to assure accuracy of raw data values, but a thorough analysis and interpretation of the data has not been completed. Consequently, the initial analyses of data in this report are provisional and subject to change.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocol.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

Printed copies of reports in these series may be produced in a limited quantity and they are only available as long as the supply lasts. This report is also available from the National Capital Region Network I&M Network website (<http://www.nature.nps.gov/im/units/NCRN>) on the internet, or by sending a request to the address on the back cover.

Please cite this publication as:

Norris, M. E., and J. M. Pieper. 2010. National Capital Region Network 2009 water resources monitoring data report: water chemistry, nutrient dynamics, and surface water dynamics vital signs. Natural Resource Data Series NPS/NCR/NCRN/NRDS-2010/095. National Park Service, Fort Collins, Colorado.

Contents

	Page
Figures.....	v
Tables	
.....	xi
v	
Abbreviations & Acronyms	xv
Executive Summary	xviii
Introduction.....	1
Methods.....	3
Sampling Design.....	3
Sampling Frequency and Replication.....	5
Data Collection	5
Parameters.....	6
pH	6
Acid Neutralizing Capacity (ANC)	8
Specific conductance	8
Salinity.....	9
Nitrogen	10
Ammonia	10
Nitrate	11
Total Phosphorus	11
Dissolved Oxygen (DO)	11
Wetted Width.....	13
Depth.....	13
Flow	13

Discharge	13
Discussion of Findings.....	14
Antietam National Battlefield (ANTI).....	15
Catoctin Mountain Park (CATO)	24
George Washington Memorial Parkway (GWMP)	33
Harpers Ferry National Historical Park (HAFE)	42
Manassas National Battlefield Park (MANA).....	51
Monocacy National Battlefield (MONO).....	60
National Capital Parks – East (NACE).....	70
Prince William Forest Park (PRWI)	79
Rock Creek Park (ROCR)	88
Wolf Trap National Park for the Performing Arts (WOTR)	98

Figures

Page

Figure 1 : Locations of the National Parks (red) in the National Capital Region Network within the Potomac River (brighter outline within map) and Patuxent River watersheds:.....	1
Table 2: Date range, number of site visits, and data range for the information covered in this report.	6
Figure 3: Relationship of the Sharpsburg Creek monitoring site to the watershed and the park boundary	15
Figure 4: ANC in Sharpsburg Creek in FY 2009. Desired condition is above the 600 ueq/L threshold for karst waters shown in red.	17
Figure 5: pH in Sharpsburg Creek in FY 2009. Desired condition is between the 6.5 and 9.0 thresholds shown in red.	18
Figure 6: Specific Conductance in Sharpsburg Creek, FY 2009. Desired condition is below the 400 uS/cm threshold shown in red.....	18
Figure 7: Salinity in Sharpsburg Creek FY 2009. Desired condition is below the 0.5 ppt threshold shown in red.	19
Figure 8: Ammonia in Sharpsburg Creek, FY 2009. Desired condition is below the 0.443 threshold shown in red.	19
Figure 9: Nitrate in Sharpsburg Creek, FY 2009. Desired condition is below the 2.0 mg/L threshold shown in red.	20
Figure 10: Total Phosphorus in Sharpsburg Creek, FY 2009. Desired condition is below the 0.1 mg/L threshold shown in red.	20
Figure 11: Dissolved Oxygen in Sharpsburg Creek, FY 2009. Desired condition is above the 5.0 mg/L threshold shown in red.	21
Figure 12: Temperatures of Sharpsburg Creek, FY 2009. Ideal temperatures for aquatic life are between 0 and 25 °C.	21
Figure 13: Discharge of Sharpsburg Creek, FY 2009.....	22
Figure 14: Flow of Sharpsburg Creek, FY 2009.....	22
Figure 15: Average depth of Sharpsburg Creek, FY 2009. Required condition is above 0.2 foot for discharge measurements and 0.5 foot for continuous measurement with data sondes.	23
Figure 16: Wetted width of Sharpsburg Creek, FY 2009.	23

Figure 17: Relationship of CATO stream monitoring sites to their watersheds and the park boundary	24
Figure 18: ANC in Catoctin Mountain Park streams in FY 2009. Desired condition is above the 200 ueq/L threshold for non-karst waters shown in red.	26
Figure 19: pH in Catoctin Mountain park streams in FY 2009. Desired condition is between the 6.5 and 9.0 thresholds shown in red.....	27
Figure 20: Specific Conductance in Catoctin Mountain park streams, FY 2009. Desired condition is below the 400 uS/cm threshold shown in red.	27
Figure 21: Salinity in Streams of Catoctin Mountain Park FY 2009. Desired conditon is below the 0.5 ppt threshold shown in red.	28
Figure 22: Ammonia in Catoctin Mountain Park streams, FY 2009. Desired condition is below the 0.443 threshold shown in red.	28
Figure 23: Nitrate in Catoctin Mountain Park streams, FY 2009. Desired condition is below the 2.0 mg/L threshold shown in red.	29
Figure 24: Total Phosphorus in Catoctin Mountain Park streams, FY 2009. Desired condition is below the 0.1 mg/L threshold shown in red.....	29
Figure 25: Dissolved Oxygen in Catoctin Mountain Park streams, FY 2009. Desired condition is above the 5.0 mg/L threshold shown in red.....	30
Figure 26: Temperatures of Catoctin Mountain Park Streams, FY 2009. Ideal temperatures for aquatic life are between 0 and 25 °C.	30
Figure 27: Wetted Width of Catoctin Mountain Park Streams, FY 2009.....	31
Figure 28: Average depth of Catoctin Mountain Park Streams, FY 2009. Required condition is above 0.2 foot for discharge measurements and 0.5 foot for continuous measurement with data sondes.....	31
Figure 29: Discharge of Catoctin Mountain Park Streams, FY 2009.	32
Figure 30: Flow of Catoctin Mountain Park Streams, FY 2009.	32
Figure 31: Relationship of the stream monitoring sites to their watersheds and the park boundary in the George Washington Memorial Parkway.....	33
Figure 32: ANC in George Washington Memorial Parkway Streams, FY 2009. Desired condition is above the 200 ueq/L threshold for non-karst waters shown in red.	35
Figure 33: pH in George Washington Memorial Parkway Streams, FY2009. Desired condition is between the 6.5 and 9.0 thresholds shown in red.	36

Figure 34: Specific Conductance in George Washington Memorial Parkway Streams FY 2009. Desired condition is below the 400 uS/cm threshold shown in red.	36
Figure 35: Salinity in George Washington Memorial Parkway Streams over time. Desired condition is below the 0.5ppt threshold shown in red.	37
Figure 36: Dissolved Oxygen in George Washington Memorial Parkway Streams, FY 2009. Desired condition is above the 5.0mg/l threshold shown in red.	37
Figure 37: Nitrate in George Washington Memorial Parkway Streams FY 2009. Desired condition is below the 2.0 mg/L threshold shown in red.	38
Figure 38: Ammonia in George Washington Memorial Parkway Streams FY 2009. Desired condition is below the 0.443 mg/L threshold shown in red.	38
Figure 39: Total Phosphorus in George Washington Memorial Parkway Streams FY 2009. Desired condition is below the 0.1 mg/L threshold shown in red.	39
Figure 40: Temperatures in George Washington Memorial Parkway Streams FY 2009. Ideal temperatures for aquatic life are between 0 and 25 °C.	39
Figure 41: Wetted Width in George Washington Memorial Parkway Streams FY 2009.	40
Figure 42: Average depth in George Washington Memorial Parkway Streams FY 2009. Required condition is above 0.2 foot for discharge measurements and 0.5 foot for continuous measurement with data sondes.	40
Figure 43: Discharge in George Washington Memorial Parkway Streams FY 2009.	41
Figure 44: Flow in George Washington Memorial Parkway Streams, FY 2009.	41
Figure 45: Relationship of the Flowing Springs monitoring site to the watershed and the park boundary.	42
Figure 46: ANC in Flowing Springs in FY 2009. Desired condition is above the 600 ueq/L threshold for karst waters shown in red.	44
Figure 47: pH in Flowing Springs in FY 2009. Desired condition is between the 6.5 and 9.0 thresholds shown in red.	45
Figure 48: Specific Conductance in Flowing Springs, FY 2009. Desired condition is below the 400 uS/cm threshold shown in red.	45
Figure 49: Salinity in Flowing Springs FY 2009. Desired condition is below the 0.5 ppt threshold shown in red.	46
Figure 50: Ammonia in Flowing Springs, FY 2009. Desired condition is below the 0.443 threshold shown in red.	46

Figure 51: Nitrate in Flowing Springs, FY 2009. Desired condition is below the 2.0 mg/L threshold shown in red.	47
Figure 52: Total Phosphorus in Flowing Springs, FY 2009. Desired condition is below the 0.1 mg/L threshold shown in red.	47
Figure 53: Dissolved Oxygen in Flowing Springs, FY 2009. Desired condition is above the 5.0 mg/L threshold shown in red.	48
Figure 54: Temperatures in Flowing Springs, FY 2009. Ideal temperatures for aquatic life are 0 to 25 °C.	48
Figure 55: Wetted Width in Flowing Springs, FY 2009.....	49
Figure 56: Average depth in Flowing Springs, FY 2009. Required condition is above 0.2 foot for discharge measurements and 0.5 foot for continuous measurement with data sondes.	49
Figure 57: Discharge in Flowing Springs, FY 2009	50
Figure 58: Flow in Flowing Springs, FY 2009	50
Figure 59: Relationship of MANA stream monitoring sites to their watersheds and the park boundary.	51
Figure 60: ANC in Youngs Branch in FY 2009. Desired condition is above the 200 ueq/L threshold for non-karst waters shown in red.....	53
Figure 61: pH in Youngs Branch in FY 2009. Desired condition is between the 6.5 and 9.0 thresholds shown in red.	53
Figure 62: Specific Conductance in Youngs Branch FY 2009. Desired condition is below the 400 uS/cm threshold shown in red.....	54
Figure 63: Salinity in Youngs Branch in FY 2009. Desired condition is below the 0.5 ppt threshold shown in red.	54
Figure 64: Ammonia in Youngs Branch in FY 2009. Desired condition is below the 0.443 threshold shown in red.	55
Figure 65: Nitrate in Youngs Branch in FY 2009. Desired condition is below the 2.0 mg/L threshold shown in red.	55
Figure 66: Total Phosphorus in Youngs Branch in FY 2009. Desired condition is below the 0.1 mg/L threshold shown in red.	56
Figure 67: Dissolved Oxygen in Youngs Branch in FY 2009. Desired condition is above the 5.0 mg/L threshold shown in red.	56

Figure 68: Temperature in Youngs Branch, FY 2009. Ideal temperatures for aquatic life are 0 to 25 °C.	57
Figure 69: Wetted Width in Youngs Branch, FY 2009.	57
Figure 70: Average depth in Youngs Branch FY 2009. Required condition is above 0.2 foot for discharge measurements and 0.5 foot for data sondes.	58
Figure 71: Discharge in Youngs Branch FY 2009.	58
Figure 72: Flow in Youngs Branch FY 2009.	59
Figure 73: Relationship of the MONO stream monitoring sites to their watersheds and the park boundary.	60
Figure 74: ANC in Monocacy National Battlefield streams in FY 2009. Desired condition is above the 600 ueq/L threshold for karst waters shown in red.	63
Figure 75: pH in Monocacy National Battlefield streams in FY 2009. Desired condition is between the 6.5 and 9.0 thresholds shown in red.	63
Figure 76: Specific Conductance in Monocacy National Battlefield streams, FY 2009. Desired condition is below the 400 uS/cm threshold shown in red.	64
Figure 77: Salinity in Streams of Monocacy National Battlefield FY 2009. Desired condition is below the 0.5 ppt threshold shown in red.	64
Figure 78: Ammonia in Monocacy National Battlefield streams, FY 2009. Desired condition is below the 0.443 threshold shown in red.	65
Figure 79: Nitrate in Monocacy National Battlefield streams, FY 2009. Desired condition is below the 2.0 mg/L threshold shown in red.	65
Figure 80: Total Phosphorus in Monocacy National Battlefield streams, FY 2009. Desired condition is below the 0.1 mg/L threshold shown in red.	66
Figure 81: Dissolved Oxygen in Monocacy National Battlefield streams, FY 2009. Desired condition is above the 5.0 mg/L threshold shown in red.	66
Figure 82: Temperatures of Monocacy National Battlefield Streams, FY 2009. Ideal temperatures for aquatic life are 0 to 25 °C.	67
Figure 83: Average depth of Monocacy National Battlefield Streams, FY 2009. Required condition is above 0.2 foot for discharge measurements and 0.5 foot for data sondes.	67
Figure 84: Wetted Width of Monocacy National Battlefield Streams, FY 2009.	68
Figure 85: Flow of Bush Creek, Monocacy National Battlefield, FY 2009.	68

Figure 86: Discharge of Bush Creek, Monocacy National Battlefield, FY 2009.	69
Figure 87: Relationship of the Stream monitoring sites in NACE to their watersheds and the park subunit boundaries.	70
Figure 88: ANC in National Capital Parks - East Streams in FY 2009. Desired condition is above the 200 ueq/L threshold for non-karst waters is shown in red.	72
Figure 89: Dissolved Oxygen in National Capital Parks - East Streams in FY 2009. Desired condition is above the 0.5 mg/L threshold shown in red.	73
Figure 90: pH in National Capital Parks - East Streams in FY 2009. Desired condition is between the 6.5 and 9.0 thresholds shown in red.	73
Figure 91: Phosphorus in National Capital Parks - East Streams in FY 2009. Desired conditions is below the 0.1 mg/L threshold shown in red.	74
Figure 92: Ammonia in National Capital Parks - East streams FY 2009. Desired condition is below the 0.443 mg/L threshold shown in red.	74
Figure 93: Nitrate in National Capital Parks - East streams FY 2009. Desired condition is below the 2.0 mg/L threshold shown in red.	75
Figure 94: Specific Conductance in National Capital Parks - East streams FY 2009. Desired condition is below the 400 us/cm threshold shown in red.	75
Figure 95: Salinity in National Capital Parks - East streams, FY 2009. Desired condition is below the 0.5 ppt threshold shown in red.	76
Figure 96: Water Temperature in National Capital Parks - East streams, FY 2009. Ideal condition for aquatic life is between the 0°C and 25°C thresholds shown in red.	76
Figure 97: Flow in National Capital Parks - East streams in FY 2009.	77
Figure 98: Discharge in National Capital Parks - East streams in FY 2009.	77
Figure 99: Average Water Depth in National Capital Parks - East streams in FY 2009. Required condition is above 0.2 foot for discharge measurements and 0.5 foot for data sondes.	78
Figure 100: Wetted Width of National Capital Parks - East streams in FY 2009.	78
Figure 101: Relationship of PRWI stream monitoring sites to their watersheds and the park boundary.	79
Figure 102: ANC in Prince William Forest Park streams FY 2009. Desired condition is above the 200 ueq/L threshold for non-karst waters shown in red.	81
Figure 103: pH in Prince William Forest Park streams FY 2009. Desired condition is between the 6.5 and 9.0 thresholds shown in red.	82

Figure 104: Specific Conductance in Prince William Forest Park streams FY 2009. Desired condition is below the 400 uS/cm threshold shown in red.	82
Figure 105: Salinity in Prince William Forest Park Streams. Desired condition is below the 0.5 threshold shown in red.	83
Figure 106: Ammonia in Prince William Forest Park streams FY 2009. Desired condition is below the 0.443 threshold shown in red	83
Figure 107: Nitrate in Prince William Forest Park streams FY 2009. Desired condition is below the 2.0 mg/L threshold shown in red.	84
Figure 108: Total Phosphorus in Prince William Forest Park streams FY 2009. Desired condition is below the 0.2 mg/L threshold shown in red.	84
Figure 109: Dissolved Oxygen in Prince William Forest Park streams FY 2009. Desired condition is above the 5.0 mg/L threshold shown in red.	85
Figure 110: Water temperature in Prince William Forest Park streams, FY 2009. Ideal conditions for aquatic life are between the 0° C and 25° C thresholds shown in red.	85
Figure 111: Average water depth in Prince William Forest Park streams, FY 2009. Required condition is above 0.2 foot for discharge measurements and 0.5 foot for data sondes.	86
Figure 112: Stream flow in Prince William Forest Park, FY 2009.	86
Figure 113: Discharge of Prince William Forest Park streams, FY 2009.	87
Figure 114: Wetted width of Prince William Forest Park streams, FY 2009.	87
Figure 115: Relationship of the stream monitoring sites to their watersheds and the park boundary	89
Figure 116: ANC in Rock Creek Park streams in FY 2009. Desired condition is above the 200 ueq/L threshold for non-karst waters shown in red.	91
Figure 117: pH in Rock Creek park streams in FY 2009. Desired condition is between the 6.5 and 9.0 thresholds shown in red.	92
Figure 118: Specific Conductance in Rock Creek park streams, FY 2009. Desired condition is below the 400 uS/cm threshold shown in red.	92
Figure 119: Salinity in Streams of Rock Creek Park FY 2009. Desired condition is below the 0.5 ppt threshold shown in red.	93
Figure 120: Ammonia in Rock Creek Park streams, FY 2009. Desired condition is below the 0.443 threshold shown in red.	93

Figure 121: Nitrate in Rock Creek Park streams, FY 2009. Desired condition is below the 2.0 mg/L threshold shown in red.	94
Figure 122: Total Phosphorus in Rock Creek Park streams, FY 2009. Desired condition is below the 0.1 mg/L threshold shown in red.	94
Figure 123: Dissolved Oxygen in Rock Creek Park streams, FY 2009. Desired condition is above the 5.0 mg/L threshold shown in red.	95
Figure 124: Temperatures of Rock Creek Park Streams, FY 2009. Ideal temperatures for aquatic life are 0 to 25 °C.	95
Figure 125: Wetted Width of Rock Creek Park Streams, FY 2009.	96
Figure 126: Average depth of Rock Creek Park Streams, FY 2009. Required condition is above 0.2 foot for discharge measurements and 0.5 foot for data sondes.	96
Figure 127: Discharge of Rock Creek Park Streams, FY 2009.	97
Figure 128: Flow of Rock Creek Park Streams, FY 2009.	97
Figure 129: Relationship of the Wolf Trap Creek monitoring site to the watershed and the park boundary.	98
Figure 130: ANC in Wolf Trap Farm Park streams in FY 2009. 200 ueq/L threshold shown in red.	100
Figure 131: pH in Wolf Trap Farm Park streams in FY 2009. 6.5 and 9.0 thresholds shown in red.	100
Figure 132: Specific Conductance in Wolf Trap Farm Park streams, FY 2009. 400 uS/cm threshold shown in red.	101
Figure 133: Salinity in Wolf Trap Farm Park streams FY 2009. 0.5 ppt threshold shown in red.	101
Figure 134: Nitrate in Wolf Trap Farm Park streams, FY 2009. 2.0 mg/L threshold shown in red.	102
Figure 135: Total Phosphorus in Wolf Trap Farm Park streams, FY 2009. 0.1 mg/L threshold shown in red.	102
Figure 136: Ammonia in Wolf Trap Farm Park streams, FY 2009. 0.443 threshold shown in red.	103
Figure 137: Dissolved Oxygen in Wolf Trap Farm Park streams, FY 2009. 5.0 mg/L threshold shown in red.	103

Figure 138: Temperature in Wolf Trap Farm Park streams, FY 2009. 0°C and 25°C thresholds shown in red.....	104
Figure 139: Average depth of Wolf Trap Farm Park streams. Required condition is above 0.2 foot for discharge measurements and 0.5 foot for data sondes.....	104
Figure 140: Discharge of Wolf Trap Creek, FY 2009.....	105
Figure 141: Flow of Wolf Trap Creek, FY 2009.....	105
Figure 142: Wetted Width of Wolf Trap Farm Park streams, FY 2009.	106

Tables

Page

Table 1 Water Chemistry Monitoring Sites for 2009 excluding CHOH streams	4
Table 2: Date range, sample size (N), and data range for the vital signs data collected at Antietam National Battlefield.	16
Table 3: Date range, sample size (N), and data range for the vital signs data collected at Catoclin Mountain Park.....	25
Table 4: Date range, sample size (N), and data range for the vital signs data collected at George Washington Memorial Parkway.	34
Table 5: Date range, sample size (N), and data range for the vital signs data collected at Harper’s Ferry National Historical Site.	43
Table 6: Date range, sample size (N), and data range for the vital signs data collected at Manassas National Battlefield Park.	52
Table 7: Date range, sample size (N), and data range for the vital signs monitored in Monocacy National Battlefield.	61
Table 8: Date range, sample size (N), and data range for the vital signs data collected at National Capital Parks – East.	71
Table 9: Date range, sample size (N), and data range for the vital signs data collected at Prince William Forest Park.	80
Table 10: Date range, sample size (N), and data range for the vital signs data collected at Rock Creek Park.....	90
Table 11: Date range, sample size (N), and data range for the vital signs data collected at Wolf Trap National Park for the Performing Arts.	99

Abbreviations & Acronyms

°C	Degrees Centigrade or Celsius
µeq/L	Microequivalents per liter
µg/L	Micrograms per liter (equivalent to parts per billion)
µm	Micrometer
µS/cm	Microsiemens per centimeter
ac	Acres
ANC	Acid-Neutralizing Capacity
ANTI	Antietam National Battlefield
BSS	Biological Stream Survey
Ca	Calcium
CaCO ₃	Calcium carbonate
CATO	Catoctin Mountain Park
CCC	Chronic Concentration Criteria
cfs or ft ³ /s	Cubic feet per second
CHOH	Chesapeake and Ohio Canal National Historical Park
cm	Centimeters
CO ₂	Carbon dioxide
CO ₃ ²⁻	Carbonate
COE	(Army) Corps of Engineers
COG	Metropolitan Washington Council of Governments
CWA	Clean Water Act
DC	District of Columbia
DI	Deionized water
DO	Dissolved Oxygen
DOI	Department of Interior
DOT	Department of Transportation
DPD	N,N-diethyl-p-phenylenediamine
EPA	Environmental Protection Agency
ft	Feet
g	Gram
g/L	Gram per liter
gal	Gallons
gal/min	Gallon per minute
GIS	Geographic Information System
GPRA	Government Performance and Results Act
GPS	Global positioning system
GWMP	George Washington Memorial Parkway
H ₂ SO ₄	Hydrogen sulfide
ha	Hectares
HAFE	Harpers Ferry National Historical Park
HCO ₃ ⁻	Carbonate
HNO ₃	Nitrate
HUC	Hydrologic Unit Code
I&M	Inventory & Monitoring Program

ICPRB	Interstate Commission on the Potomac River Basin
in	Inch
km	Kilometers
L	Liters
m	Meters
M	molar
MANA	Manassas National Battlefield Park
MBSS	Maryland Biological Stream Survey
MD	Maryland
MD DNR	Maryland Department of Natural Resources
MDE	Maryland Department of the Environment
MDL	Method Detection Limit
meq/L	Milliequivalent per liter
Mg	Magnesium
mg/L	Milligrams per liter (equivalent to parts per million)
Mgal/d	Million gallons per day
mi	Miles
mL	Milliliters
MONO	Monocacy National Battlefield
MSDS	Material Safety Data Sheets
MV	Millivolts
N	Normality
NACE	National Capital Parks - East
NAWQA	National Water Quality Assessment (USGS Program)
NCRN	National Capital Region Network Inventory and Monitoring Program
NGO	Nongovernmental organizations
NIST	National Institute of Standards and Testing
NO ₃	Nitrate
NPDES	National Point Discharge Elimination System
NPS	National Park Service
NPSTORET	National Park Service version of EPA's STORET database
NPS-WRD	National Park Service – Water Resources Division
NRC	Natural Resource Challenge
NTU	Nephelometric Turbidity Unit
NWIS	National Water Information System
ORP/Eh	Oxidation-Reduction Potential
PCB	Polychlorinated Biphenyls
PO ₄	Phosphate
POGO	Potomac Gorge, covers parts of CHOH and GWMP.
POPs	Persistent Organic Pollutants
POTW	Publicly Owned Treatment Work
ppb	Parts per billion (equivalent to microgram per liter)
ppm	Parts per million (equivalent to milligram per liter)
ppt	Parts per thousand
PRWI	Prince William Forest Park
pt	Pints

PVC	Polyvinyl Chloride
QA/QC	Quality assurance/quality control
ROCR	Rock Creek Park
SOPs	Standard Operating Procedures
STORET	STOrage and RETrieval (EPA's Water Quality database)
TDS	Total Dissolved Solids
TMDL	Total Maximum Daily Load
TOC	Total organic carbon
TSS	Total Suspended Solids
USDA	United States Department of Agriculture
USGS	United States Geological Survey
VA	Virginia
WASA	Washington Area Sewer Authority
WOTR	Wolf Trap National Park for the Performing Arts
WRD	Water Resources Division (National Park Service)
YSI	Yellow Springs Instruments

Executive Summary

Water chemistry is important to maintaining a healthy habitat for many aquatic organisms, wildlife, and humans. Water quality can provide insights into overall system productivity, shift species abundances and distributions, and alter nutrients cycles. Water quality parameters such as pH, specific conductance, dissolved oxygen, and temperature are good measurements that provide an overview of water quality. Water quality monitoring is required to comply with relevant environmental legislation and NPS mandates and to evaluate potential stressors in NCRN waters.

In 2005, the National Capital Region Inventory and Monitoring Network (NCRN) initiated a long-term water quality and quantity monitoring program, funded in part by the Water Resources Division. The program is carried out through monthly sampling, weather permitting (see Table 1) at more than 40 sites within 10 of the NCRN parks. The National Capital Region Network, 2009 Water Resources Monitoring Data Report focuses on data collected under the Water Chemistry Monitoring Protocol and Surface Water Dynamics Protocol of the National Capital Region Network (NCRN) Inventory and Monitoring (I&M) Program (Norris et al. 2008).

Parks monitored for this report include Antietam National Battlefield(ANTI), Catocin Mountain Park(CATO), Harpers Ferry National Historical Park(HAFE), George Washington Memorial Parkway(GWMP), Manassas National Battlefield Park(MANA), Monocacy National Battlefield(MONO), National Capital Parks – East (NACE), Prince William Forest Park(PRWI), Rock Creek Park(ROCR), and Wolf Trap National Park for the Performing Arts(WOTR). The streams monitored are all part of the Potomac River Watershed. The Potomac is the second largest drainage of the nine river basins that form the 64,000 square mile Chesapeake Bay watershed.

Table 1: Winter weather impeded sampling December 2008 through March 2009 and the following sites were not sampled.

December 2008	January 2009	February 2009	March 2009
CATO	CATO	CATO except Big Hunting Creek	MANA
GWMP	NACE except Henson Creek	GWMP	NACE
MANA	Wolf Trap Creek	MONO	
MONO		NACE	
NACE		WOTR	

Dissolved oxygen fell below the desired condition of 5.0mg/L October 2008 in Carter's Run, Mawavi Run and Orrenda Run (PRWI); Fenwick Branch, Rock Creek, and Pinehurst Branch (ROCR) had low readings in spring and summer 2007, and Soapstone Valley, Normanstone, and Rock Creek at Dumbarton (ROCR) had low readings in late summer 2008; and Taylor Run (PRWI) in September 2009. The rest of the stream sampled had sufficient oxygen to support aquatic life when measured.

Ammonia is low and frequently not detected in streams in NCR. Higher ammonia levels are associated with sewage spills and septic leaks in developed areas. Ammonia was only above aquatic health criteria of 0.443 mg/L in Big Hunting Creek in April 2009 in CATO; in Pimmit

Run (GWMP) where the threshold was exceeded in September 2009; in Youngs Branch (MANA) in April 2009; except Henson Creek (NACE) in January 2009; at Carter's Run, Mawavi Run, North Fork Quantico Creek, Orenda Run, and Taylor's Run (PRWI) in April 2009; and in Dumbarton Oaks (ROCR) in February 2009.

Nitrate was above desired condition always in ANTI and MONO; all GWMP sites in January, Minnehaha Creek (GWMP) throughout FY 2009, Pimmit Run (GWMP) in April and June, and Turkey Run June through September 2009; December 2008 – March 2009, and June and August 2009 in Flowing Springs (HAFE); Oxon Run (NACE) in April; ROCR streams are frequently above the desired level of 2.0 mg/L nitrate, the exceptions being November 2008 when Broad Branch, Fenwick Branch, Pinehurst Branch, Soapstone Valley Stream met the threshold and Dumbarton Oaks and Palisades Creek met the threshold in December 2008. Pinehurst Branch did not meet threshold February through June 2009. Rock Creek met the threshold half the year, except December – February, April, and August. Courthouse Creek exceeded nitrate threshold in January and April through September 2009. Wolf Trap Creek exceeded the threshold in April and September.

Streams of ANTI, CATO, GWMP, HAFE, PRWI, and WOTR always had too much phosphorus in FY 2009. Youngs Branch exceeded the total phosphorus threshold in October 2008, and July and August 2009 in MANA. Total phosphorus in MONO streams always exceeded the threshold except for Gambrill Mill Creek in June 2009. Only Still Creek met the threshold in October and November 2008 and Henson Creek in March 2009 in NACE streams; ROCR streams exceeded the threshold with the exception of Piney Branch in February.

ANC in Sharpsburg Creek (ANTI), Flowing Springs (HAFE), and Gambrill Mill and Bush Creek (MONO) was always well above the 600 $\mu\text{S}/\text{cm}$ threshold for karst areas. The higher ANC values for these streams are due to dissolution of the limestone and dolomite bedrock. ANC was always well above the threshold of 200 $\mu\text{eq}/\text{L}$ for non-karst streams in CATO; in GWMP except for March 2009 when Mine Run, Pimmit Run, and Turkey Run values were at or barely above 200 $\mu\text{eq}/\text{L}$; in PRWI streams except in Carter's Run and Orenda Run, which were never above the detection limit of 10 $\mu\text{eq}/\text{L}$; all sites in ROCR and NACE met the ANC threshold of 200 $\mu\text{eq}/\text{L}$ for buffered non-karst waters.

The pH was always within the range comfortable to aquatic life (6.5 and 9) at or slightly above 8 (8.09 – 8.32) in Sharpsburg Creek (ANTI) and Flowing Springs (HAFE), whereas pH in Bush Creek and Gambrill stream exceeded threshold a number of times. The higher pH of Bush Creek, Gambrill Stream, Sharpsburg Creek and Flowing Spring Run are due to dissolution of the limestone and dolomite bedrock. This may also contribute to the higher specific conductance, though fertilizers, pesticides, and livestock runoff may also contribute. Limestone (CaCO_3) and dolomite ($\text{CaMg}(\text{CO}_3)_2$) are ionic salts that dissociate in pure water to their constituent ions: Ca^{2+} and CO_3^{2-} ; $\text{Ca}^{2+} + \text{Mg}^{2+} + 2 \text{CO}_3^{2-}$. Groundwater in karst areas can also contain sulfate ions from gypsum beds and weathered sulfite materials, chlorides from deeper circulating ground water and seawater mining, sodium, potassium, dissolved oxygen. Hilderbrand et al. (2005) speculated the high pH recorded at some water quality sampling sites may be in response to agricultural lime applications in the area. This increase in dissolved ions also increases the specific

conductance (White 1998). pH tends to be at the low end of desirable condition in PRWI streams: Carter's Run is always acidic and below the lower threshold of 6.5, Mawavi Run and Taylor Run were below the 6.5 threshold for the first half of FY09, North and Middle Branches of Chopawamsik were less than 6.5 on one occasion each in 2009. There were 2 incidents of unusually high pH, South Fork Quantico Creek in September 2006 and Mary Bird Branch in August 2006. Streams of ROCR, CATO, GWMP, NACE and WOTR all fell within this range.

Specific conductance always exceeded the threshold in Flowing Springs. Specific conductance is lower in Monocacy streams than it is in HAFE or ANTI. This may be due to differences in the chemistry and physical extent of the two areas of karst terrain. The threshold exceedances for Gambrill Mill Creek may be due to adjacent pollution sources (former Visitor's Center septic field for Gambrill Mill Creek). PRWI and CATO stream shave the lowest specific conductance in the region, well within the desired range for aquatic life. Specific conductance is usually below the current threshold of 400 $\mu\text{S}/\text{cm}$ for all GWMP sites except Minnehaha Creek which was always high, and Pimmit and Turkey Runs in late winter 2008. Young's Branch (MANA) exceeded the specific conductance threshold at some time. In NACE, the unnamed tributary of Accokeek Creek was never above threshold; Henson Creek and Oxon Run were at or above the threshold October through April and again in August; Still Creek was at or above threshold March and April; and Henson Creek showed a typical stream response to wintry weather with a spike of 3500 $\mu\text{S}/\text{cm}$ in January 2009, most likely due to road salt or other deicing compounds. The sampling site on Henson Creek is downstream from a military landing strip. It is possible that the stream is receiving runoff of airplane and other vehicle deicing compounds in the winter. In WOTR only Courthouse Creek exceeded the threshold for specific conductance, once in March.

Salinity exceeded the freshwater defining point of 0.5 ppt in NACE in January in Henson Creek and March in Still Creek; in Carter's Run (PRWI) in January 2009; in ROCR in February when Broad Branch, Soapstone Valley Stream, and Hazen Creek had salinities around 0.6. ANTI, CATO, GWMP, HAFE, MANA, MONO, WOTR were always freshwater.

Water Temperature follows expected seasonal trends and stays within the comfort range of most aquatic organisms in most streams sampled in NCRN. The exception was Oxon Run exceeding 25° C in July 2009. In conclusion, ten of 41 streams had instances of low DO. DO is occasionally of concern in select streams. Nitrate and phosphorus are of concern at most sites. pH and ANC are only of concern at sites that are geologically prone to low values for both and therefore naturally more susceptible to anthropogenic impacts such as acid rain (CATO and PRWI).

Table 2: Sites with sufficient depth for flow and discharge measurements, by month

10/2009	3/2010	4/2010	5/2010	6/2010	7/2010	8/2010
		ANTI		ANTI	ANTI	
CATO Big Hunting Creek		CATO Big Hunting Creek Whiskey Still Creek	CATO Big Hunting Creek Owens Creek	CATO Big Hunting Creek	CATO Big Hunting Creek	CATO Big Hunting Creek
GWMP Minnehaha Creek Pimmit Run		GWMP Minnehaha Creek Pimmit Run Mine Run	GWMP Minnehaha Creek Pimmit Run Mine Run Turkey Run	GWMP Minnehaha Creek Pimmit Run Mine Run	GWMP Minnehaha Creek Pimmit Run Mine Run Turkey Run	
HAFE	HAFE			HAFE	HAFE	
					MANA	MANA
MONO Bush Creek		MONO Bush Creek	MONO Bush Creek	MONO Bush Creek	MONO Bush Creek	MONO Bush Creek
		NACE Oxon Run Henson Creek Still Creek	NACE Oxon Run Henson Creek Still Creek	NACE Henson Creek Still Creek	NACE Oxon Run Henson Creek Still Creek	
	PRWI			PRWI		PRWI
ROCR		ROCR	ROCR	ROCR		ROCR
WOTR Wolf Trap Creek			WOTR Wolf Trap Creek	WOTR Wolf Trap Creek	WOTR Wolf Trap Creek	

For the 2009 sampling year and beyond, Difficult Run will be dropped from the sampling design, due to the fact that VA DEQ lists it as a 5th order stream in their annual stream quality reporting. Youngs Branch (MANA) and Carters Run and Mary Bird Branch (PRWI) went dry in September 2009 (see Table 2). One of the recommendations of the WRD review panel in 2008 was “The network should do the most robust, quantitative flow (discharge measures) at a few high quality index sites. These fewer, higher quality flow measurement sites would be the only ones where the network would statistically analyze for long term trends.” We continue to hope to identify sites with sufficient depth for monthly long-term flow measurements.

Introduction

Almost all of the parks in the National Capital Region Inventory and Monitoring Network (NCRN I&M) lie within the Potomac River watershed with the exception of parts of the Suitland Parkway and Baltimore and Washington Parkway within National Capital Parks – East (NACE), which are located in the Patuxent River watershed.

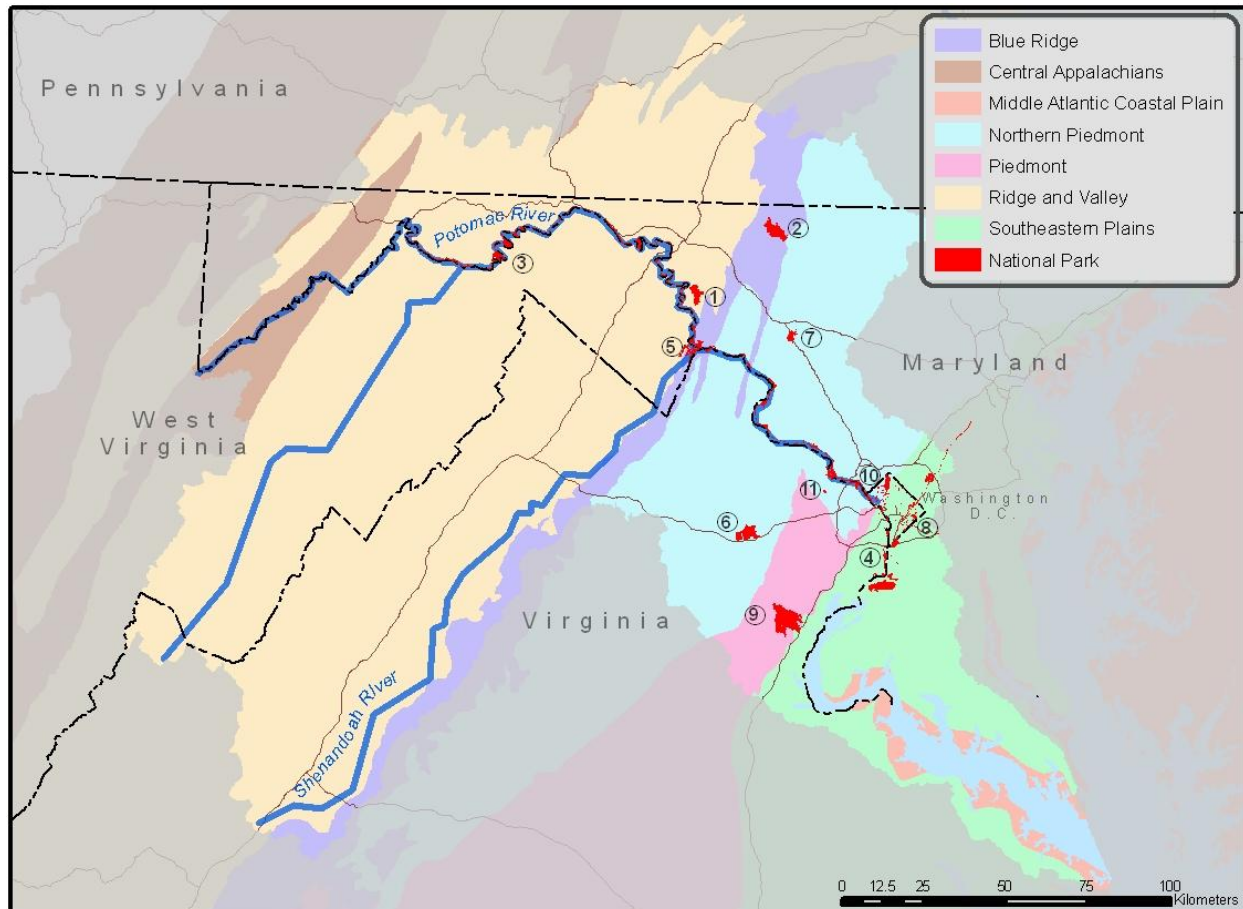


Figure 1 : Locations of the National Parks (red) in the National Capital Region Network within the Potomac River (brighter outline within map) and Patuxent River watersheds. The Level III Ecoregions (Woods et al. 1999) are indicated by the pastel areas:

1. Antietam National Battlefield (ANTI)
2. Catoclin Mountain Park (CATO)
3. Chesapeake & Ohio Canal National Historical Park (CHOH)
4. George Washington Memorial Parkway (GWMP)
5. Harpers Ferry National Historical Park (HAFE)
6. Manassas National Battlefield Park (MANA)
7. Monocacy National Battlefield (MONO)
8. National Capital Parks–East (NACE)
9. Prince William Forest Park (PRWI)
10. Rock Creek Park (ROCR)
11. Wolf Trap National Park for the Performing Arts (WOTR)

The Potomac River Watershed covers seven physiographic provinces and subprovinces: Blue Ridge, Central Appalachians, Middle Atlantic Coastal Plain, Northern Piedmont, Piedmont, Ridge and Valley, and the Southeastern Plains (Figure 1). Though several parks (CHOH, GWMP, HAFE, NACE), are adjacent to the river, the parks do not manage the waters of the Potomac. The Potomac is the second largest drainage of the nine river basins that form the 64,000 square mile Chesapeake Bay watershed. The Chesapeake Bay is the largest estuary in the United States, providing habitat for abundant and diverse wildlife populations and supporting an economy that includes fishing, shipping, and recreation (Burke et al. 1999). The National Park Service is a co-signer of the Chesapeake Bay Agreements for restoration of the Chesapeake Bay.

The NCRN's long-term water monitoring program, funded in part by the Water Resources Division (WRD), is designed to ensure the National Capital Region's (NCR) parks possess science-based information needed for effective natural resource management. To achieve this, program staff collect data for the following vital signs¹:

- water chemistry
- nutrient dynamics
- surface water dynamics
- physical habitat index
- aquatic macroinvertebrates
- fish

A Water Chemistry Monitoring Protocol was developed by NCRN which includes nutrient dynamics (Norris et al. 2008). In collaboration with the United States Geological Survey (USGS), NCRN also developed a Surface Water Dynamics protocol. The NCRN Biological Stream Survey (BSS) (Norris and Sanders 2009), which includes as vital signs the physical habitat index (PHI), aquatic macroinvertebrates, and fish was adapted from the Maryland Biological Stream Survey in collaboration with researchers from Frostburg State University and The Maryland Department of Natural Resources (Kazyak et al. 2007). This report will contain regional water chemistry and surface water dynamics data. Data analysis on the Biological Stream Survey (BSS) data will be published every six years when a full survey of the parks is completed. The next BSS report is expected in 2014.

Measurable Objectives of the Water Chemistry and Quantity Monitoring Protocol:

1. Assess variance in temperature, specific conductance, pH, dissolved oxygen, nutrients and Acid Neutralizing Capacity (ANC) in priority streams of the NCRN, on a diurnal and seasonal basis as well as over the long term
2. Assess trends in temperature, specific conductance, pH, dissolved oxygen, nutrients and ANC within and between watersheds and stream orders with reference to (a) urban reference streams drawn from Maryland Biological Stream Survey (MBSS) and/or National Water-Quality Assessment Program (NAWQA) data in the region and/or (b) comparison of current to past condition.

¹ Vital signs are selected physical, chemical, and biological elements and processes of park ecosystems that represent the overall health or condition of the park.

3. Assess stream condition by identifying single parameters with values out of bounds (a) biologically (determined through literature reviews), (b) according to drinking water standards, (c) according to Environmental Protection Agency (EPA) and State designated use standards, or (d) of previous variability
4. Monitor the flow volume (discharge) of surface water in select streams of the NCRN parks.
5. Assess the availability of sufficient water for ecological, recreational, and aesthetic purposes of the parks.
6. Develop rating curves for a range of environmental conditions, land use, and weather patterns, for each water body (e.g., a drought year vs. an El Niño year) in order to gain an overall understanding of hydrologic systems within the NCRN.
7. Determine seasonal and annual trends.
8. Provide support data for other Vital Signs indicators in order to help understand trends in aquatic species populations, pollution transport, erosion/deposition, and other natural processes and features.
9. Share data with state and local groups for calculation of Total Maximum Daily Loads (TMDL) and other regulatory decision-making purposes.

Methods

Sampling Design

The Water Quality Monitoring Program funded by WRD is primarily interested in 1st to 4th order wadeable non-tidal freshwater streams in the parks of NCRN. The sample design for streams is based on stream location (defined at a scale of 1:24,000) bisected by park boundaries. Since water chemistry monitoring sites serve as the pool from which the biological sampling sites are chosen, in-park stream segments less than 75m long were eliminated (the length used for MBSS sampling). Sampling of streams focuses on those segments of streams that are the furthest downstream and still in park boundaries. Measurements downstream generally reflect conditions in the watershed upstream. It was initially envisioned that once the list of potential monitoring locations was developed; a randomization process would be used to determine which sites would be sampled. However the final list was short enough that rather than a random subset, all sites are sampled.

During the FY 2009 sampling season a total of 41 sites were sampled (Table 1). Eleven additional sites that were initially rejected due to uncertainty about their flow status (perennial or ephemeral), were added in the 2007-2008 sampling season. In 2009 one stream was dropped because it exceeded wadeable stream order (Difficult Run, GWMP, is listed by the state as a 5), five were dropped because they were not perennial (Harding Run, MONO; Chinns Branch, Dogans Branch and Holkums Branch, MANA; Ft. Dupont Stream, NACE), and one was dropped for a better site farther downstream (Rock Creek, ROCR).

Table 2 Water Chemistry Monitoring Sites for 2009 excluding CHOH streams

Site	Watershed	Physiographic Region	State	County	Stream Order
Antietam National Battlefield					
Sharpsburg Creek	Antietam Creek	Ridge and Valley	MD	Washington	1
Catoctin Mountain Park					
Big Hunting Creek	Upper Monocacy River	Blue Ridge	MD	Frederick	2
Owens Creek	Upper Monocacy River	Blue Ridge	MD	Frederick	2
Whiskey Still Creek	Upper Monocacy River	Blue Ridge	MD	Frederick	1
George Washington Memorial Parkway					
Minnehaha Creek	Cabin John	Northern Piedmont	MD	Montgomery	2
Mine Run	Difficult Run	Northern Piedmont	VA	Fairfax	2
Pimmit Run	Rock Creek	Northern Piedmont	VA	Arlington	3
Turkey Run	Difficult Run	Northern Piedmont	VA	Fairfax	2
Harpers Ferry National Historical Park					
Flowing Springs Run	North Fork Shenandoah River	Ridge and Valley	WV	Jefferson	2
Manassas National Battlefield					
Youngs Branch	Bull Run	Northern Piedmont	VA	Prince William	3
Monocacy National Battlefield					
Bush Creek Visitor's Center Creek	Lower Monocacy River	Northern Piedmont	MD	Frederick	3
Visitor's Center Creek	Lower Monocacy River	Northern Piedmont	MD	Frederick	2
National Capital Parks – East					
Henson Creek	Middle Potomac Tidal	Southeastern Plains	MD	Prince Georges	1
Oxon Run	Middle Potomac Tidal	Southeastern Plains	MD	Prince Georges	1
Still Creek	Anacostia River	Southeastern Plains	MD	Prince Georges	1
Unnamed Tributary to Accokeek Creek	Middle Potomac Tidal	Southeastern Plains	MD	Prince Georges	1
Prince William Forest Park					
Carter's Run	Quantico Creek	Southeastern Plains	VA	Prince William	1
Mawavi Run	Quantico Creek	Piedmont	VA	Prince William	1
Mary Bird Branch	Quantico Creek	Southeastern Plains	VA	Prince William	2
Middle Branch Chopawamsic Creek	Quantico Creek	Piedmont	VA	Prince William	2
North Branch Chopawamsic Creek	Quantico Creek	Piedmont	VA	Prince William	2
North Fork Quantico Creek	Quantico Creek	Southeastern Plains	VA	Prince William	2
Orenda Run	Quantico Creek	Piedmont	VA	Prince William	1
South Fork Quantico Creek	Quantico Creek	Southeastern Plains	VA	Prince William	3
Sow Run	Quantico Creek	Piedmont	VA	Stafford	2
Taylor Run	Quantico Creek	Piedmont	VA	Prince William	1
Rock Creek Park					
Broad Branch	Rock Creek	Northern Piedmont	DC	Washington	2
Dumbarton Oaks	Rock Creek	Northern Piedmont	DC	Washington	1
Fenwick Branch	Rock Creek	Northern Piedmont	DC	Washington	2
Hazen Creek	Rock Creek	Northern Piedmont	DC	Washington	1

Site	Watershed	Physiographic Region	State	County	Stream Order
Klinge Valley Stream	Rock Creek	Northern Piedmont	DC	Washington	1
Luzon Branch	Rock Creek	Northern Piedmont	DC	Washington	1
Normanstone Creek	Rock Creek	Northern Piedmont	DC	Washington	1
Palisades Creek	Rock Creek	Northern Piedmont	DC	Washington	1
Pinehurst Branch	Rock Creek	Northern Piedmont	DC	Washington	1
Piney Branch	Rock Creek	Northern Piedmont	DC	Washington	1
Rock Creek above Fenwick Branch	Rock Creek	Northern Piedmont	DC	Washington	4
Rock Creek below Dumbarton Oaks	Rock Creek	Northern Piedmont	DC	Washington	4
Soapstone Valley Park Stream	Rock Creek	Southeastern Plains	DC	Washington	1
Wolf Trap National Park for the Performing Arts					
Wolf Trap Creek	Difficult Run	Northern Piedmont	VA	Fairfax	2
Courthouse Creek	Difficult Run	Northern Piedmont	VA	Fairfax	1

No sites are monitored in CHOH at this time. The linear nature of the park and the large number of streams that cross it provide additional challenges to water monitoring. Each individual stream is within the park for only a short distance, and drains only a small portion of the park. Due to these factors the park has little control over the water quality of most of these streams, and each individual stream has a small impact on the park as a whole. Therefore it is difficult to design an appropriate sampling effort that proved both affordable and meaningful. However, the unique orientation of the park and its length may actually be a benefit with respect to water sampling. The state of Maryland's Department of Natural Resources (MD DNR) has a comprehensive biological sampling program (MBSS) that is spatially and temporally designed to provide statistically valid estimates of stream health across the state and within specific watersheds based on a stratified random sampling design. The MBSS is the basis of our biological sampling and the data is comparable. Therefore, this data can be used to assess the waters of CHOH.

Sampling Frequency and Replication

All parameters are measured monthly as weather and site access permits. Any gaps in sampling data are described along with each park's monitoring results and are summarized for the year in the Executive Summary.

Data Collection

We collect data for temperature, dissolved oxygen (DO), specific conductance, pH, acid neutralizing capacity (ANC), nutrients (ammonia, nitrate, and total phosphorus), and flow (Norris et al. 2008). These parameters provide information that characterize a waterbody or stream segment, are fundamental components of monitoring and regulatory programs, and are relatively easy to measure with multi-parameter probes or Hach test kits. The Water Resources Specialist and Hydrologic Technician collect in situ data with handheld meters once a month at every perennial wadeable stream in the parks (Table 1) for temperature, dissolved oxygen, specific conductance, and pH. At the same time samples are collected and brought back to the lab for acid neutralizing capacity analysis by titration with Hach reagents, and ammonia, nitrate,

and total phosphorus analysis using Hach reagents and spectrophotometer. These parameters provide information that characterize a waterbody or stream segment, are fundamental components of monitoring and regulatory programs, and are relatively easy to measure with multi-parameter probes or Hach test kits. Sites are photographed during each sampling visit to provide a visual record of existing conditions.

Parameters

Surface Water Quality is important to maintaining a healthy habitat for many aquatic organisms, wildlife, and humans. Water Quality can provide insights into overall system productivity, shift species abundances and distributions, and alter nutrients cycles. Parameters such as pH, specific conductance, dissolved oxygen, and temperature are good indicators of water quality. Water quality monitoring is required to comply with relevant environmental legislation and NPS mandates and to evaluate potential stressors in NCRN waters.

The NCRN collects data for water temperature, dissolved oxygen, specific conductance, pH, acid neutralizing capacity, ammonia, nitrate, total phosphorus, wetted width, water depth, flow, and discharge (Table 2). These parameters provide information that characterize a water body or stream segment, are fundamental components of monitoring and regulatory programs, and are relatively easy to measure with multi-parameter probes or Hach test kits. Parameters are described in detail below. Park specific information for each parameter is included in each park's summary.

Table 2: Date range, number of site visits (N), and data range for the information covered in this report.

Parameters	Units	Period of Record	N	Minimum	Maximum	Mean	Median	Standard Deviation
ANC	µeq/l	10/7/2008 - 9/29/2009	330	202	6680	1488	1324	1132
Discharge	cfs	10/7/2008 - 9/29/2009	85	0.002	57.960	5.264	2.040	9.071
Dissolved Oxygen	mg/l	10/7/2008 - 9/29/2009	348	2.28	19.80	9.44	8.95	2.68
Flow	ft/sec	10/7/2008 - 9/29/2009	85	0.0012	13.5000	0.7559	0.4868	1.4810
Nitrate	mg/l	10/7/2008 - 9/29/2009	351	0.2	8.0	2.2	1.8	1.5
Ammonia	mg/l	10/7/2008 - 9/29/2009	147	0.031	1.900	0.142	0.062	0.244
pH	None	10/7/2008 - 9/29/2009	350	5.48	9.04	7.56	7.60	0.53
Total Phosphorus	mg/l	10/7/2008 - 9/29/2009	351	0.03	1.07	0.27	0.23	0.16
Salinity	ppt	10/7/2008 - 9/29/2009	353	0	1.85	0.21	0.20	0.18
Specific Conductance	µS/cm	10/7/2008 - 9/29/2009	353	35.88	3490.00	424.00	368.00	353.40
Water Depth	ft	10/7/2008 - 9/29/2009	113	0.106	3.360	0.461	0.379	0.369
Water Temperature	°C	10/7/2008 - 9/29/2009	354	0.15	25.95	13.79	15.10	6.32
Wetted Width	ft	10/7/2008 - 9/29/2009	316	0	89	15	13	12

pH

The pH of water directly affects physiological functions of plants and animals, and is, therefore, an important indicator of the health of a water system (U.S. Geological Survey 1980, Stednick and Gilbert 1998). pH is measured to determine the acid/base characteristics of water and is controlled by interrelated chemical reactions that produce or consume hydrogen ions (Hem 1989). The term pH literally means “power of hydrogen.” The more hydrogen ions that are

available for reaction, the lower the pH. The concentration of these ions is measured on a log scale that most commonly ranges from 0 (acid) to 14 (base / alkaline), so each pH unit increase represents a 10X decrease in hydrogen ion concentration. Pure water has a pH of 7 (neutral), which means that it is equally able to accept or donate hydrogen ions. At $\text{pH} < 7$, (acid) hydrogen ions are more readily donated (Hem 1989, Stednick and Gilbert 1998).

Generally, dissolution of carbon dioxide to carbonic acid is the most important acidifying factor in extremely fresh natural waters to affect pH ($\sim \text{pH}$ of 6) in the absence of some other site-specific conditions. However, most natural (fresh and salt) waters are slightly basic ($\sim \text{pH}$ of 8) due to the presence of carbonates (CO_3^{2-}) and bicarbonates (HCO_3^-). In freshwater, the $\text{CO}_2 \rightleftharpoons \text{HCO}_3^- \rightleftharpoons \text{CO}_3^{2-}$ equilibrium serves as the primary buffering mechanism. In natural waters, carbonic acid is the main source of hydrogen ions, resulting in a pH of 5.7. Rain-water normally is acid because of its carbon dioxide content and naturally occurring sulfate. Normally these acids are neutralized as rain-water passes through the soil. In catchments of hard rocks, little buffering capacity, and high surface water (as opposed to groundwater) inputs, stream water will be acid even if pollution is absent. Organic acids also contribute to low pH values. Industrial activity has contributed to acid precipitation in many areas. Strong inorganic acids H_2SO_4 and HNO_3 , formed in the atmosphere from oxides of sulfur and nitrogen, have dramatically lowered surface water pH in large areas of Europe and North America, especially in granitic drainages with poor buffering capacity (Hem 1989, Stednick and Gilbert 1998).

The pH of water is important in the toxicity and solubility of many constituents. The ideal natural range of pH for aquatic life in streams is 6.5 to 9. Freshwaters can vary widely in acidity and alkalinity due to natural causes as well as anthropogenic inputs. Extreme pH values, generally those much below 5 or above 9, are harmful to most organisms, and the buffering capacity of water is critical to life. Estimating the toxicity of ammonia, aluminum, and some other contaminants requires accurate pH values. Increases or decreases in pH from their normal range into extreme ranges can result in severe harm to aquatic life (Hem 1989). Changes in pH affect the dissociation of weak acids or bases, which in turn affects the toxicity of many compounds. For example, hydrogen cyanide toxicity to fish increases with lowered pH; rapid increases in pH increase NH_3 concentrations; and the solubility of metal compounds is affected by pH. Metals mobility is also enhanced by low pH which can have a significant impact to water bodies located in areas contaminated by heavy metals (e.g. mining). The desired range of pH for fish depends upon many other factors such as temperature, DO, and the content of various anions and cations. The importance of pH as a parameter for monitoring is reflected by potential impacts to the life cycle stages of aquatic macroinvertebrates and certain salmonids that can be adversely affected when pH levels above 9.0 or below 6.5 occur. Temporal causes of variation of pH can range from primary production by fauna and flora (diurnal and seasonal) to fractionation during snowmelt, changes in runoff processes, and changes in atmospheric deposition (monthly and/or seasonal) (MacDonald et al. 1991).

Limestone (CaCO_3) and dolomite ($\text{CaMg}(\text{CO}_3)_2$) are ionic salts that dissociate in pure water to their constituent ions: Ca^{2+} and CO_3^{2-} ; $\text{Ca}^{2+} + \text{Mg}^{2+} + 2 \text{CO}_3^{2-}$. Groundwater in karst areas can also contain sulfate ions from gypsum beds and weathered sulfite materials, chlorides from deeper circulating ground water, sodium, potassium, dissolved oxygen. There is another background carbonate-bicarbonate-carbonic acid dissolution equilibrium that occurs in most

fresh surface waters and provides the buffering against low pH that is known as acid neutralizing capacity. The carbonates and bicarbonates that occur in surface waters neutralize the pH to between 6.5 and 7.5. The calcite and dolomite ions' dissolution increases this carbonate buffering, increasing the pH of the water above neutral to 8 and even 9. This increase in dissolved ions also increases the specific conductance.

NCRN used a Yellow Springs Instruments, Inc. handheld meter, model number 63, and a Pro Plus meter to measure the pH at each site in FY 2009.

Acid Neutralizing Capacity (ANC)

ANC is the prime indicator of a waterbody's susceptibility to acid inputs. ANC is a measure of the amount of carbonate and other compounds in the water that neutralize low pH. ANC refers to the alkalinity of an unfiltered water sample (i.e. alkalinity due to both dissolved and suspended matter). The pH of water does not indicate its "buffering capacity", which is controlled by the amounts of alkalinity and acidity present. ANC is typically caused by anions in natural waters that can enter into a chemical reaction with a strong acid. These are primarily the carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) ions. Dissolution of these species is most typically caused by the partial pressure of CO_2 in the atmosphere but their presence may be further elevated in areas of carbonate rock dissolution where waters are often of a bicarbonate type (elevated in HCO_3^-). Borates, phosphates, silicates, arsenate, ammonium, and organic ligands (e.g. acetate and propionate) can also contribute to alkalinity when present. However, except for unusual natural waters or waters significantly impacted by anthropogenic sources, non-carbonate ionized contributors are rarely present in large enough quantities to affect alkalinity or ANC determinations (Wilde and Radtke 1998). It is particularly important to measure in areas where acid mine drainage (e.g. PRWI) or acid precipitation (entire NCR) is a potential concern. Acid sensitive waters generally have specific conductance below 25 $\mu\text{S}/\text{cm}$, acid neutralizing capacity (ANC) below 100 $\mu\text{eq}/\text{L}$ for episodic acidification (50 $\mu\text{eq}/\text{L}$ for chronic acidification), total base cation (calcium, magnesium, sodium, and potassium) concentration below 100 $\mu\text{eq}/\text{L}$, and pH below 6.0. Turk and Spahr (1989) state that surface waters with ANC less than or equal to 200 $\mu\text{eq}/\text{L}$ are considered sensitive to acidification. In karst terrain, ANC below 600 $\mu\text{eq}/\text{L}$ CaCO_3 is cause for concern (Turk and Spahr 1989). NPS-WRD (National Park Service 1995, 1996, 1997) indicates that surface waters in three parks—Antietam National Battlefield, Chesapeake and Ohio Canal National Historical Park and Manassas National Battlefield were not susceptible to acidification from atmospheric deposition. However this data ranges in age from 8 to 30 years and circumstances may have changed.

In FY 2009 NCRN used Hach Alkalinity Method 8203 (Sulfuric Acid Method) to determine phenolphthalein and total alkalinity which are used to calculate the acid neutralizing capacity.

Specific conductance

Specific conductance is the electrical conductivity of an aqueous solution (in this case stream water) and is directly related to concentration of ionic species. Conductivity is a measure of the capacity of water to conduct an electrical current and is a function of the types and quantities of dissolved, electrically charged substances (ions) in water (Radtke et al. 1998). The conductivity of solutions of ionic species is highly dependent on temperature and may change as much as 3%

for each 1°C change. Thus a significant apparent change in conductivity may simply be a function of the water body's diurnal or seasonal temperature change. In addition, the temperature correction coefficient itself varies with the charge and abundance of the ionic species present (e.g. Na⁺ vs Ca²⁺) so no universally applied algorithm will be exact. A raw conductivity value is not temperature compensated making it difficult to compare measurements of the same or different water bodies when not at the same temperature (e.g. conducting trend analysis over time). When the raw conductivity measurement of a substance is normalized to unit length and unit cross-section at a specified temperature (e.g. a compensation temperature of 25 °C), it is called specific conductance (U.S. Geological Survey 1980, Stednick and Gilbert 1998, National Park Service 2002). Specific conductance is dependent upon the types and quantities of dissolved substances and is a good indication of total dissolved solids (TDS) and total ion concentration.

Specific conductance is useful in estimating the concentration of dissolved solids in water. Electric current is carried by dissolved inorganic solids such as chloride, carbonate, nitrate, sulfate and phosphate anions (negatively charged particles), as well as sodium, calcium, magnesium, potassium, iron, and aluminum cations (positively charged particles). Common sources of pollution that can affect specific conductance are deicing salts, dust reducing compounds, agriculture (primarily from the liming of fields) and acid mine drainage (AMD) associated with mining operations (U.S. Geological Survey 1980, Stednick and Gilbert 1998, National Park Service 2002). Organic materials such as oils, phenols, alcohols, and sugars do not carry electric current.

The electrical conductivity of a water body has little or no direct effect on aquatic life but because it is essentially due to the sum of all ionic species, its change (increase) may be detrimental if the particular ionic species or groups of ionic species (e.g. specific salts) causing the change is toxic to aquatic life. Small quantities of mineral salts are usually contained in natural inland waters, but in waters polluted by brines and various chemical wastes, salt concentrations may rise to levels harmful to living organisms due to the increase in osmotic pressure. Salinity is often expressed as specific electrical conductance in studies of waters used for irrigation and fish production. Collectively, all substances in solution exert osmotic pressure on the organisms living in it, which in turn adapt to the condition imposed upon the water by its dissolved constituents. With excessive salts in solution, osmotic pressure becomes so high that water may be drawn from gills and other delicate external organs resulting in cell damage or death of the organism (U.S. Geological Survey 1980, Stednick and Gilbert 1998, National Park Service 2002). The Maryland Biological Stream Survey has found that fish exhibit stress at specific conductances greater than 400 µS/cm (Morgan II and Cushman 2005).

NCRN averaged multiple measurements displayed by both YSI handheld meters, model numbers 63 and 85, and used a YSI Pro Plus in FY 2009 to determine the specific conductance at each site.

Salinity

Salinity is an important unit-less property of industrial and natural waters. It was originally conceived as a measure of the mass of dissolved salts in a given mass of solution. The only reliable way to determine the true or absolute salinity of natural water is to make a complete

chemical analysis. However this method is time-consuming and precision is limited. To determine salinity one normally uses indirect methods involving the measurement of a physical property such as conductivity, density, sound speed, or refractive index. From an empirical relationship of salinity and the physical property determined for a standard solution it is possible to calculate salinity. The resultant salinity is no more accurate than the empirical relationship. The precision of the measurement of a physical property will determine the precision in salinity. Although conductivity has the greatest precision (± 0.0002), it responds only to ionic solutes. Density, though less precise ($\pm 3 \times 10^{-6} \text{ g/cm}^3$), responds to all dissolved solutes (Eaton et al. 2005).

Salinity refers to the sum of the concentrations of all dissolved ions, and so is a more inclusive term than total dissolved solids (TDS), although for all practical purposes it is the same quantity. In urban areas, the runoff of salts and other deicing compounds applied to roads can significantly elevate the salinity of receiving waters and cause large fluctuations at short time scales. In the United States, some 1-15 million tons of road salt are used each year (Benbow and Merritt 2005), primarily in the Northeast and Midwest, and quantities have increased dramatically since 1950 (Jackson and Jobbágy 2005). Kaushal et al. (2005) report chloride concentrations as high as 25% of seawater in some northeastern streams during winter, and the long-term trend is increasing (Allan and Castillo 2007). Freshwater is defined as 0.5 ppt salinity or less. Water with a salinity above 0.5 ppt is considered brackish (Allan and Castillo 2007).

NCRN averaged multiple measurements displayed by both YSI handheld meters, model numbers 63 and 85, and used a YSI Pro Plus in FY 2009 to determine the salinity at each site.

Nitrogen

Nitrogen in surface water may occur in dissolved or particulate form and result from inorganic or organic sources. The dissolved, inorganic forms of nitrogen most available for biological uptake and chemical transformation that can lead to eutrophication of water bodies are ammonia (NH_3), ammonium ion (NH_4^+), nitrate (NO_3^-), and nitrite (NO_2^-). NCRN monitors ammonia and nitrate.

Ammonia

Ammonia is a major limiting nutrient in most aquatic systems, an increase of which may result in eutrophication. It is typically indicative of agricultural pollution or anaerobic degradation of nitrogen containing compounds such as humic matter or urea from animal or human waste (agricultural waste lagoons or publicly owned treatment works). Ammonia (NH_3) is a more toxic form of nitrogen with an aquatic life toxicity that varies with pH and temperature.

Ammonia is also bioavailable to plants including phytoplankton. When ammonium ions are in high concentrations in natural waters containing oxygen, it is oxidized to nitrate by bacteria in the nitrification process. This microbial facilitated redox reaction consumes oxygen at a ratio of 4.5 mg of O_2 to every 1 mg of NH_4^+ , thus rapidly depleting available oxygen for aquatic organism respiration. At higher pH (above 7.5 or 8.0), the $\text{NH}_4^+ \rightleftharpoons \text{NH}_3$ equilibrium reaction begins to favor ammonia, which is directly toxic to aquatic life because it may be taken up through membranes, and interferes with cell metabolism. Higher temperatures also favor the uptake of ammonia (movement across membranes, e.g. gills) by aquatic organisms causing the CCC for aquatic organisms to be lowered as temperature increases. The lowest value for CCC is 0.442 mg/L NH_3 , which we use as our threshold (EPA 2000).

Ammonia is a difficult parameter to measure. We frequently get readings below zero and the estimated detection limit of ± 0.032 . Much of the data is excluded from analysis (206 of 343 readings in FY2009, see Table 2).

NCRN used Hach Methods 10023 (Nitrogen, Ammonia, Salicylate Method, Low-Range Test 'N Tube) and 10031 (Nitrogen, Ammonia, Salicylate Method, High-Range Test 'N Tube) to determine the concentration of ammonia in a sample in FY 2009.

Nitrate

Nitrate is the oxidized form of aqueous nitrogen reported as mg/l NO_3 or mg/l $\text{NO}_3 - \text{N}$. Nitrate is a bioavailable form of nitrogen which aquatic plants can absorb and incorporate into proteins, amino acids, nucleic acids, and other essential molecules. Nitrate is highly mobile in surface and groundwater and may seep into streams, lakes, and estuaries from groundwater enriched by animal or human wastes and commercial fertilizers. High concentrations of nitrate can enhance the growth of algae and aquatic plants in a manner similar to enrichment in phosphorous and thus cause eutrophication of a water body. Nitrate also presents a human health concern particularly to infants that can develop blue-baby syndrome at relatively low levels of nitrate in water supplies. In most natural waters, inorganic nitrogen as ammonium or nitrate is not the growth-limiting nutrient unless phosphorous is unusually high (see section below for sensor discussion). Nitrate is typically indicative of agricultural pollution. Nitrate in surface water is considered a nutrient and may occur in dissolved or particulate form resulting from inorganic sources. The dissolved, inorganic forms of nitrogen are most available for biological uptake and chemical transformation. The drinking water standard is 10 mg/L. Nitrate also travels freely through soil and therefore may pollute ground waters. Nitrate above 2.0 mg/L can lead to eutrophication of water bodies (EPA 2000).

NCRN used Hach Method 10020 (Nitrate, Chromotropic Acid Method, Test 'N Tube) to determine the concentration of nitrate in FY 2009.

Total Phosphorus

Total phosphorus is frequently a limiting nutrient in aquatic systems. A minor increase in phosphorous concentration can significantly affect water quality by changing the population and community dynamics of algae and diatoms leading to eutrophication (Allan 1995). Sources of phosphorous include sediments, fertilizer application (e.g. irrigation return flow), soaps, and detergents. The published threshold for eutrophication of flowing surface waters is 0.1 mg/L PO_4 (EPA 2000).

NCRN used Hach Method 8190 (Phosphorus, total, PhosVer 3 with Acid Persulfate Digestion, Low-Range Test 'N Tube) to determine the total phosphorus concentrations in FY 2009.

Dissolved Oxygen (DO)

DO is a measure of the amount of oxygen in solution. DO enters the water one of two ways—photosynthesis of plants and directly from the atmosphere via diffusion or mechanical aeration (e.g., waves, waterfalls). The primary losses of DO from water are respiration and biochemical

oxygen demand (BOD). Dissolved oxygen (DO) concentration of surface water is dependent on water temperature and air pressure, and, to a lesser extent, the amount of dissolved ions (measured as salinity or conductivity - correction factors for salinity are normally applied after measuring DO). The higher the pressure and cooler the temperature, the more oxygen from the atmosphere can be dissolved into the water until a balance or equilibrium is reached; this is called saturation (Hem 1989; Radtke et al. 1998). Oxygen has strong daily and seasonal variability. In organically enriched streams, DO is often lowest just before sunrise because plants have not been photosynthesizing and only respiration has been occurring. Conversely, DO increases after sunrise until the sun's angle of incidence is greatest because the rate of photosynthesis is dependent on sunlight. In less enriched streams, this pattern may be less apparent or absent because stream temperatures are lower at night and thus can contain more dissolved oxygen. Therefore it is important to always monitor a particular site at the same time of day. Because oxygen is sparingly soluble, the balance between sources and sinks can be easily upset leading to oxygen extremes of supersaturation or total/near total depletion (NPS-WRD 2002; Stednick and Gilbert 1998; USGS 1980).

DO is necessary in aquatic systems for the survival and growth of many aquatic organisms. The presence and amount of dissolved oxygen in surface water also determines the extent to which many chemical and biological reactions will occur (Wilde and Radke 1998). Low dissolved oxygen is of greatest concern due to detrimental effects on aquatic life. Conditions that generally contribute to low DO levels include warm temperatures, low flows, water stagnation and shallow gradients (streams), organic matter inputs, and high respiration rates. Decay of excessive organic debris that are in the water column from aquatic plants, municipal or industrial discharges, or storm runoff can also cause dissolved oxygen concentrations to be undersaturated or depleted. Insufficient DO can lead to unsuitable conditions for aquatic life, and its absence can result in the unpleasant odors associated with anaerobic decomposition. Furthermore, the presence of toxic substances such as cyanides and some metals can exacerbate the lethal effects of low concentrations of DO. Minimum required DO concentration to support fish varies because the oxygen requirements of fish vary with a number of factors, including the species and age of the fish, prior acclimatization, temperature, and concentration of other substances in the water.

It is essential that consideration of the natural regimes of DO be included in applying criteria to specific water bodies. Higher absolute concentrations of dissolved oxygen (mg/L) at saturation are achievable in the natural environment under conditions of higher atmospheric pressure and lower temperature and lower dissolved solids content of the water. Thus, water bodies occurring at higher elevations, subject to a barometric low pressure system, or having warmer temperatures and/or higher dissolved solids content would be expected to contain less dissolved oxygen at saturation. Supersaturation of surface water with respect to dissolved oxygen may also result from turbulence associated with high gradient streams or waterfalls. In rocky, high gradient streams, mechanical aeration is often great enough that even streams with highly elevated oxygen demand are at or near saturation levels. In low gradient coastal plain systems, even moderate oxygen demand (referred to as BOD or biochemical oxygen demand) can result in DO levels that are low enough to harm aquatic biota (NPS-WRD 2002; Stednick and Gilbert 1998; USGS 1980).

When DO drops below 5 mg/L early life stages and sensitive species become stressed. Because oxygen is sparingly soluble, the balance between sources and sinks can be easily upset leading to oxygen extremes of supersaturation or total/near total depletion (NPS-WRD 2002; Stednick and Gilbert 1998; USGS 1980).

NCRN used a Yellow Springs Institute (YSI) handheld meter model number 85 and a Pro Plus to measure the percent saturation and concentration of dissolved oxygen in FY2009.

Wetted Width

Wetted width is measured from water's edge to water's edge of the stream. NCRN has no defined desired value other than >0 feet. Wetted width is used to calculate discharge and determine the number of chemistry readings taken at a site. NCRN used a Lufkin fiberglass 50 meter tape to measure the wetted width in FY2009.

Depth

Depth is measured for every flow measurement location and averaged for that transect. Desired values are based on equipment requirements. The Flowtracker requires a minimum of 0.2 feet to function. The hydrolab and YSI continuous loggers require a minimum of 0.5 feet. NCRN used a Sontek Flowtracker wading rod to measure the depth in FY2009.

Flow

Flow is used to calculate discharge. NCRN has no defined desired value other than 0 ft/s. Streamflow at any point in time is an integration of the streamflow generation and routing mechanisms in a watershed at that time. This integration also defines the water quality at that time, including land use activities, point source discharges, and natural sources. Streamflow measurements are useful for water quality data comparisons over time, interpretation of water quality data, and calculation of parameter loads. Streamflow monitoring is necessary to calibrate and verify ground-water-flow models. Streamflow measurements are made periodically to define or verify the stage-discharge relation and to define the time and magnitude of variations in that relation. Understanding the relationship between flow and concentrations and loading helps determine when it is logical to concentrate sampling (Stednick and Gilbert 1998).

Surface Water Dynamics such as flow are also a key component in calculating chemical and physical loading of a flowing water body that are the basis for Total Maximum Daily Load (TMDL) studies. Data must be normalized by flow, especially in freshwater streams, because many constituents have strong relationships with flow (trend work in running waters is typically difficult unless one calculates flow-adjusted concentrations). NCRN used a Sontek Flowtracker to measure the flow in FY2009.

Discharge

We currently have no defined desired condition value other than >0 cfs.

Surface Water Dynamics such as flow or discharge for flowing waterbodies and stage or level for non-flowing waterbodies are in many instances a critical component of monitoring. The most

fundamental of hydrological measurements that characterize all river and stream ecosystems is that of discharge, the volume of water flowing through a cross section of a stream channel per unit time. The amount of water flowing past a given point, when combined with the slope of the stream channel, yields an indication of stream power or the ability of the river to do work. This potential energy is dissipated as frictional heat loss on the stream bed and when the stream picks up and moves material. The work performed by the stream is important to lotic ecologists because it influences the distribution of suspended sediment, bed material, particulate organic matter, and other nutrients. The distribution of these materials has substantial influence on the distribution of riverine biota (Vannote et al. 1980, Vannote and Minshall 1982, Statzner et al. 1988). In addition, discharge and stream power combine with other basin conditions to influence meander pattern and floodplain dynamics (Leopold et al. 1964, Gore 1996), which are important in providing habitat for flora and fauna.

Hydrographs show variation in discharge over time, and allow lotic scientists to examine characteristics that influence the watershed such as runoff and storage. A hydrograph can be plotted from gauging records to display yearly, monthly, daily, or instantaneous discharges (Gore 1996). A hydrograph can also provide information on daily and monthly total flow, mean monthly discharge, base (often groundwater maintained) flow, stage height, and periods of high and low flow.

Examination of the shape of a daily hydrograph during a storm event can indicate the condition of the stream and its watershed. The rising limb of the curve is usually concave and is an index of infiltration capacity of the watershed. In a small watershed, the time from the onset of precipitation to the rise in the ascending limb of the hydrograph curve represents the time to reach soil saturation. A watershed with a large storage capacity, absorptive surface, or large channel will have a lower stage-height peak than a similar size basin with little storage (e.g., small channel, lower vegetation density, more clay in soils, greater human development, etc.). Agricultural land produces a more rapid response in the hydrograph than woodlands (Gregory and Walling 1973) because densely wooded areas restrict surface flow and enhance infiltration. The shape of the hydrograph also reflects the longitudinal profile and watershed shape. A steep watershed gradient is reflected in a rapid response curve, whereas a gentle watershed gradient will produce a hydrograph with a slow and prolonged response curve. A watershed with many headwater streams but few tributaries in lower reaches will produce a hydrograph with a sharp flood peak. However, the peak is delayed from the onset of the precipitation event. An elongated watershed with many tributaries has a hydrograph that rises rapidly and falls over a longer period of time. A watershed with many subwatersheds often produces a hydrograph with several flood peaks depending upon distribution of rainfall in the area (Gore 1996). NCRN used a Sontek Flowtracker to measure discharge in FY2009.

Discussion of Findings

Each park will be discussed individually. The NCRN does not yet have enough data to observe seasonal trends. However we are evaluating the data in reference to water quality thresholds. These measures constitute a snap shot of stream conditions in time and space, and are not representative of quality over a 24 hour period. All of these measures are influenced to a certain degree by biological activity which follows diurnal and seasonal patterns of temperature and sunlight.

Antietam National Battlefield (ANTI)

The park is located near the town of Sharpsburg in Washington County, Maryland. As part of the Great Valley of the Ridge and Valley physiographic province, the park exhibits classic features of a karst landscape.

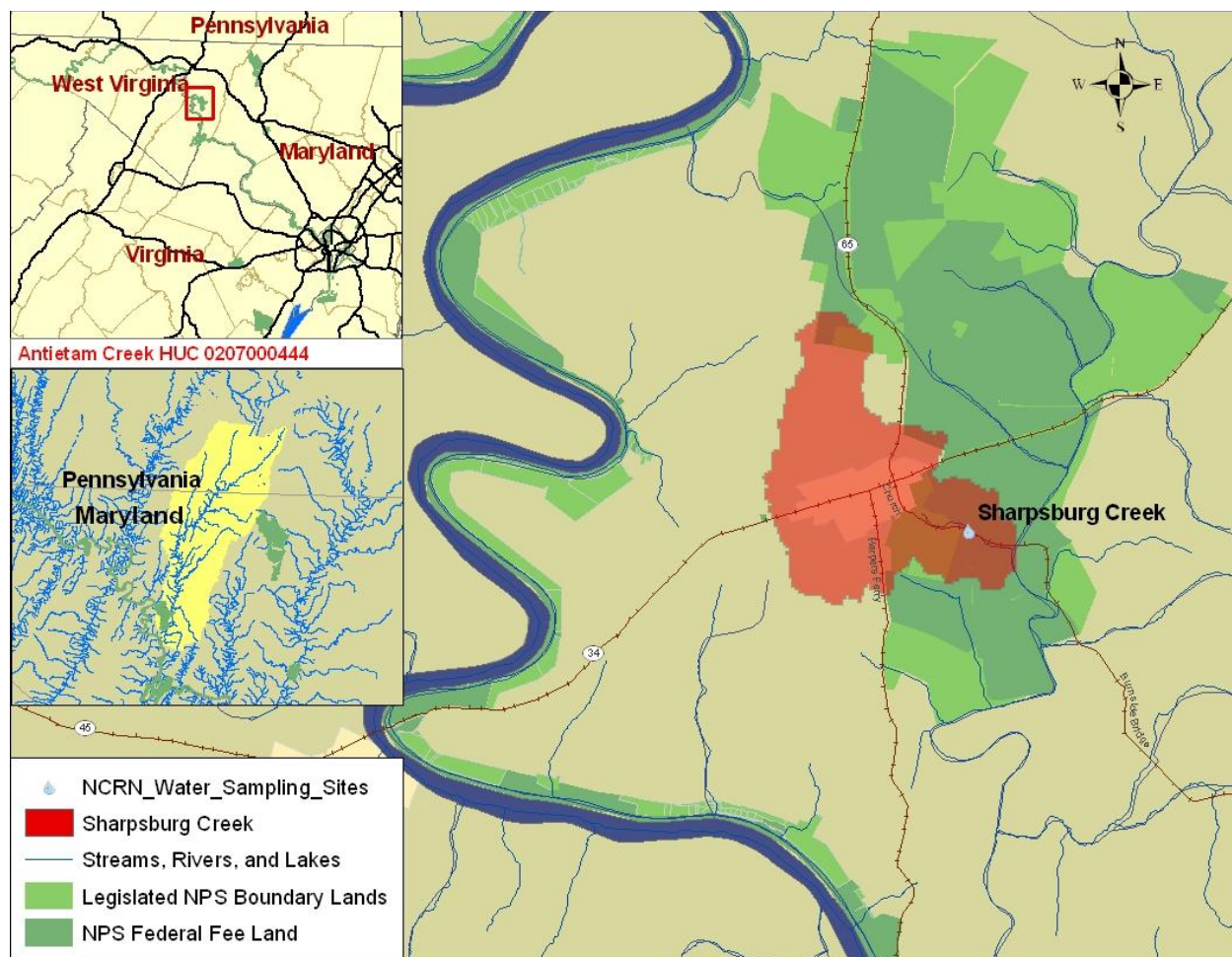


Figure 3: Relationship of the Sharpsburg Creek monitoring site to the watershed and the park boundary

ANTI is part of the Antietam Creek drainage basin. Antietam Creek passes through ANTI, then through private land and into CHOH before emptying into the Potomac River. Land use within the Antietam Creek drainage basin is 69 percent agriculture, 24 percent forest and 7 percent urban (National Park Service 1995).

This report discusses data collected October 2008 through September 2009 in Sharpsburg Creek, the only perennial tributary of Antietam Creek in the park. Summary statistics for the time period are shown in Table 2. One site was monitored in the park on a monthly basis for dissolved oxygen, pH, specific conductance, temperature, acid neutralizing capacity, nitrate, ammonia, total phosphorus, depth, wetted width, flow and discharge. Data was not collected in Sharpsburg Creek December 2008 and January and March 2009 due to inclement weather or frozen stream conditions.

Table 3: Date range, sample size (N), and data range for the vital signs data collected at Antietam National Battlefield.

Parameter	Units	Period of Record	N	Minimum	Maximum	Mean	Median	Standard Deviation
ANC	µeq/L	10/22/2008 - 9/15/2009	9	4320	6680	5073	4960	690
Discharge	cfs	10/22/2008 - 9/15/2009	3	0.83	2.60	1.94	---	0.97
DO	mg/l	10/22/2008 - 9/15/2009	9	9.3	14.6	10.6	10	1.7
Flow	ft/sec	10/22/2008 - 9/15/2009	3	0.700	1.476	1.207	---	0.439
Nitrate	mg/l	10/22/2008 - 9/15/2009	9	6	8	7	6	1
Ammonia	mg/l	10/22/2008 - 9/15/2009	5	0.032	0.061	0.051	---	0.012
pH	None	10/22/2008 - 9/15/2009	9	8.09	8.32	8.22	8.22	0.06
Phosphorus	mg/l	10/22/2008 - 9/15/2009	9	0.14	0.24	0.20	0.2	0.04
Salinity	ppt	10/22/2008 - 9/15/2009	9	0.27	0.30	0.29	0.29	0.01
Specific conductance	µS/cm	10/22/2008 - 9/15/2009	9	559.3	635.0	594.1	587.5	26.0
Water Depth	ft	10/22/2008 - 9/15/2009	4	0.151	0.231	0.192	---	0.042
Water Temperature	°C	10/22/2008 - 9/15/2009	9	7.5	17.2	13.2	14.9	3.6
Wetted Width	ft	10/22/2008 - 9/15/2009	8	7.17	11.00	8.70	---	1.41

There were no DO readings below the desired minimum of 5 mg/L to sustain aquatic life (Figure 11). Nitrate always exceeded the 2.0 mg/L threshold for eutrophication (Figure 9). Ammonia never exceeded the threshold in 2009 (Figure 8). Total Phosphorus was always above the eutrophication threshold of 2.0 mg/l (Figure 10). Much of the park is maintained as agriculture to replicate the historical Civil War landscape. The agriculture lease agreements allow for fertilizer and pesticide applications and some fields are leased for livestock grazing. These are probably among the sources of the nitrate and phosphorus. Other sources may include acid rain and atmospheric deposition as well as background levels in groundwater.

The ANC in Sharpsburg Creek was always well above the 600 µS/cm threshold for karst areas (Figure 4). The pH in Sharpsburg Creek was always within the range supporting aquatic life at or slightly above 8 (8.09 – 8.32) (Figure 5). The higher pH and ANC of Sharpsburg Creek are due to dissolution of the limestone and dolomite bedrock. This may also contribute to the higher specific conductance, though fertilizers, pesticides, and livestock runoff may also contribute. Limestone (CaCO_3) and dolomite ($\text{CaMg}(\text{CO}_3)_2$) are ionic salts that dissociate in pure water to their constituent ions: Ca^{2+} and CO_3^{2-} ; $\text{Ca}^{2+} + \text{Mg}^{2+} + 2 \text{CO}_3^{2-}$. Groundwater in karst areas can also contain sulfate ions from gypsum beds and weathered sulfite materials, chlorides from deeper circulating ground water and seawater mining, sodium, potassium, dissolved oxygen. Specific conductance was above the desired limit of 400 µS/cm (Figure 6). Agriculture may contribute, but elevated conductivity usually accompanies high ANC in karst landscapes.

Salinity in Sharpsburg Creek is within freshwater range (<0.5 ppt) (Figure 7).

Water Temperature remained within the comfort zone of most organisms (Figure 12) and followed expected seasonal patterns with lower temperatures in winter and higher temperatures in summer. The influence of groundwater is evident in the relatively low summer temperatures. There was only sufficient depth (Figure 15) for flow (Figure 14) and discharge (Figure 13) measurements in April, June, and July 2009. Wetted width (Figure 16) varied by 5 feet, less than $\frac{1}{2}$ the width of the stream.

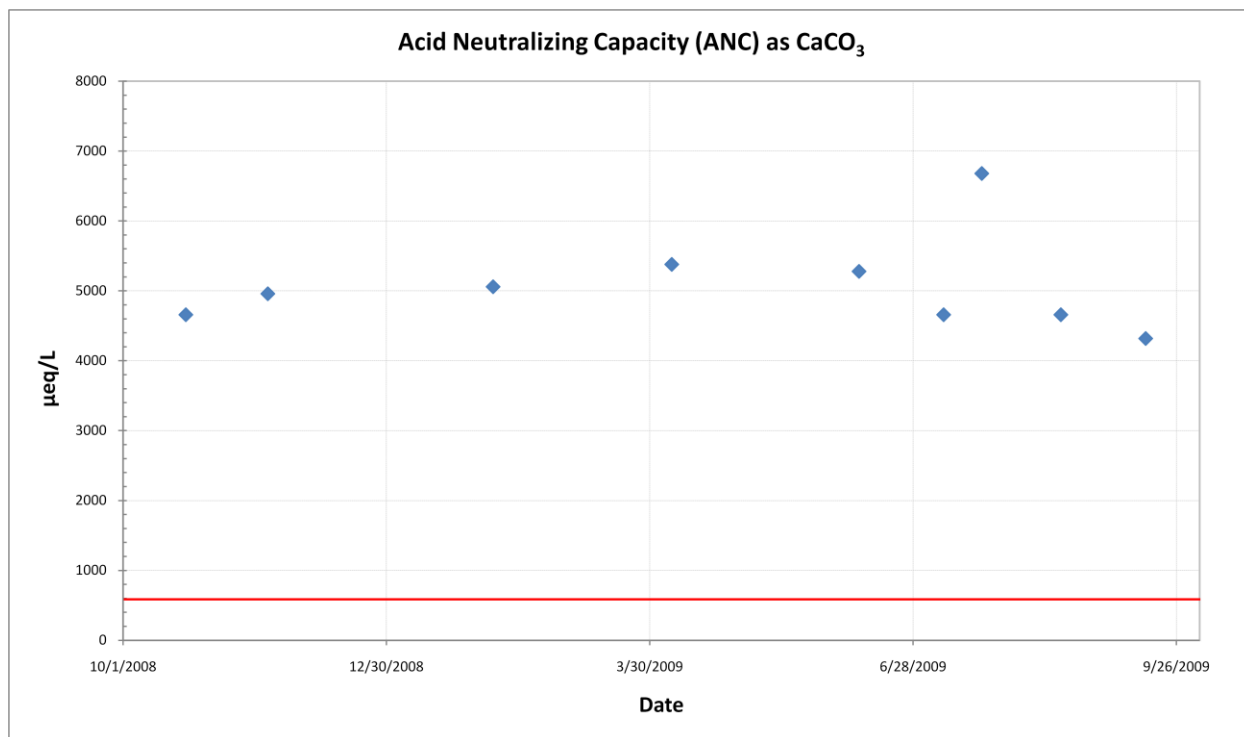


Figure 4: ANC in Sharpsburg Creek in FY 2009. Desired condition is above the 600 ueq/L threshold for karst waters shown in red.

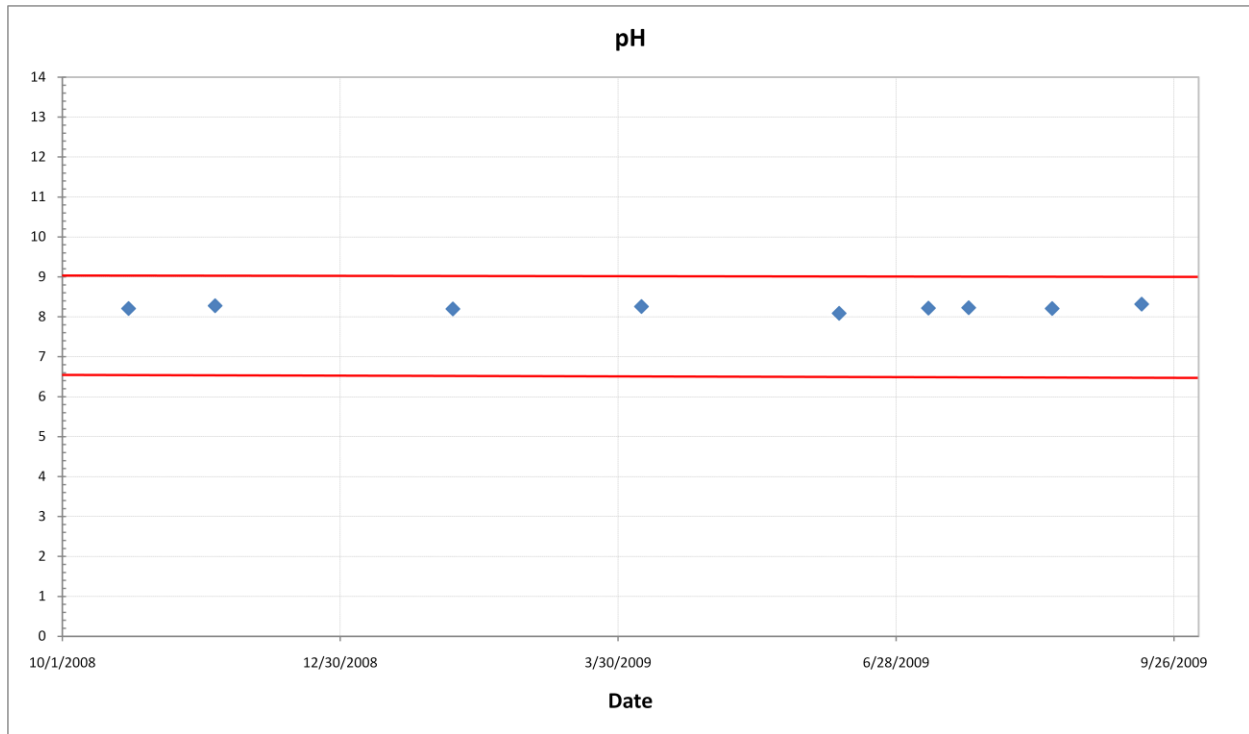


Figure 5: pH in Sharpsburg Creek in FY 2009. Desired condition is between the 6.5 and 9.0 thresholds shown in red.

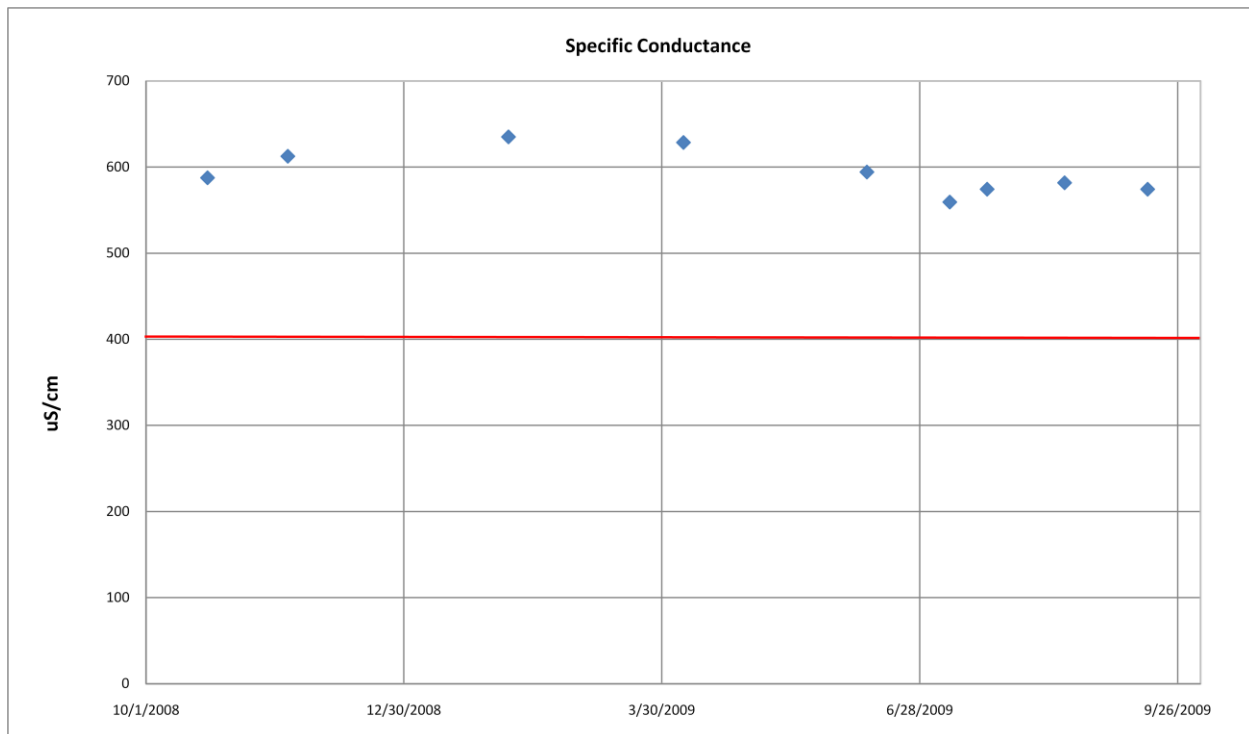


Figure 6: Specific Conductance in Sharpsburg Creek, FY 2009. Desired condition is below the 400 μ S/cm threshold shown in red.

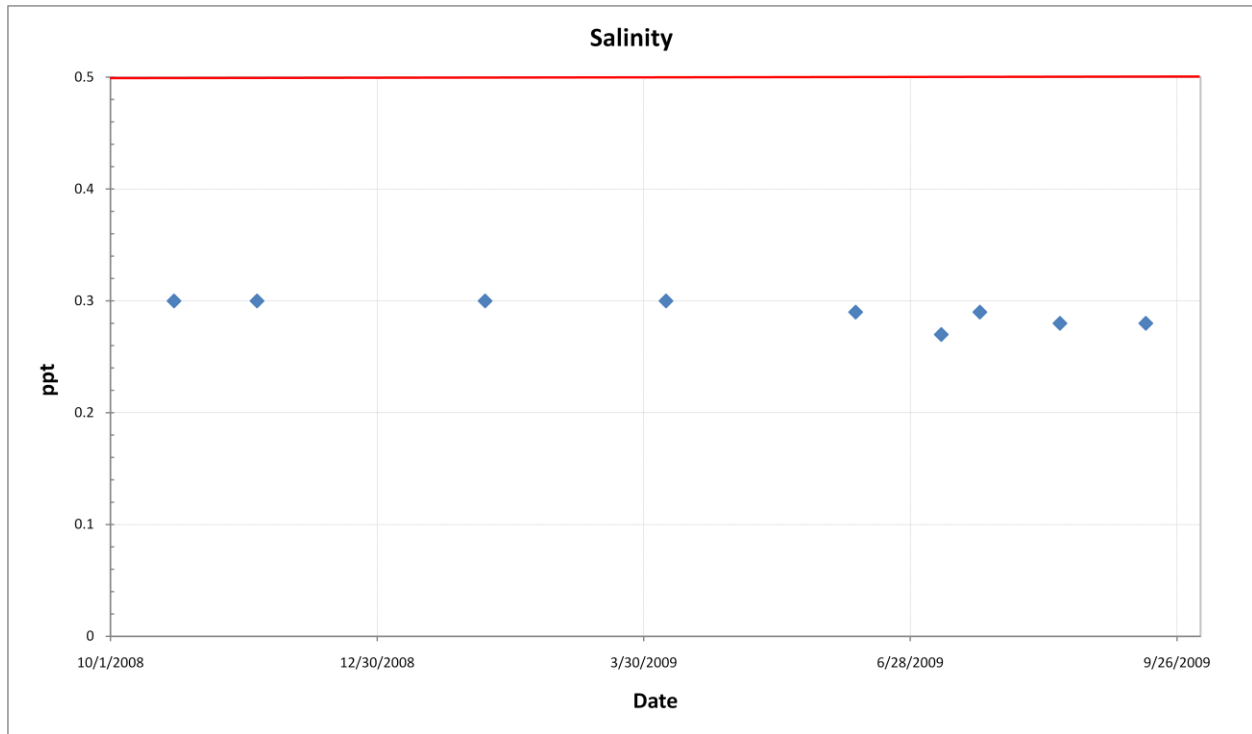


Figure 7: Salinity in Sharpsburg Creek FY 2009. Desired condition is below the 0.5 ppt threshold shown in red.

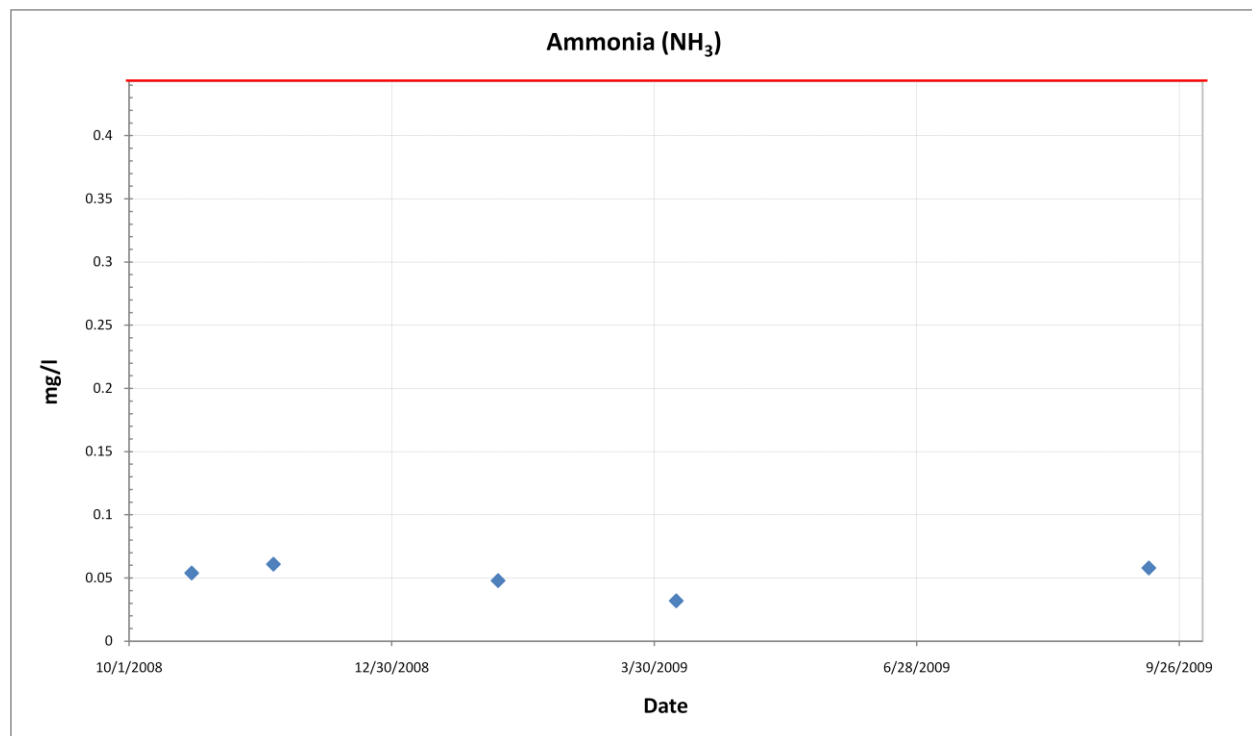


Figure 8: Ammonia in Sharpsburg Creek, FY 2009. Desired condition is below the 0.443 threshold shown in red.

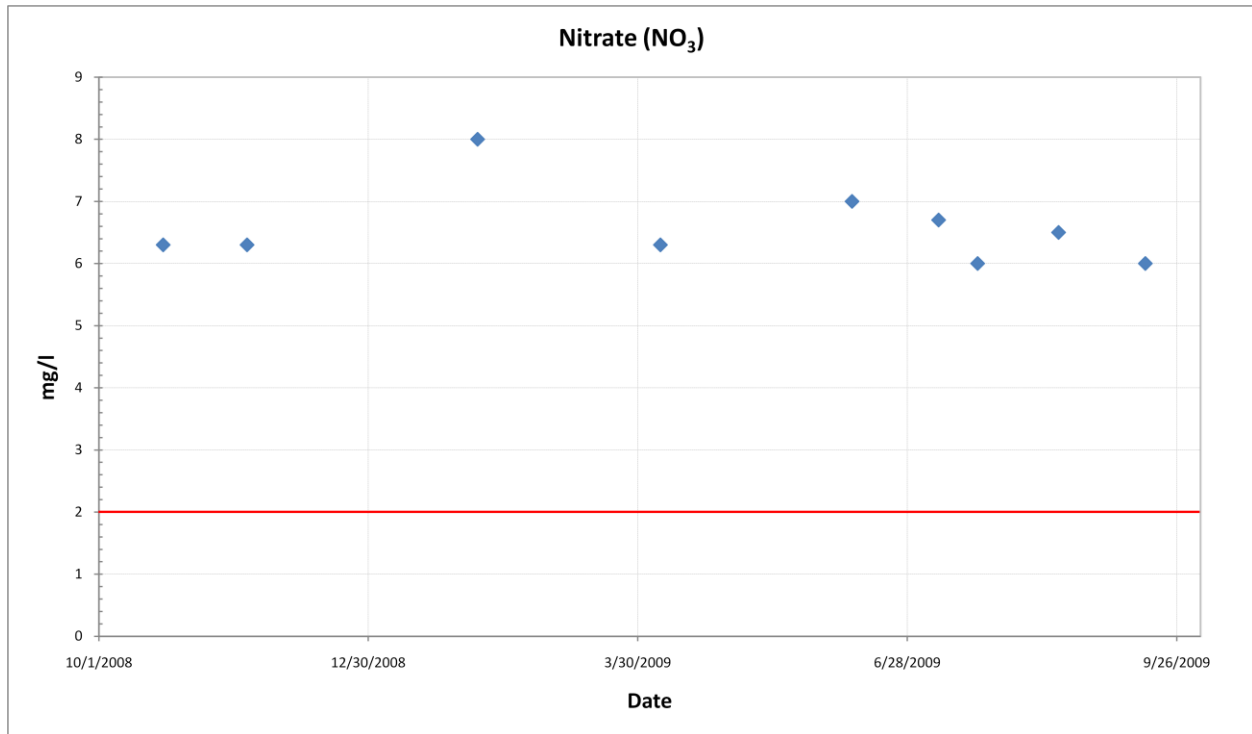


Figure 9: Nitrate in Sharpsburg Creek, FY 2009. Desired condition is below the 2.0 mg/L threshold shown in red.

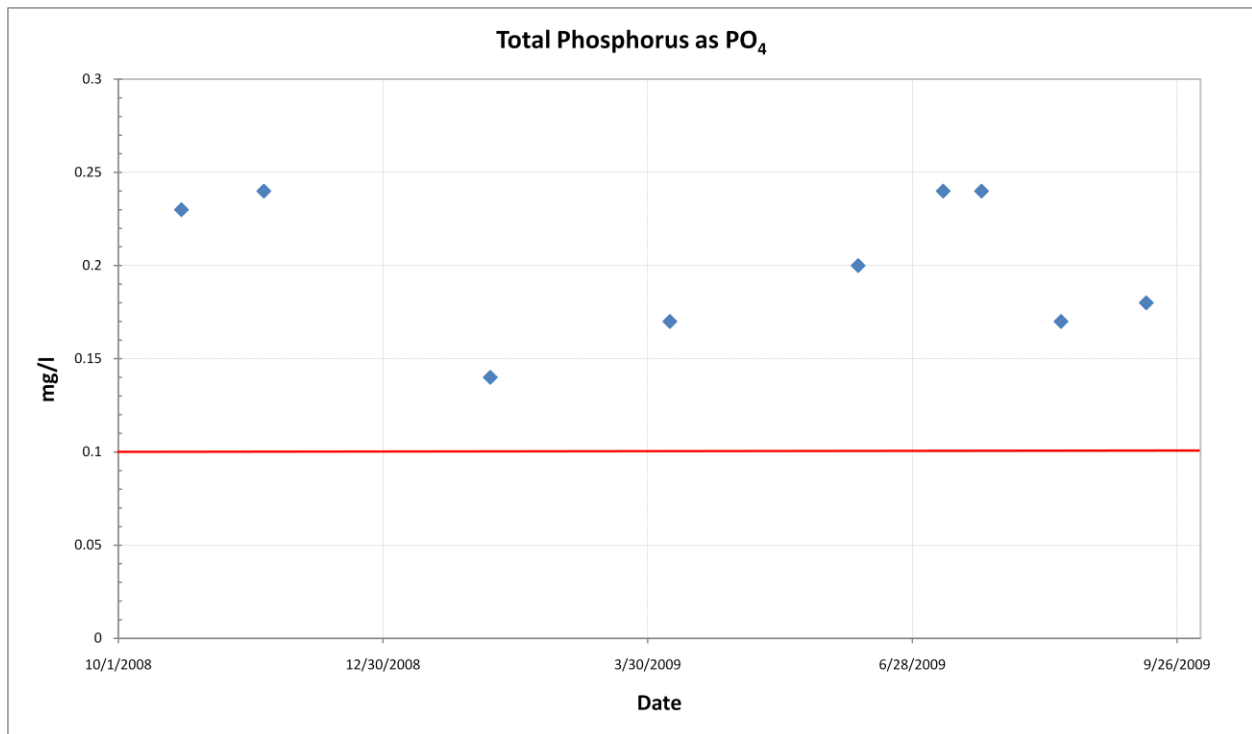


Figure 10: Total Phosphorus in Sharpsburg Creek, FY 2009. Desired condition is below the 0.1 mg/L threshold shown in red.

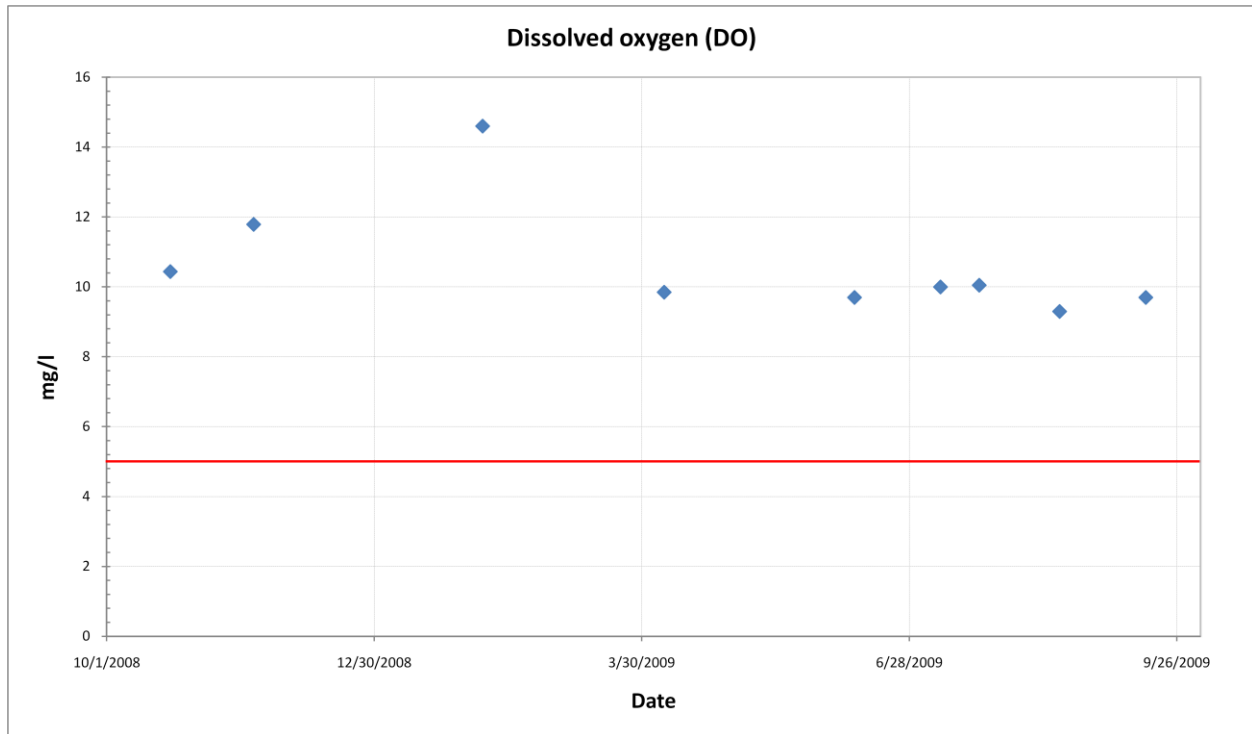


Figure 11: Dissolved Oxygen in Sharpsburg Creek, FY 2009. Desired condition is above the 5.0 mg/L threshold shown in red.

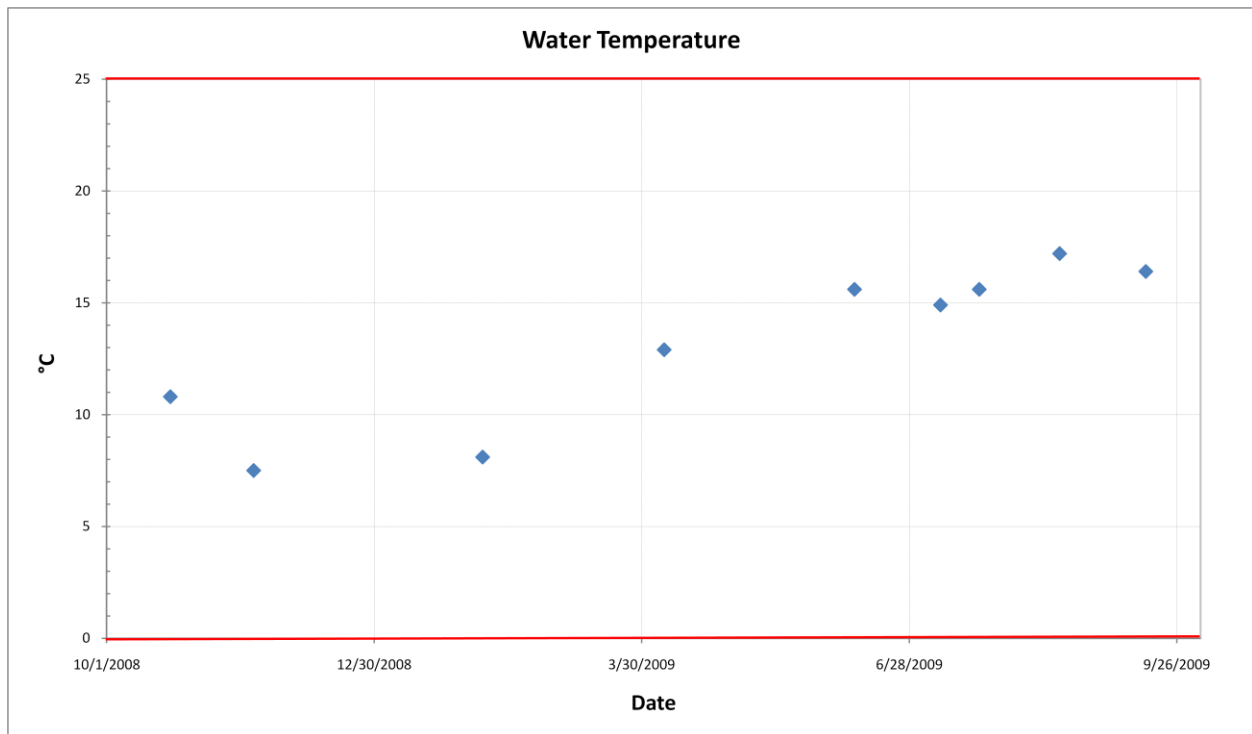


Figure 12: Temperatures of Sharpsburg Creek, FY 2009. Ideal temperatures for aquatic life are between 0 and 25 °C.

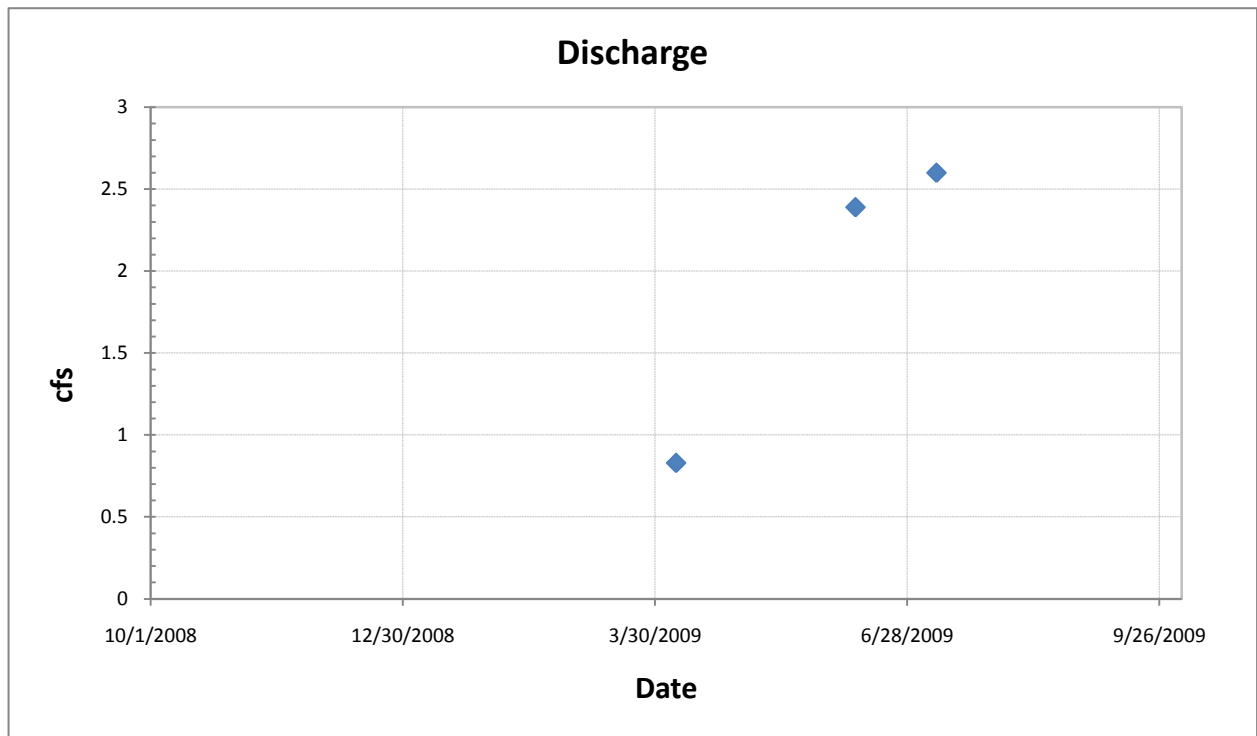


Figure 13: Discharge of Sharpsburg Creek, FY 2009.

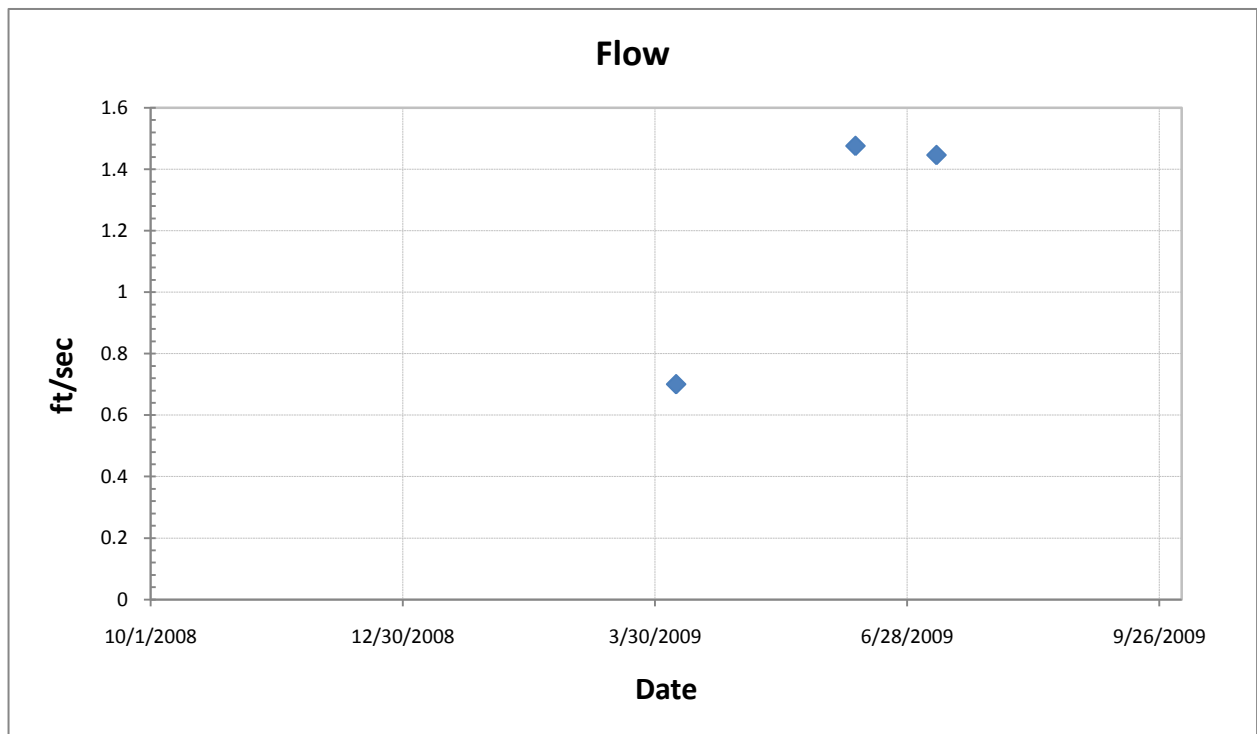


Figure 14: Flow of Sharpsburg Creek, FY 2009.

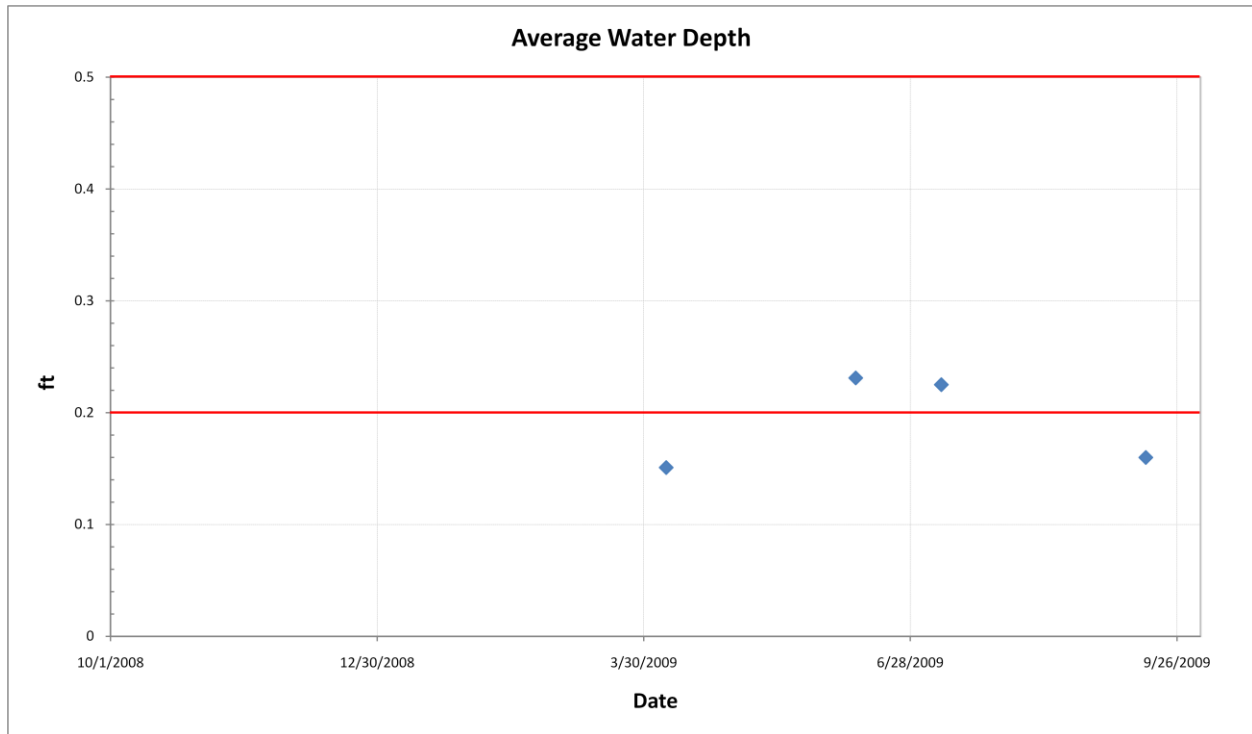


Figure 15: Average depth of Sharpsburg Creek, FY 2009. Required condition is above 0.2 foot for discharge measurements and 0.5 foot for continuous measurement with data sondes.

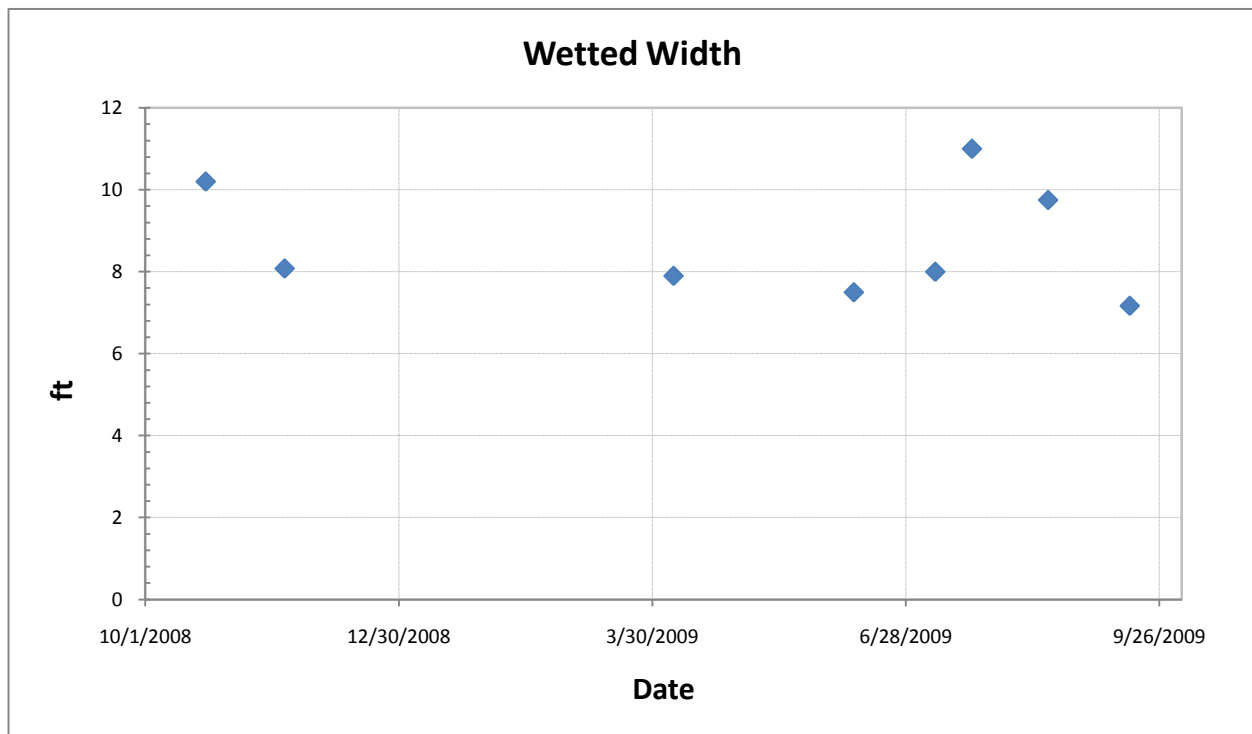


Figure 16: Wetted width of Sharpsburg Creek, FY 2009.

Catoctin Mountain Park (CATO)

The park encompasses 2,336 ha of forested landscape located in the mountains of the Catoctin Ridge in the north-central portion of Maryland. The park is located near Thurmont in Frederick County, Maryland in the Blue Ridge physiographic province. The eastern scarp (line of cliffs) of the Blue Ridge is a series of linear mountainous ridges with elevations from 1000 to 5700 feet, mostly forested with cool clear streams, steeply sloped over mostly sandstone and shale bottoms. Within these, Catoctin Mountain is a discontinuous ridge that extends from near the Pennsylvania/Maryland border to the Potomac River at Point of Rocks, Maryland. Within the park, which is a small section of the ridge, rock units are highly fractured and folded and range from quartzite along the southeast edge, phyllite and conglomerate in the southeast section and metarhyolite and metabasalt in the northwest (Hugh Engineers Inc. and R.E. Wright Associates Inc. 1981). These rocks are resistant to erosion and dissolution. Slopes in the park are generally between 10% and 20%, but occur up to 60% (Trombley and Zynjuk 1985).

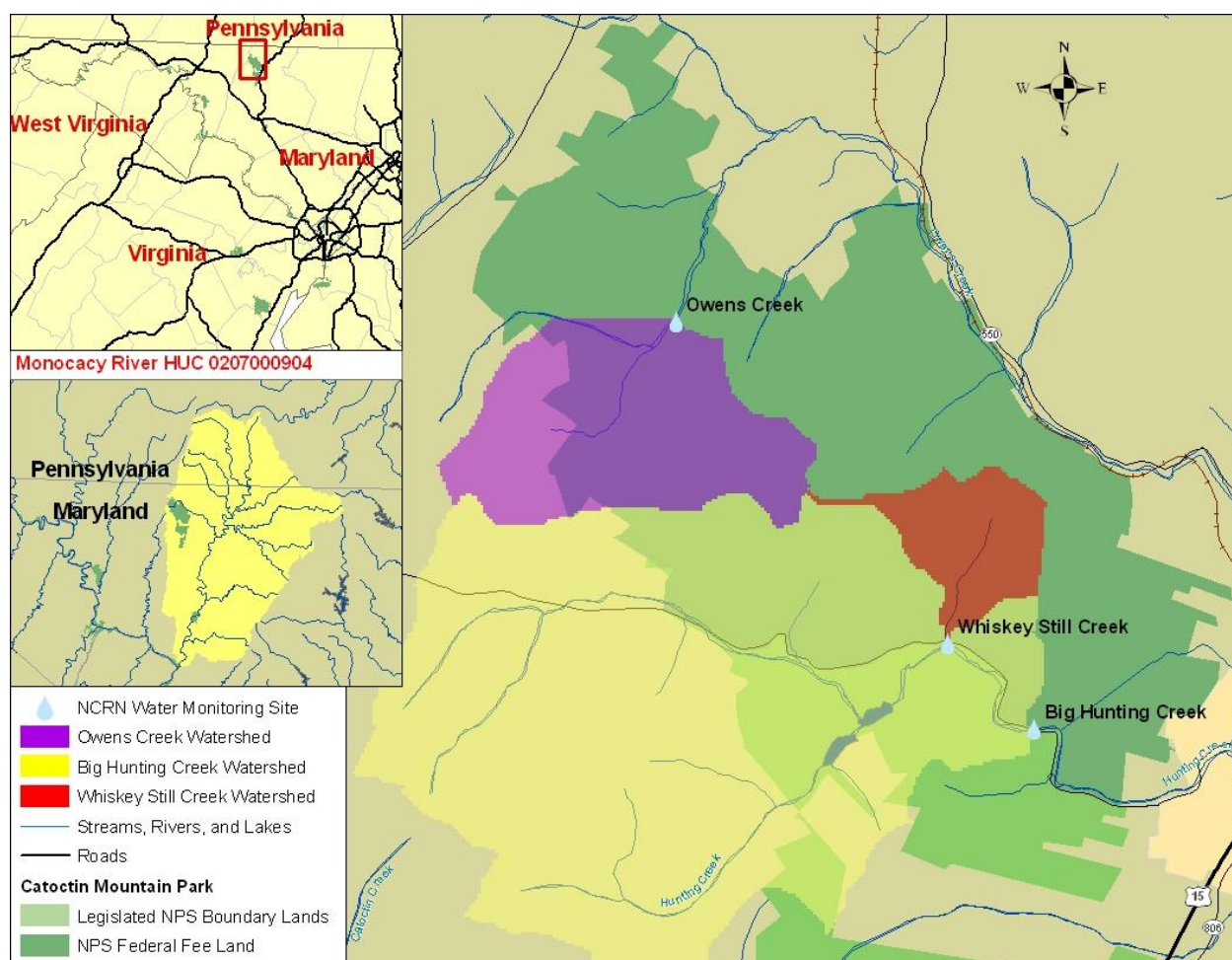


Figure 17: Relationship of CATO stream monitoring sites to their watersheds and the park boundary

The park area is separated from the main ridge by two streams: Big Hunting Creek to the south and Owens Creek to the west, north, and east (Figure 17). Big Hunting Creek is 41.8 square miles in drainage and 15 miles long. It is a tributary of the Monocacy River. Big Hunting Creek flows in and out of the CATO boundary for roughly 4 miles. The headwaters of Big Hunting

Creek are outside of the park, putting this creek at risk for potential problems that cannot be completely controlled by the park (Means 1995). Before entering the park, Big Hunting Creek runs off farms and lots and along MD Route 77. The national park contains 7% of the creek's drainage basin. Developed areas in the park (Greentop, Round Meadow, Misty Mount, Maintenance Yard, Visitors Center, Administration Office, Park Central Road, Route 77, and Camp 3) contribute runoff to the creek. Water quality in the creek is very good, with bank erosion and flow rate the most significant problems. These problems have been further affected by construction of Cunningham Falls State Park dam. Tributaries of Big Hunting Creek include Still Creek, Whiskey Still Creek (completely contained within CATO), Hauver Branch (within the state park) and Bear Branch (within the state park).

Owens Creek has a 39.8 square mile drainage and is managed for native brook trout and for naturally reproducing brown trout (Means 1995). The headwaters of Owens Creek begin inside the park. As the creek leaves through the park's north boundary it passes through an agricultural area and flows back into the park. The park contains 14.5% of Owens Creek's watershed, but fewer areas of the park contribute runoff to the creek (Round Meadow, Naval Housing Facilities, Owens Creek picnic area, Chestnut picnic area, Camp 3, and Owens Creek campground). A new wastewater treatment plant was located at the head of Owens Creek in the late 1990s. The plant discharges directly into the stream and wetland where Owens Creek originates.

This report discusses data collected October 2008 through September 2009 in Big Hunting Creek, Whiskey Still Creek, and Owens Creek. Summary statistics for the time period are presented in Table 3.

Table 4: Date range, sample size (N), and data range for the vital signs data collected at Catoctin Mountain Park.

Local Name	Units	Period of Record	N	Minimum	Maximum	Mean	Median	Standard Deviation
ANC	µeq/L	10/21/2008 - 9/15/2009	28	438	908	633	602	124
Discharge	cfs	10/21/2008 - 9/15/2009	8	3.36	28.76	10.00	---	9.89
DO	mg/l	10/21/2008 - 9/15/2009	28	7.33	17.61	9.75	9.36	1.95
Flow	ft/sec	10/21/2008 - 9/15/2009	8	0.3222	1.9600	0.7778	---	0.5768
Nitrate	mg/l	10/21/2008 - 9/15/2009	28	0.2	1.8	1.0	1.0	0.4
Ammonia	mg/l	10/21/2008 - 9/15/2009	8	0.036	0.812	0.154	---	0.267
pH	None	10/21/2008 - 9/15/2009	27	7.29	7.94	7.66	7.64	0.14
Total Phosphorus	mg/l	10/21/2008 - 9/15/2009	28	0.06	0.41	0.19	0.16	0.08
Salinity	ppt	10/21/2008 - 9/15/2009	28	0.03	0.10	0.07	0.07	0.02
Specific Conductance	µS/cm	10/21/2008 - 9/15/2009	28	68.9	169.6	132.1	139.3	26.5
Water Depth	ft	10/21/2008 - 9/15/2009	11	0.11	3.36	0.80	0.59	0.89
Water Temperature	°C	10/21/2008 - 9/15/2009	28	2.95	20.00	13.06	15.64	5.17
Wetted Width	ft	10/21/2008 - 9/15/2009	26	3.75	26.25	15.62	19.25	8.13

Three sites were monitored on a monthly basis for dissolved oxygen, pH, specific conductance, temperature, acid neutralizing capacity, nitrate, ammonia, total phosphorus, depth, wetted width, flow and discharge. Data was not collected in CATO streams in December 2008 or January

2009 due to inclement weather and / or frozen stream conditions. Only Big Hunting Creek was flowing free of ice in February 2009.

For all Catoctin streams monitored, the ANC was always well above the threshold of 200 ueq/L (Figure 18). The pH was always within healthy range for aquatic life (Figure 19). Specific Conductance was always less than 400 uS/cm (figure 20), well within the desired range for aquatic life. Salinity of Catoctin Mountain streams was within freshwater levels in 2009 (Figure 21).

Ammonia was only above aquatic health criteria of 0.443 mg/L in Big Hunting Creek in April 2009 (Figure 22). Nitrate was always below the eutrophication threshold in Catoctin streams (Figure 23). The only parameter for which Catoctin streams consistently failed to meet threshold is phosphorus, except Bush Creek in January 2009 (Figure 24). Measurements of dissolved oxygen were always above the desired minimum of 5 mg/L to sustain aquatic life (Figure 25). Water Temperature follows expected seasonal trends and stays within the comfort range of most aquatic organisms (Figure 26).

There was only sufficient depth (Figure 28) to measure flow (Figure 30) and discharge (Figure 29) in Big Hunting Creek in October 2008 and April through August 2009, and in Whiskey Still Creek in April 2009, and in Owens Creek in May 2009. Wetted width fluctuated less than 2 feet in Whiskey Still Creek and Owens Creek, and less than 10 feet in Big Hunting Creek (Figure 27).

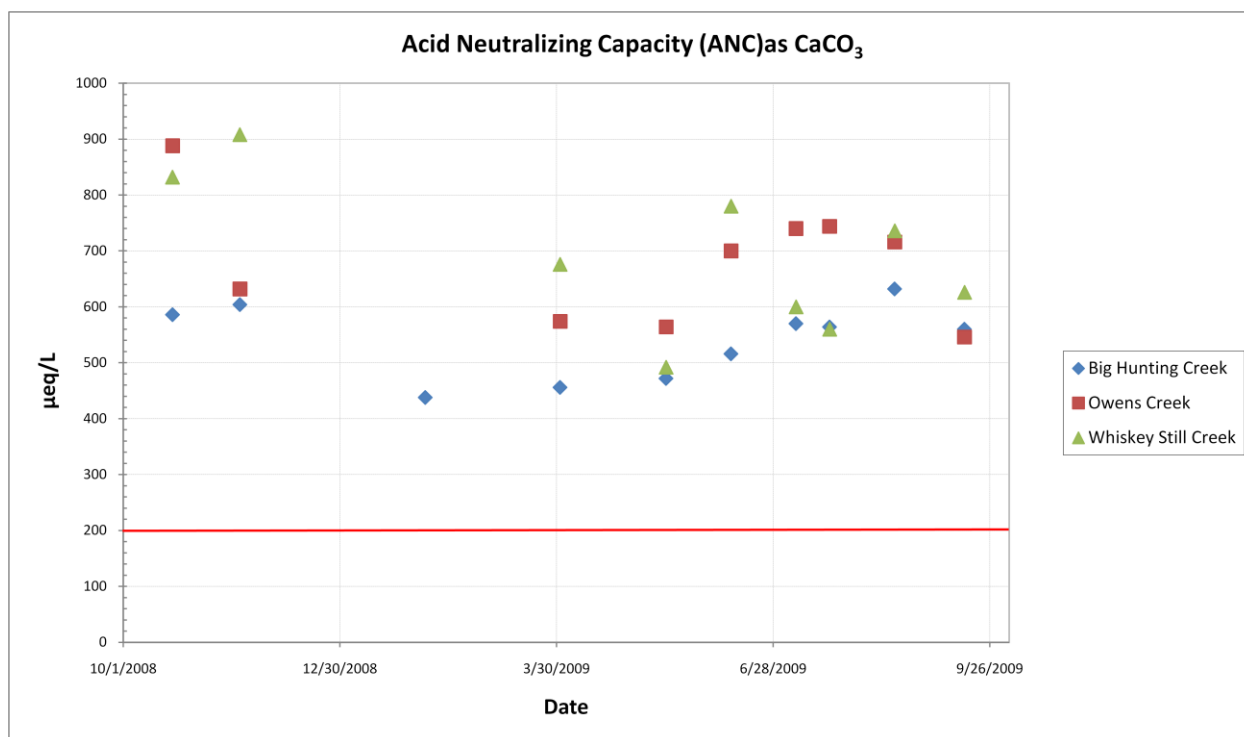


Figure 18: ANC in Catoctin Mountain Park streams in FY 2009. Desired condition is above the 200 ueq/L threshold for non-karst waters shown in red.

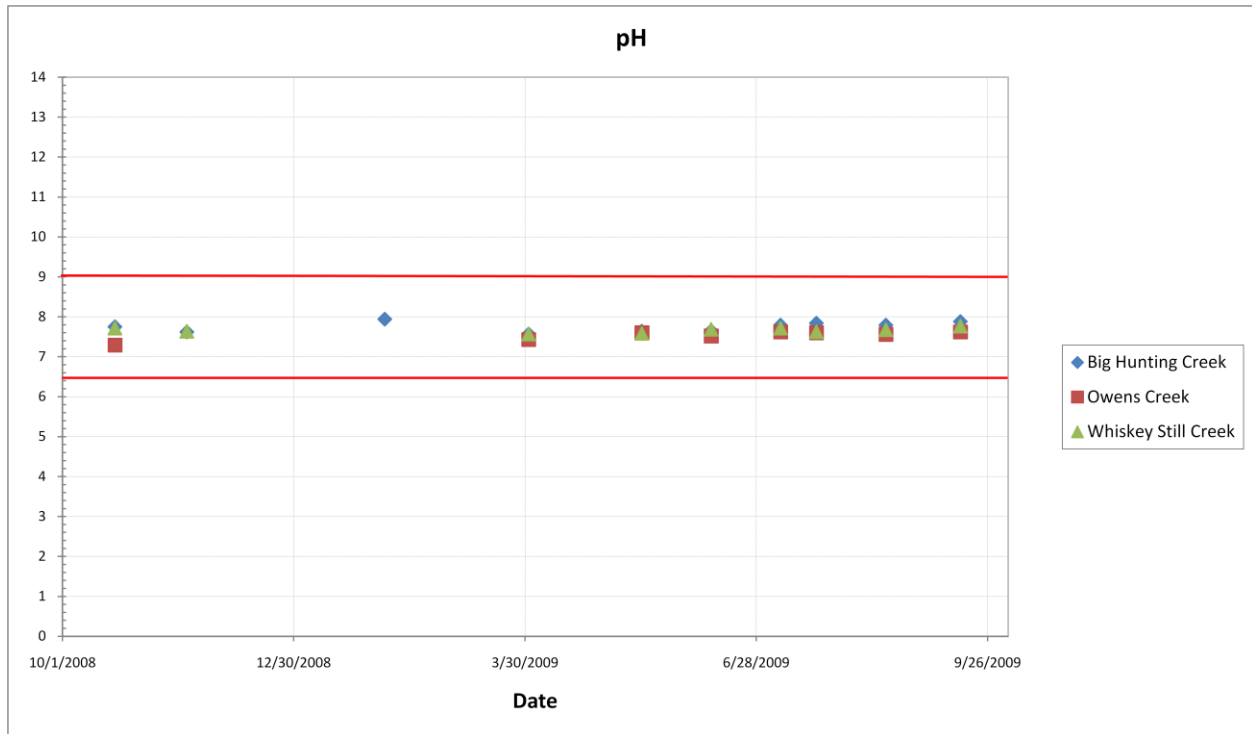


Figure 19: pH in Catoctin Mountain Park streams in FY 2009. Desired condition is between the 6.5 and 9.0 thresholds shown in red.

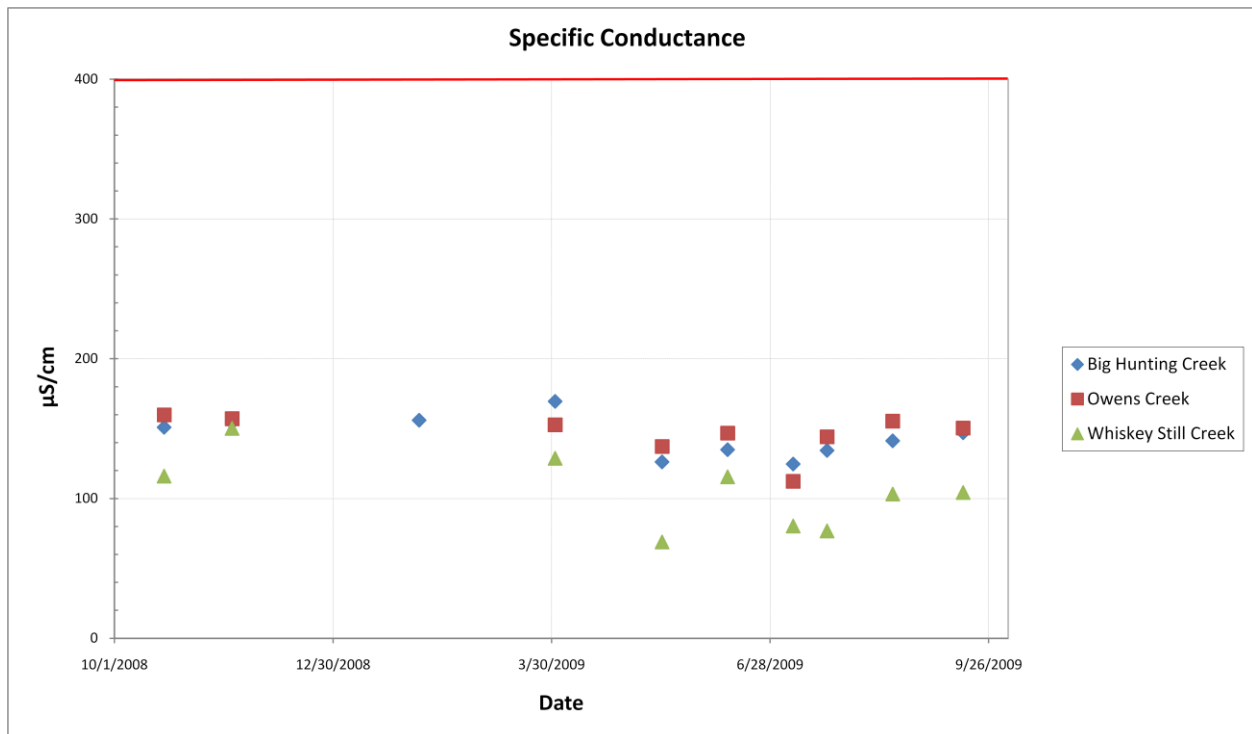


Figure 20: Specific Conductance in Catoctin Mountain park streams, FY 2009. Desired condition is below the 400 $\mu\text{S}/\text{cm}$ threshold shown in red.

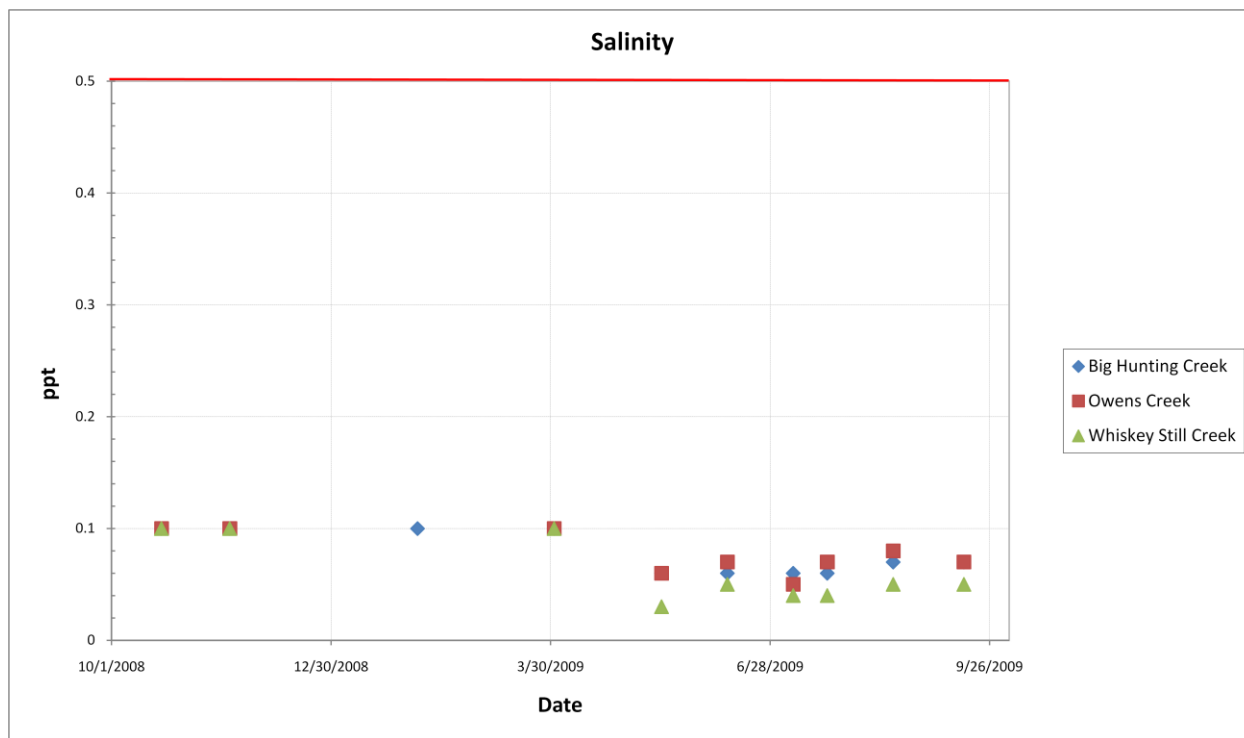


Figure 21: Salinity in Streams of Catoclin Mountain Park FY 2009. Desired condition is below the 0.5 ppt threshold shown in red.

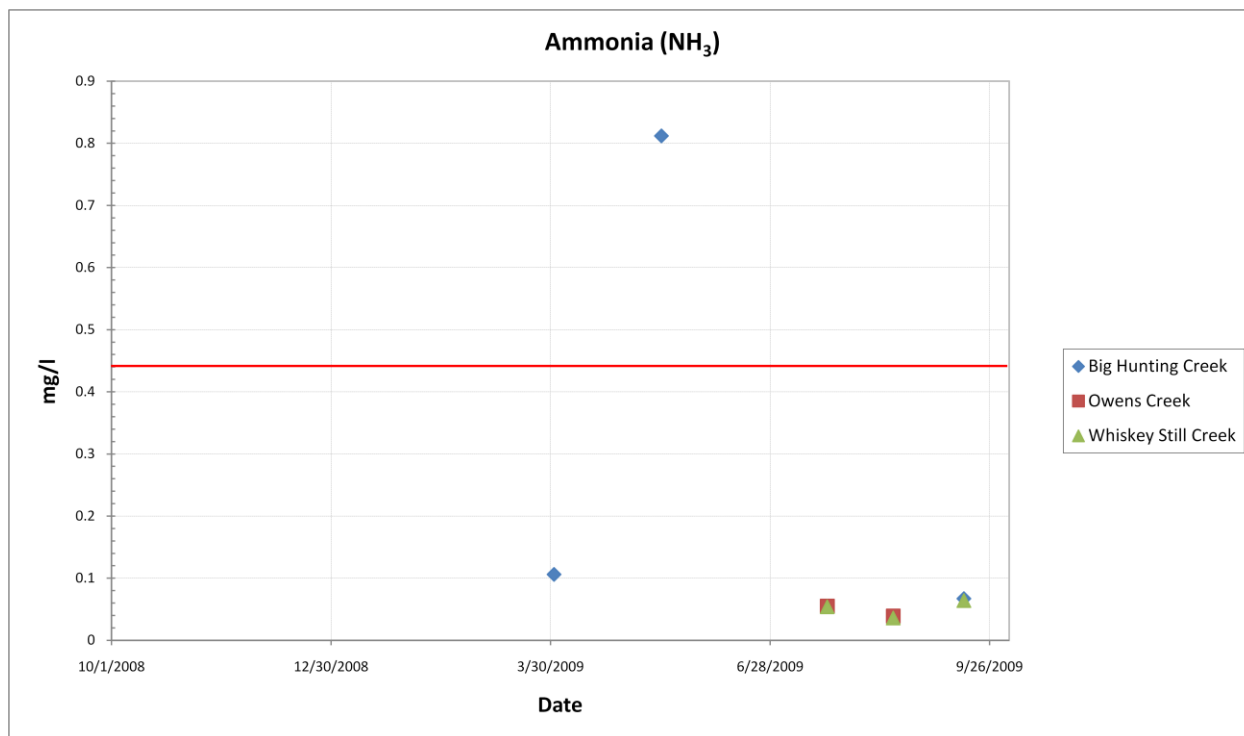


Figure 22: Ammonia in Catoclin Mountain Park streams, FY 2009. Desired condition is below the 0.443 threshold shown in red.

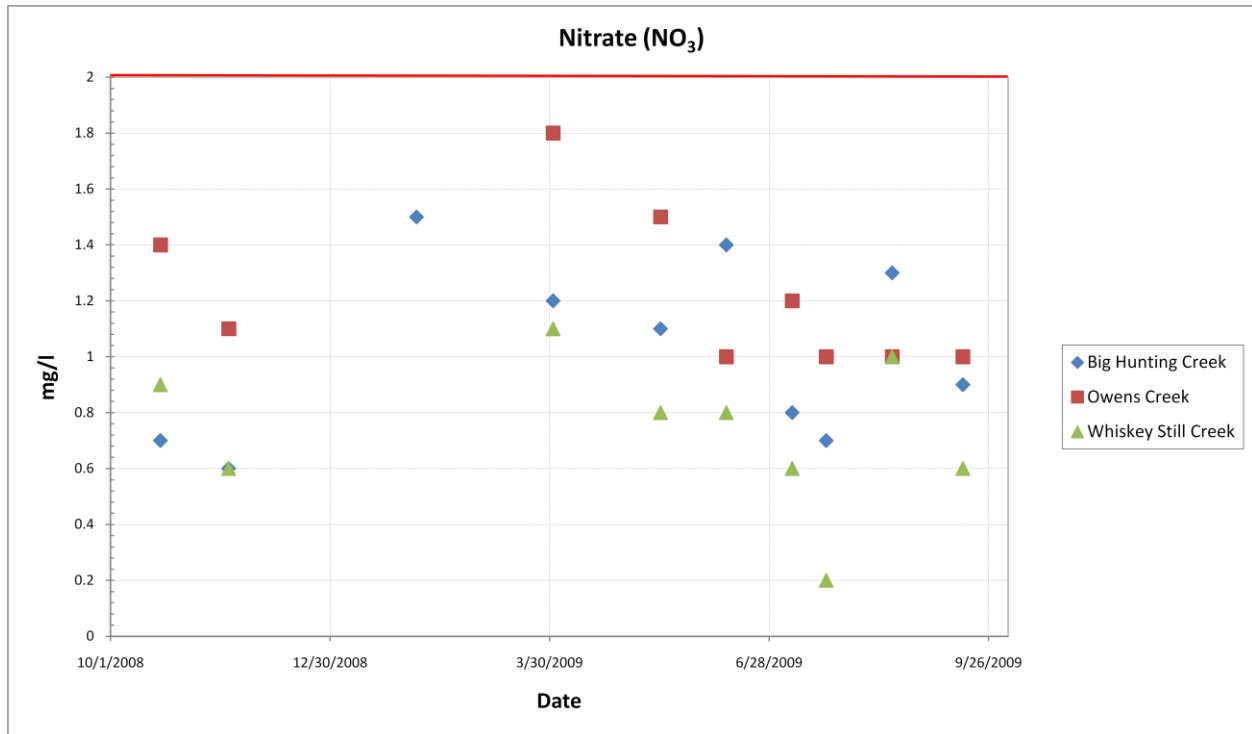


Figure 23: Nitrate in Catoclin Mountain Park streams, FY 2009. Desired condition is below the 2.0 mg/L threshold shown in red.

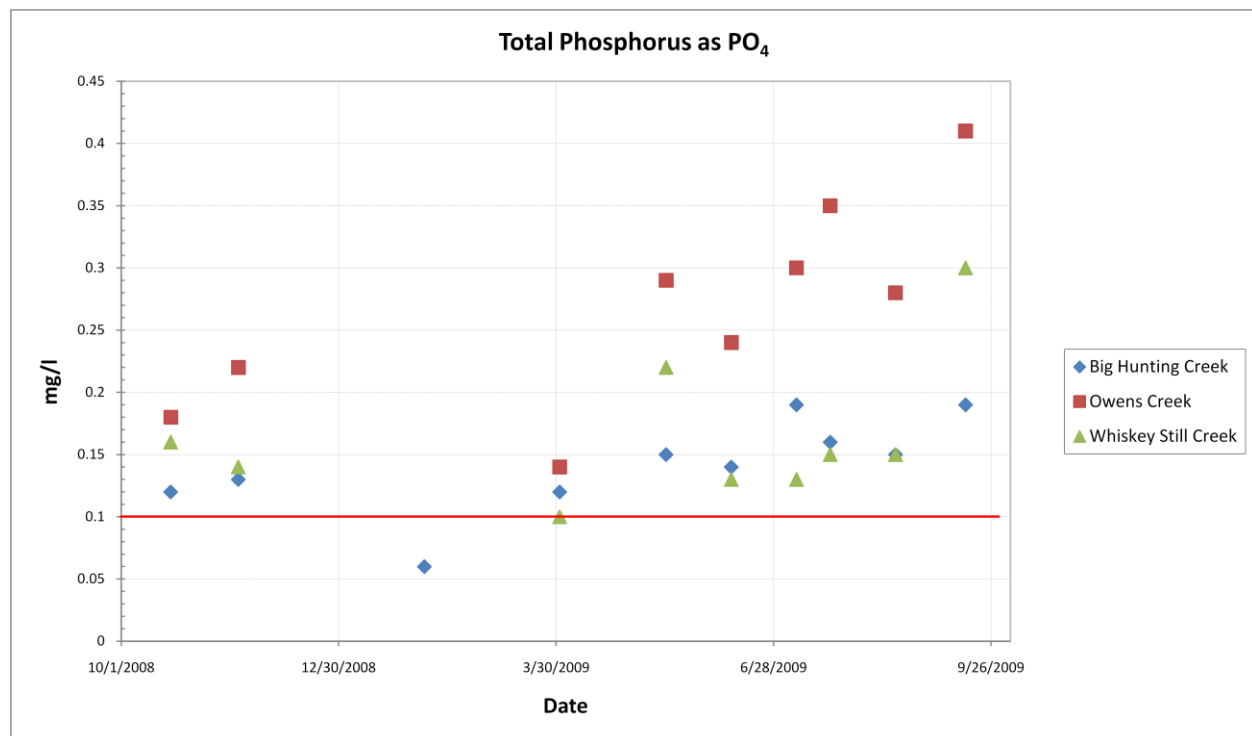


Figure 24: Total Phosphorus in Catoclin Mountain Park streams, FY 2009. Desired condition is below the 0.1 mg/L threshold shown in red.

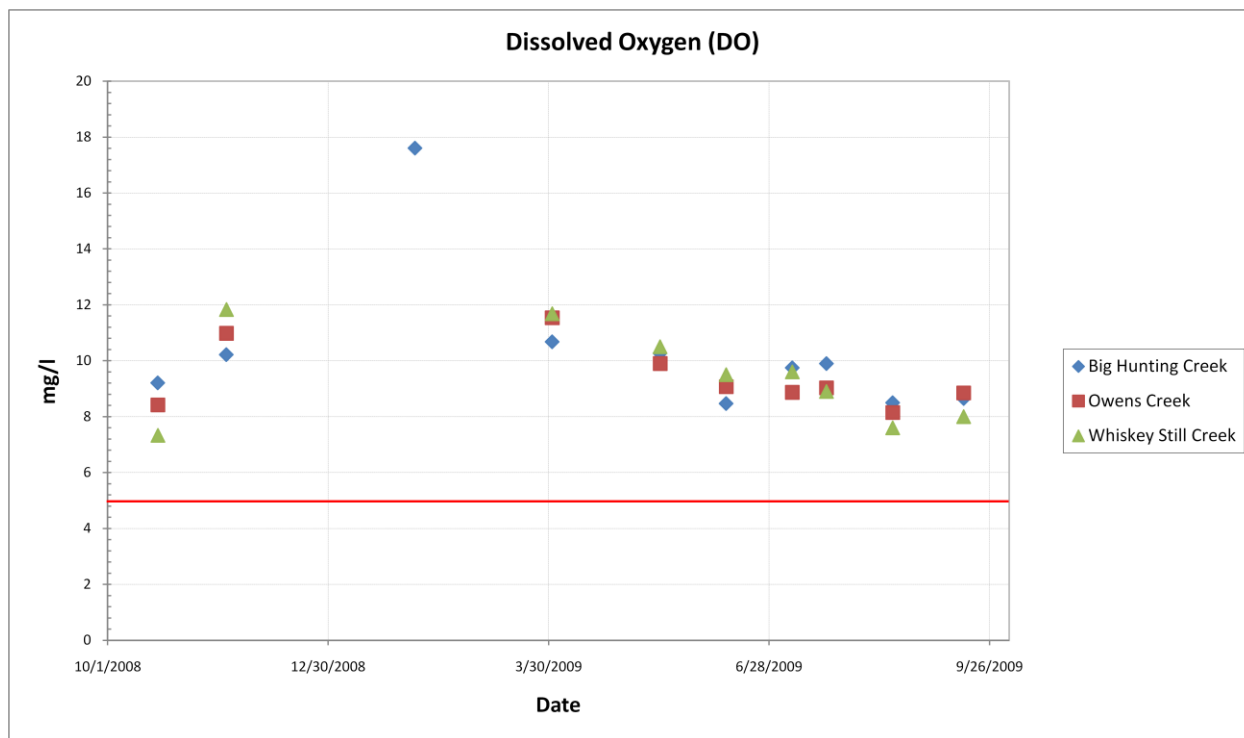


Figure 25: Dissolved Oxygen in Catoctin Mountain Park streams, FY 2009. Desired condition is above the 5.0 mg/L threshold shown in red.

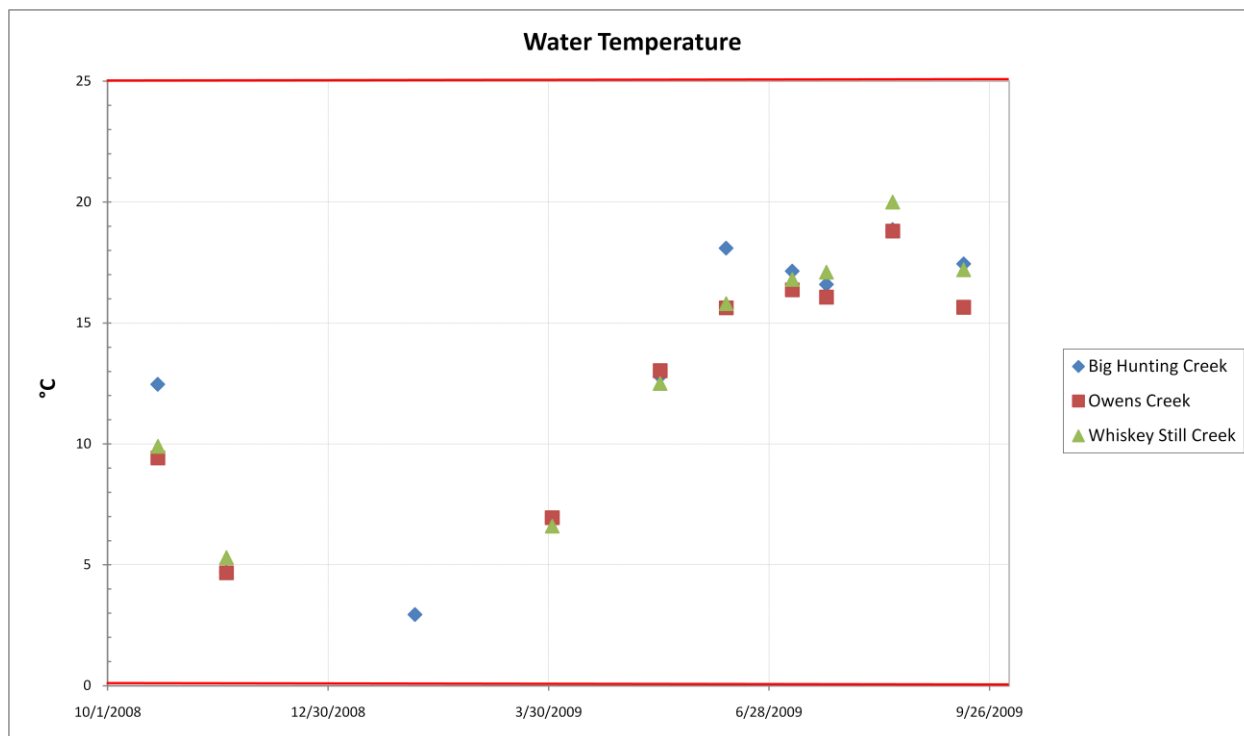


Figure 26: Temperatures of Catoctin Mountain Park Streams, FY 2009. Ideal temperatures for aquatic life are between 0 and 25 °C.

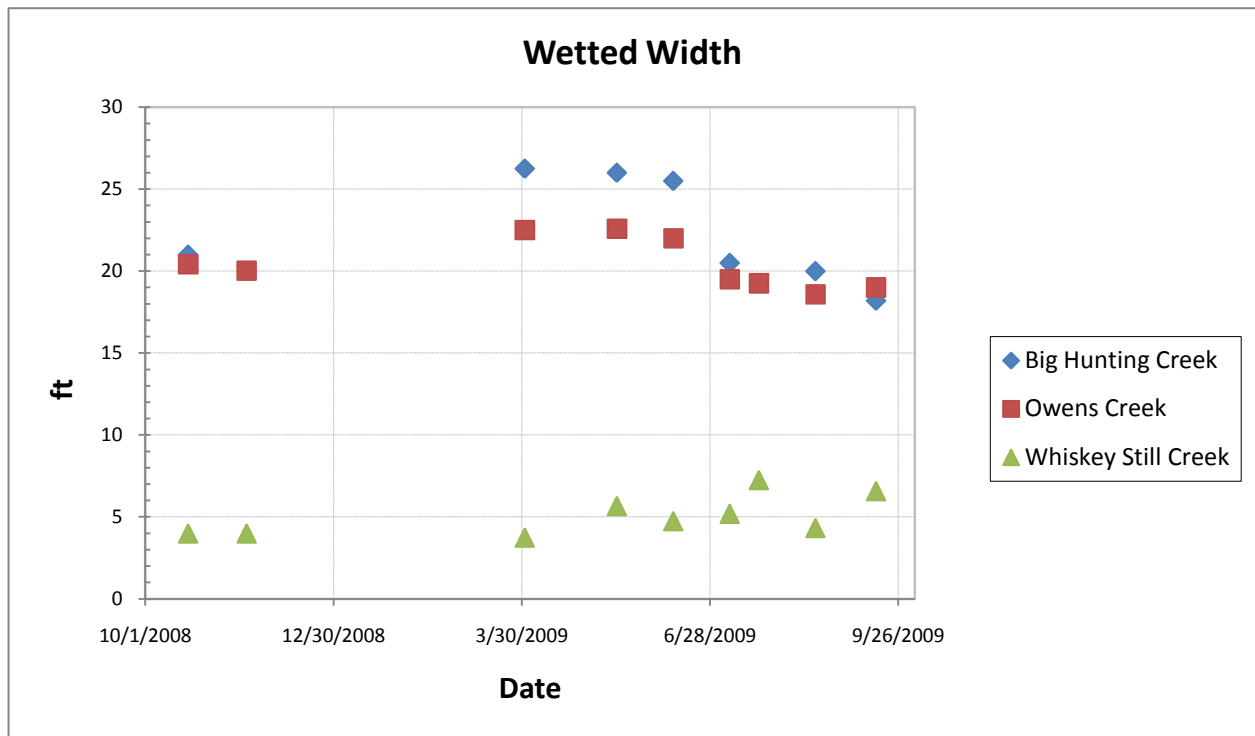


Figure 27: Wetted Width of Catoclin Mountain Park Streams, FY 2009.

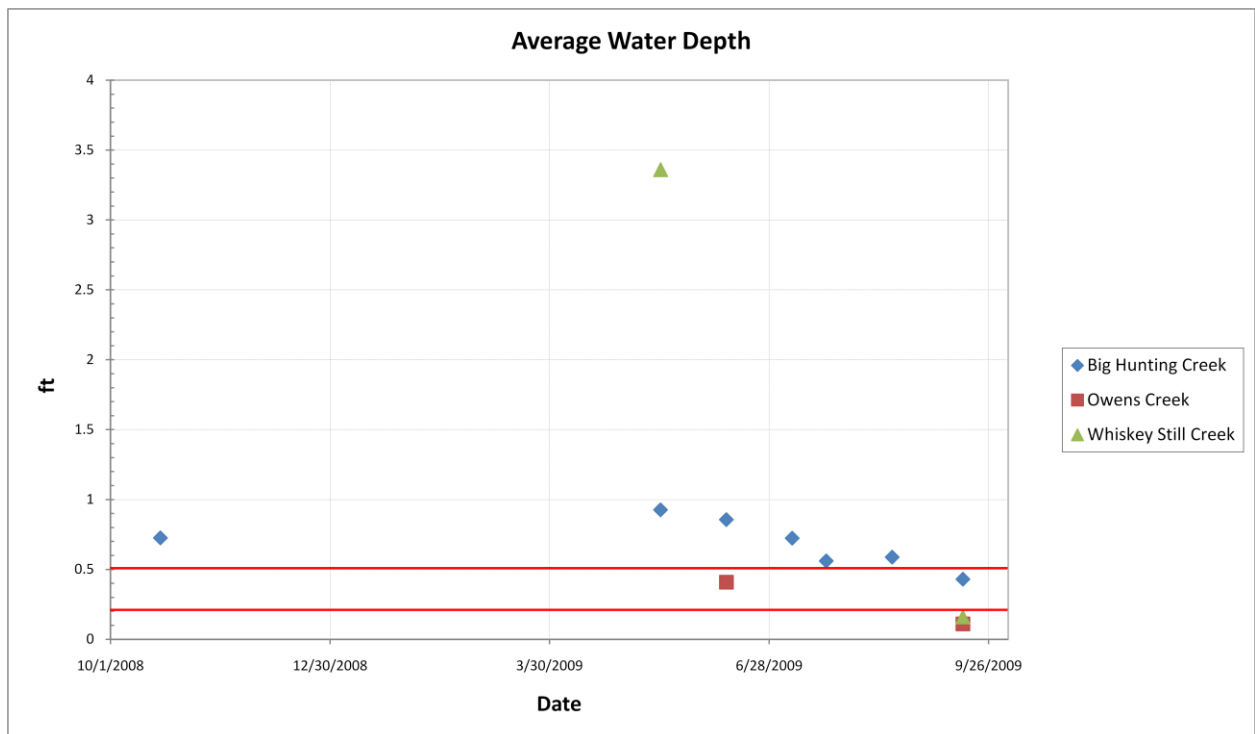


Figure 28: Average depth of Catoclin Mountain Park Streams, FY 2009. Required condition is above 0.2 foot for discharge measurements and 0.5 foot for continuous measurement with data sondes.

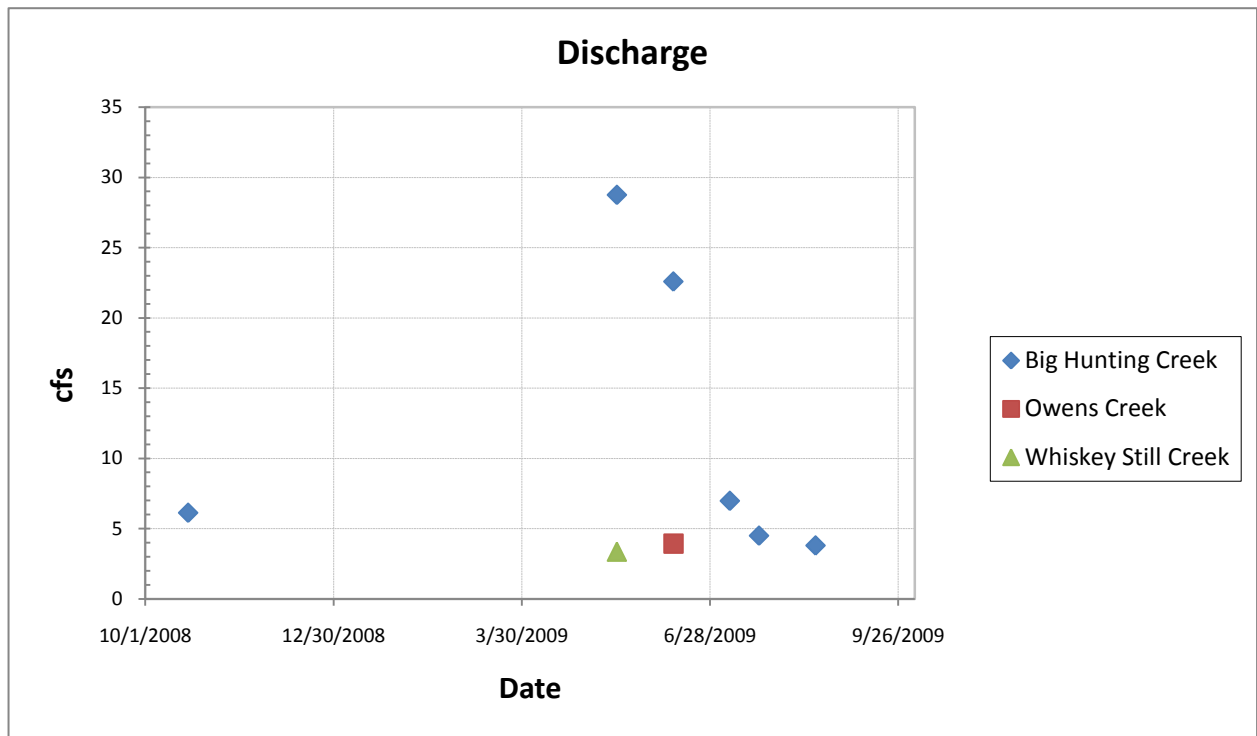


Figure 29: Discharge of Catoclin Mountain Park Streams, FY 2009.

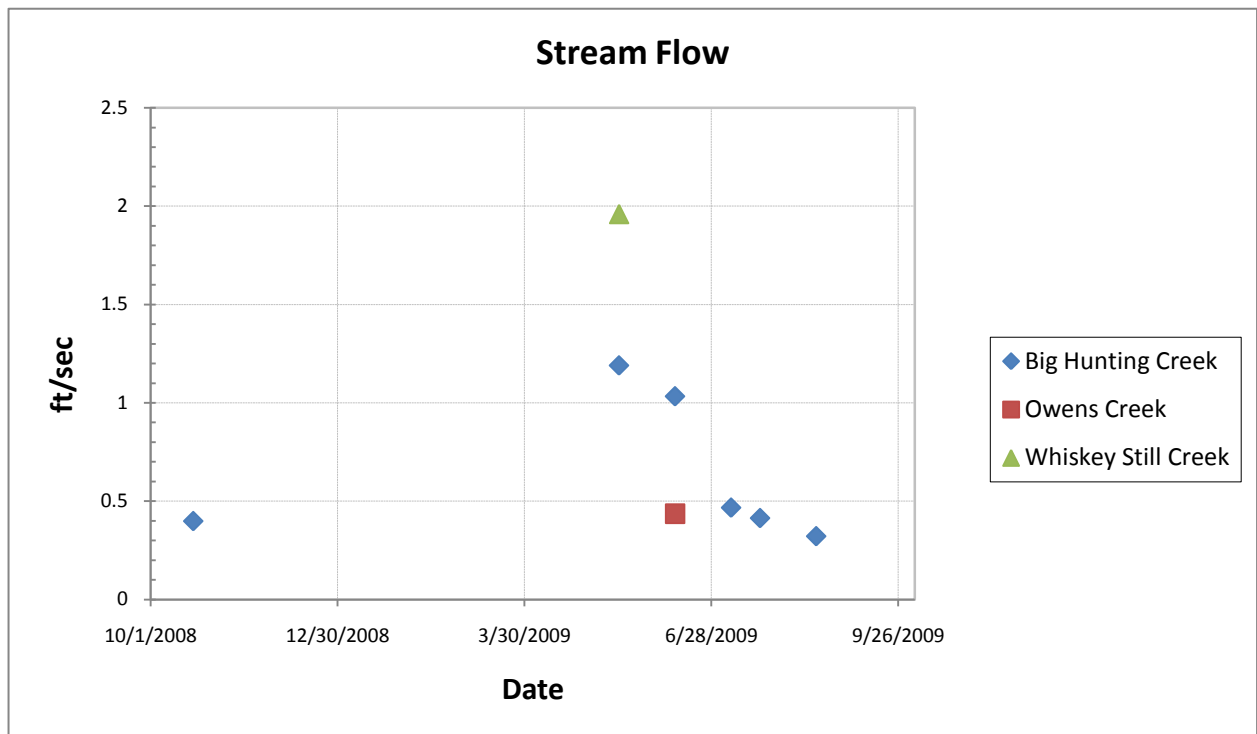


Figure 30: Flow of Catoclin Mountain Park Streams, FY 2009.

George Washington Memorial Parkway (GWMP)

The George Washington Memorial Parkway runs through Arlington and Fairfax Counties in Virginia and occurs within the Potomac River Watershed and Piedmont and Coastal Plain physiographic provinces.

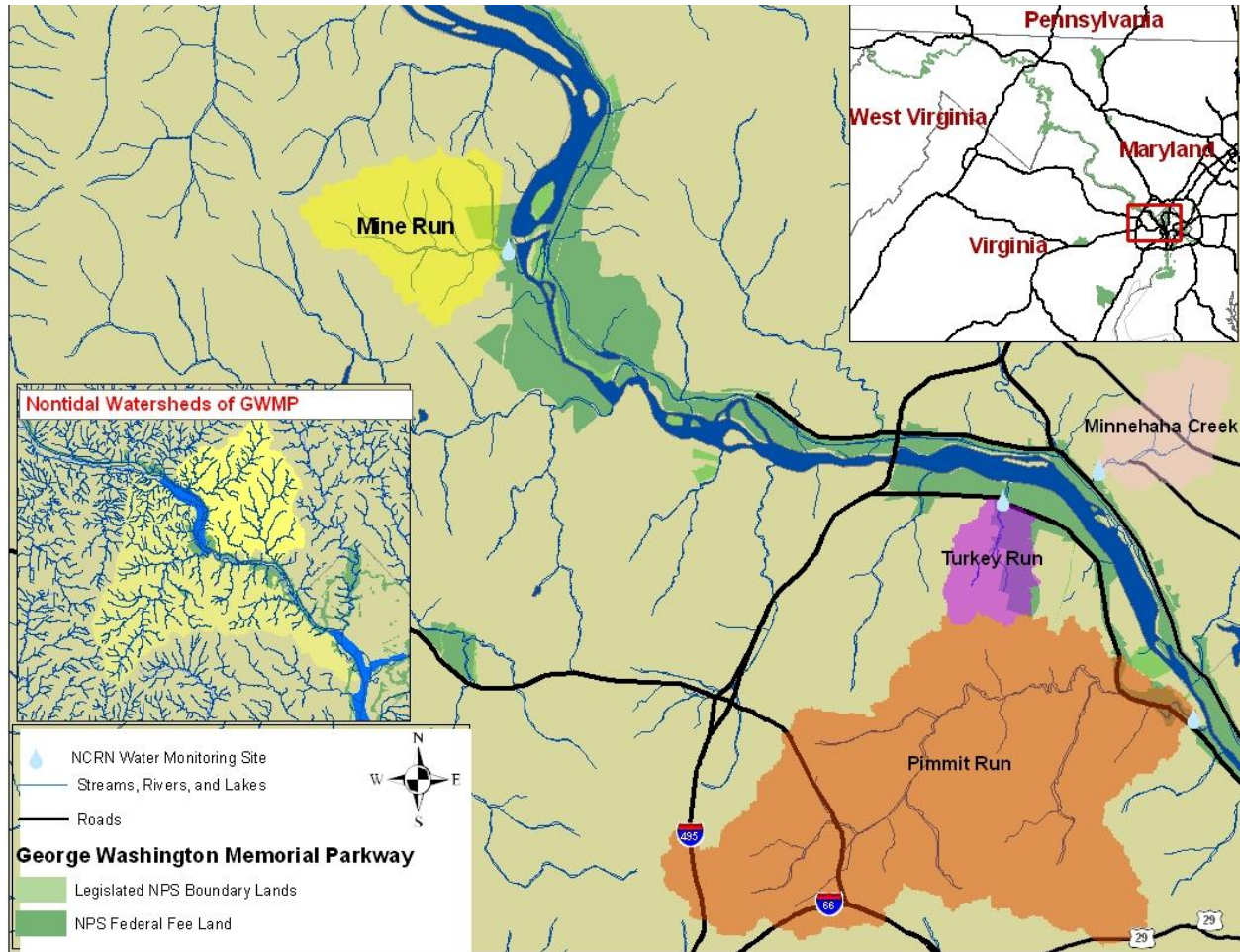


Figure 31: Relationship of the stream monitoring sites to their watersheds and the park boundary in the George Washington Memorial Parkway.

This report discusses data collected October 2008 through September 2009 in Turkey Run, Pimmit Run, Mine Run, and Minnehaha Creek along George Washington Memorial Parkway (Figure 31). Summary statistics for the time period are shown in Table 4.

Table 5: Date range, sample size (N), and data range for the vital signs data collected at George Washington Memorial Parkway.

Local Name	Units	Period of Record	N	Minimum	Maximum	Mean	Median	Standard Deviation
ANC	µeq/L	10/22/2008 - 9/24/2009	39	204	2280	1273	1168	548.6
Discharge	cfs	10/22/2008 - 9/24/2009	17	0.2	13.5	3.041	1.87	3.644
Dissolved Oxygen	mg/l	10/22/2008 - 9/24/2009	37	6.85	19.8	9.521	9	2.668
Flow	ft/sec	10/22/2008 - 9/24/2009	17	0.025	13.5	1.231	0.421	3.188
Nitrate	mg/l	10/22/2008 - 9/24/2009	38	0.8	6.3	2.321	2.05	0.9957
Ammonia	mg/l	10/22/2008 - 9/24/2009	16	0.033	1.9	0.1988	0.079	0.4574
pH	None	10/22/2008 - 9/24/2009	39	7.09	8.28	7.7	7.68	0.2359
Total Phosphorus	mg/l	10/22/2008 - 9/24/2009	39	0.12	0.62	0.2544	0.23	0.107
Salinity	ppt	10/22/2008 - 9/24/2009	39	0.05	1.4	0.2074	0.16	0.2166
Specific Conductance	µS/cm	10/22/2008 - 9/24/2009	39	115.6	2754	406.8	342	428.3
Water Depth	ft	10/22/2008 - 9/24/2009	21	0.2	1.179	0.6249	0.5	0.2706
Water Temperature	°C	10/22/2008 - 9/24/2009	39	0.15	23.7	14.26	16.9	7.048
Wetted Width	ft	10/22/2008 - 9/24/2009	32	2.25	35	14.55	11.66	11.54

Four sites were monitored in the park on a monthly basis in 2009 for dissolved oxygen, pH, specific conductance, temperature, acid neutralizing capacity, nitrate, ammonia, and total phosphorus. Data was not collected in December and February due to extreme winter weather conditions and frozen streams.

In 2009 pH was always in the range supporting aquatic life (Figure 33). Acid neutralizing capacity values were always well above the threshold except for March 2009 when Mine Run, Pimmit Run, and Turkey Run values were at or barely above 200 µeq/L (Figure 32). Specific conductance is usually below the current threshold of 400 uS/cm for all sites except Minnehaha Creek which was always high, and Pimmit and Turkey Runs in late winter 2008 (Figure 34). All GWMP streams remained freshwater (salinity<0.5 ppt, Figure 35) except for Minnehaha Creek in January 2009. Minnehaha receives runoff from streets in Bethesda, MD and presumably de-icing treatments in winter.

Ammonia was barely detected and never exceeded threshold (0.445) 2005 – 2008 except at Pimmit Run where the threshold was exceeded in September 2009 (Figure 38). In 2009 all sites were impaired for nitrate in January (Figure 37). Minnehaha Creek was always impaired for nitrate. Pimmit Run was impaired for nitrate in April and June. Turkey Run was impaired for nitrate June through September 2009. Total phosphorus was consistently above the desired range of 0.1 mg/L at all sites (Figure 39). There were no DO values below the desired level of 5mg/L in 2009 (Figure 36).

Water temperature followed expected seasonal trends and stayed within the comfort zone of desired organisms (Figure 40). For the 2009 sampling year and beyond, Difficult Run will be dropped from the sampling design, due to the fact that VA DEQ lists it as a 5th order stream in their annual stream quality reporting. Wetted width fluctuated less than 5 feet per month in

Minnehaha Creek, Pimmit Run, and Turkey Run (Figure 41). Mine Run which is sampled at a culvert and should not change, fluctuated by more than 5 feet in a month. There was only sufficient depth (Figure 42) to measure flow (Figure 44) and discharge (Figure 43) in Minnehaha Creek and Pimmit Run in October 2008, and April through July 2009, and in Mine Run April through July 2009, and in Turkey Run May and July 2009.

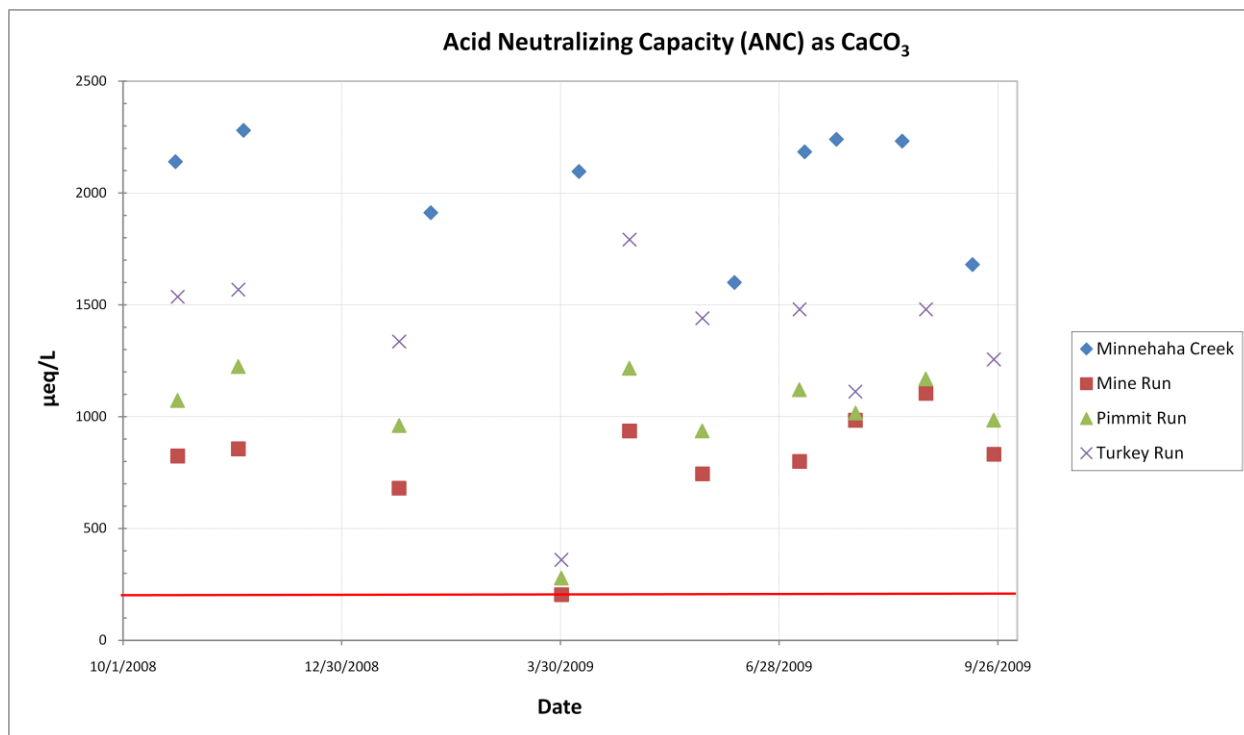


Figure 32: ANC in George Washington Memorial Parkway Streams, FY 2009. Desired condition is above the 200 ueq/L threshold for non-karst waters shown in red.

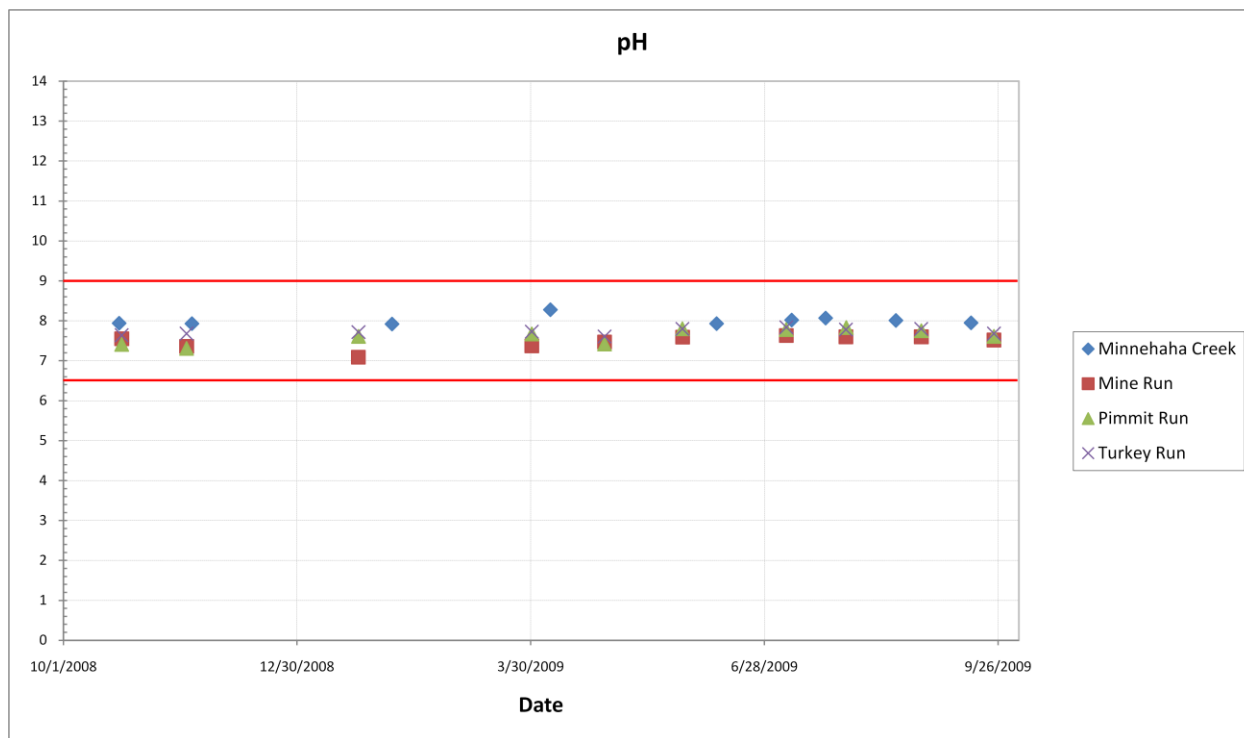


Figure 33: pH in George Washington Memorial Parkway Streams, FY2009. Desired condition is between the 6.5 and 9.0 thresholds shown in red.

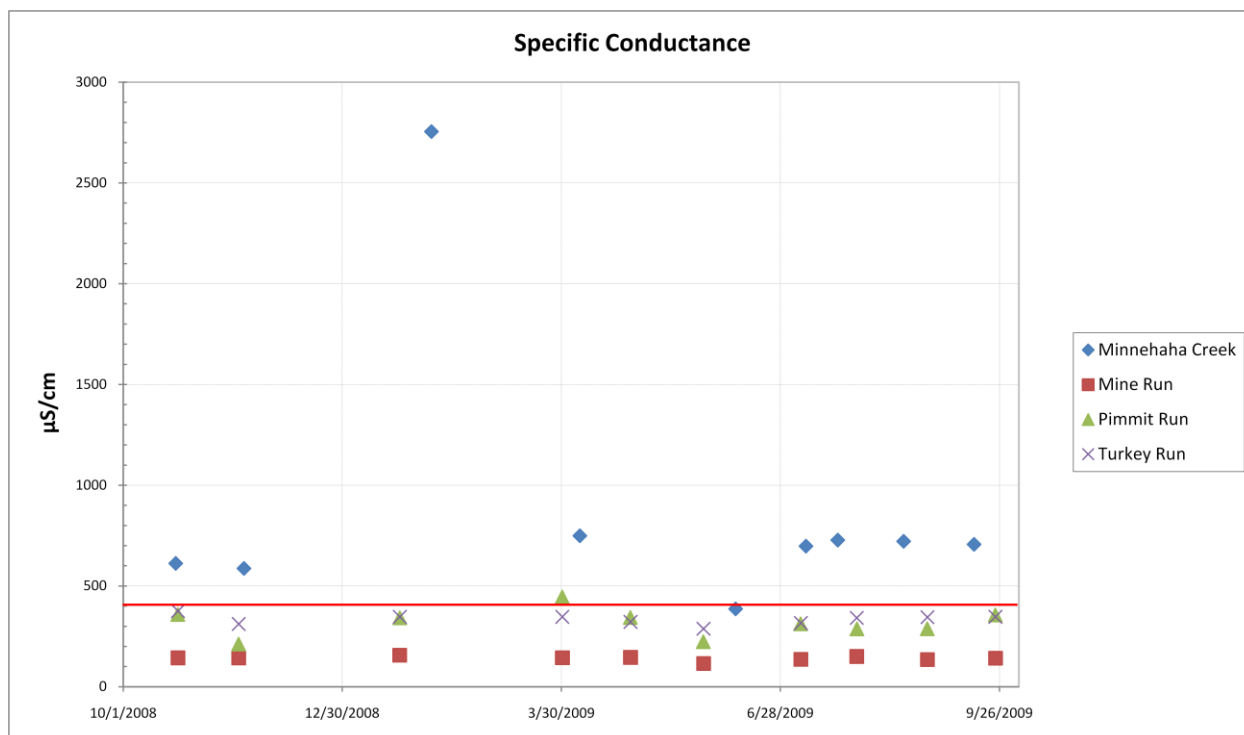


Figure 34: Specific Conductance in George Washington Memorial Parkway Streams FY 2009. Desired condition is below the 400 $\mu\text{S/cm}$ threshold shown in red.

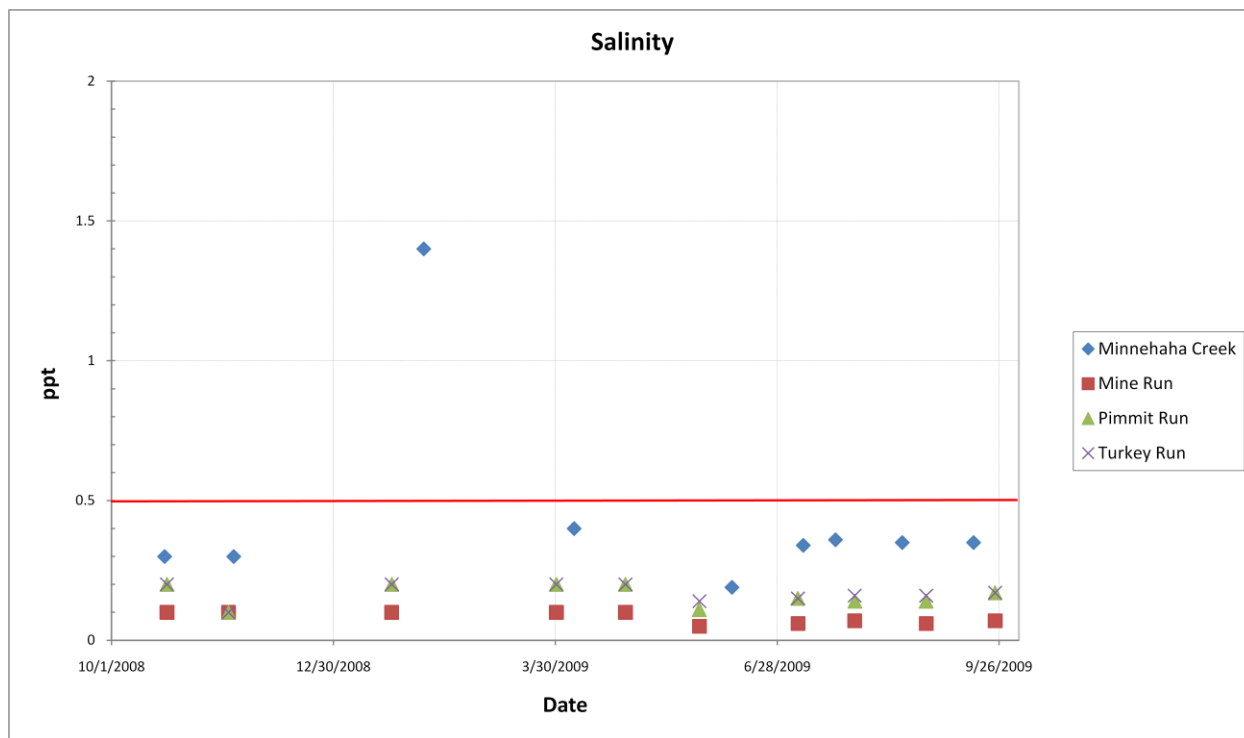


Figure 35: Salinity in George Washington Memorial Parkway Streams over time. Desired condition is below the 0.5ppt threshold shown in red.

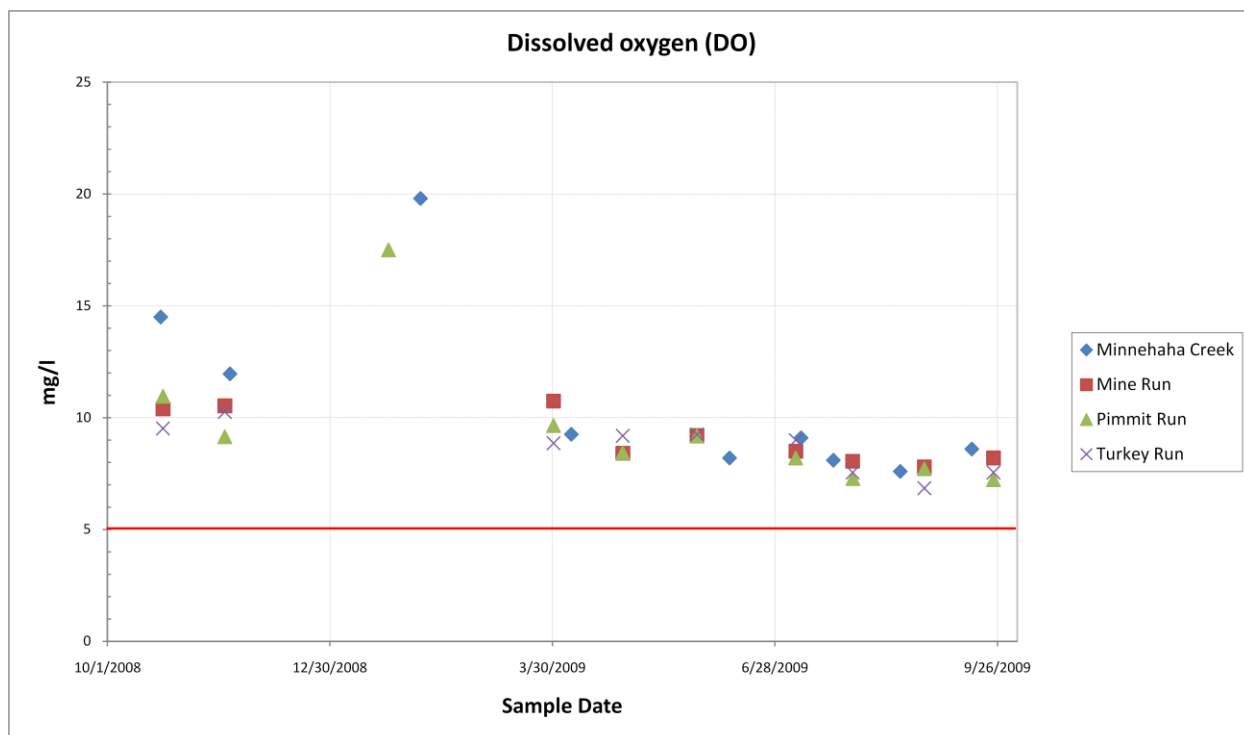


Figure 36: Dissolved Oxygen in George Washington Memorial Parkway Streams, FY 2009. Desired condition is above the 5.0mg/l threshold shown in red.

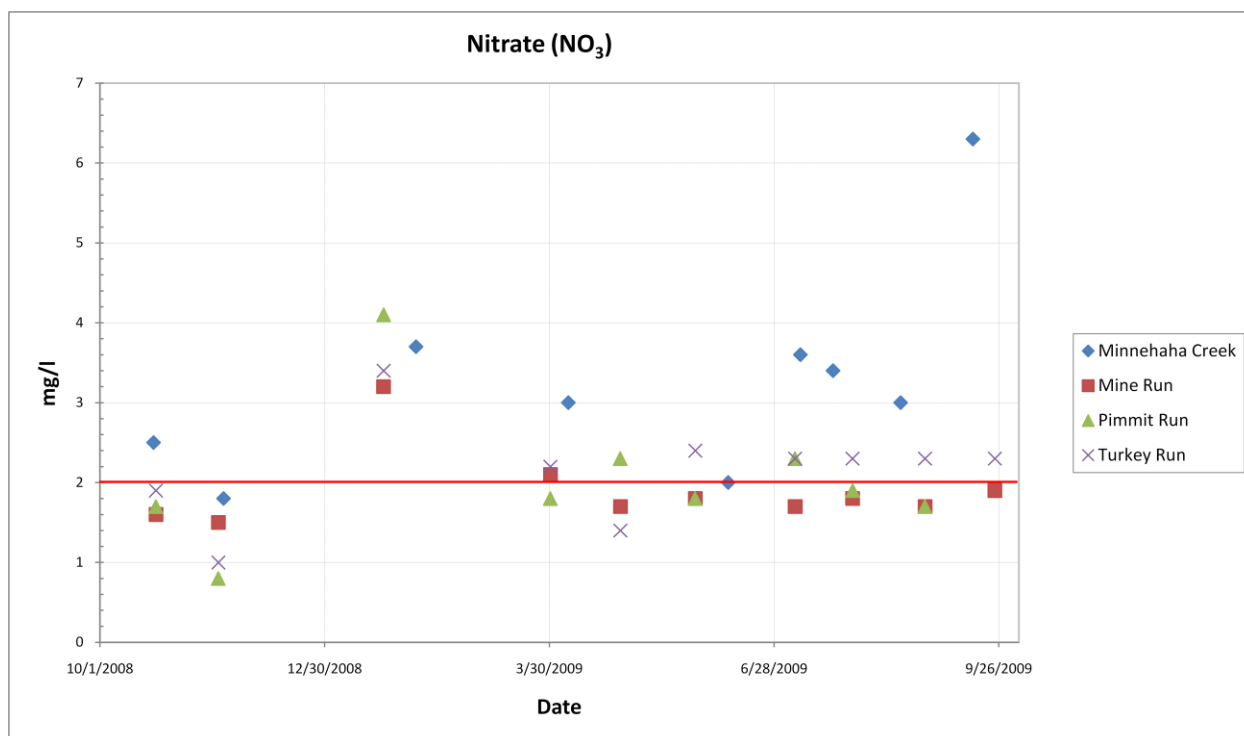


Figure 37: Nitrate in George Washington Memorial Parkway Streams FY 2009. Desired condition is below the 2.0 mg/L threshold shown in red.

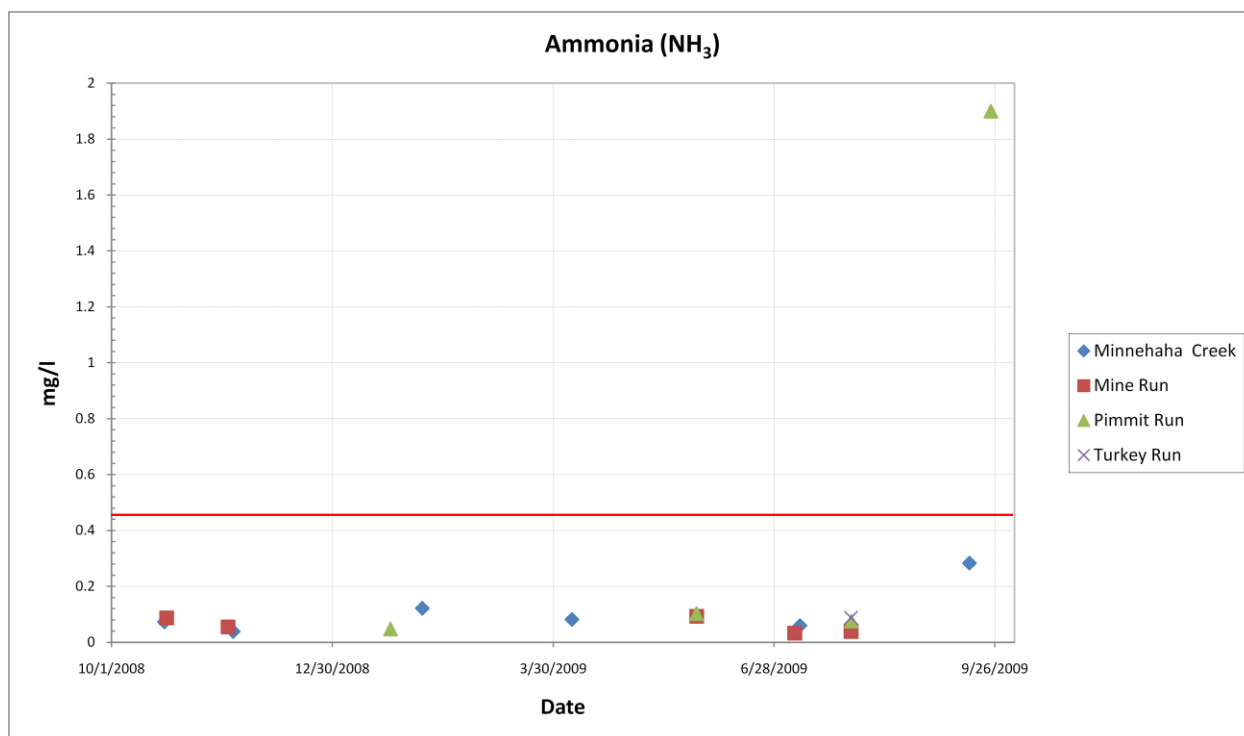


Figure 38: Ammonia in George Washington Memorial Parkway Streams FY 2009. Desired condition is below the 0.443 mg/L threshold shown in red.

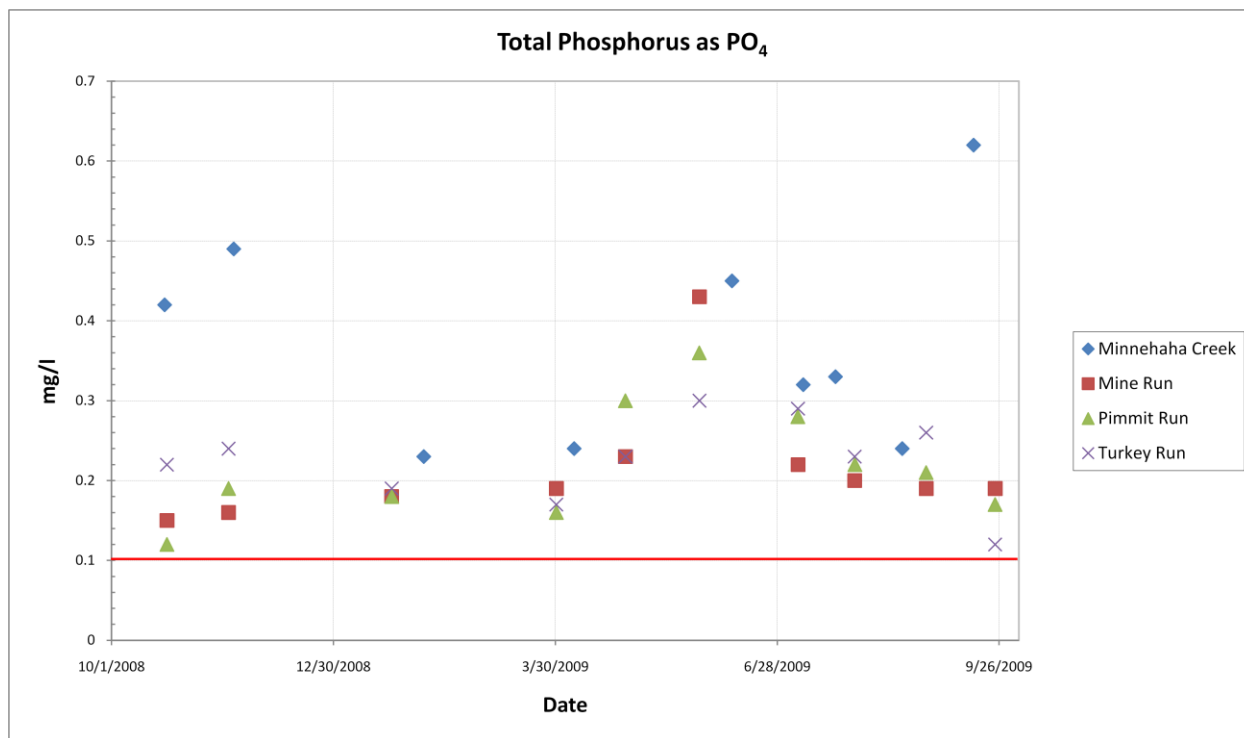


Figure 39: Total Phosphorus in George Washington Memorial Parkway Streams FY 2009. Desired condition is below the 0.1 mg/L threshold shown in red.

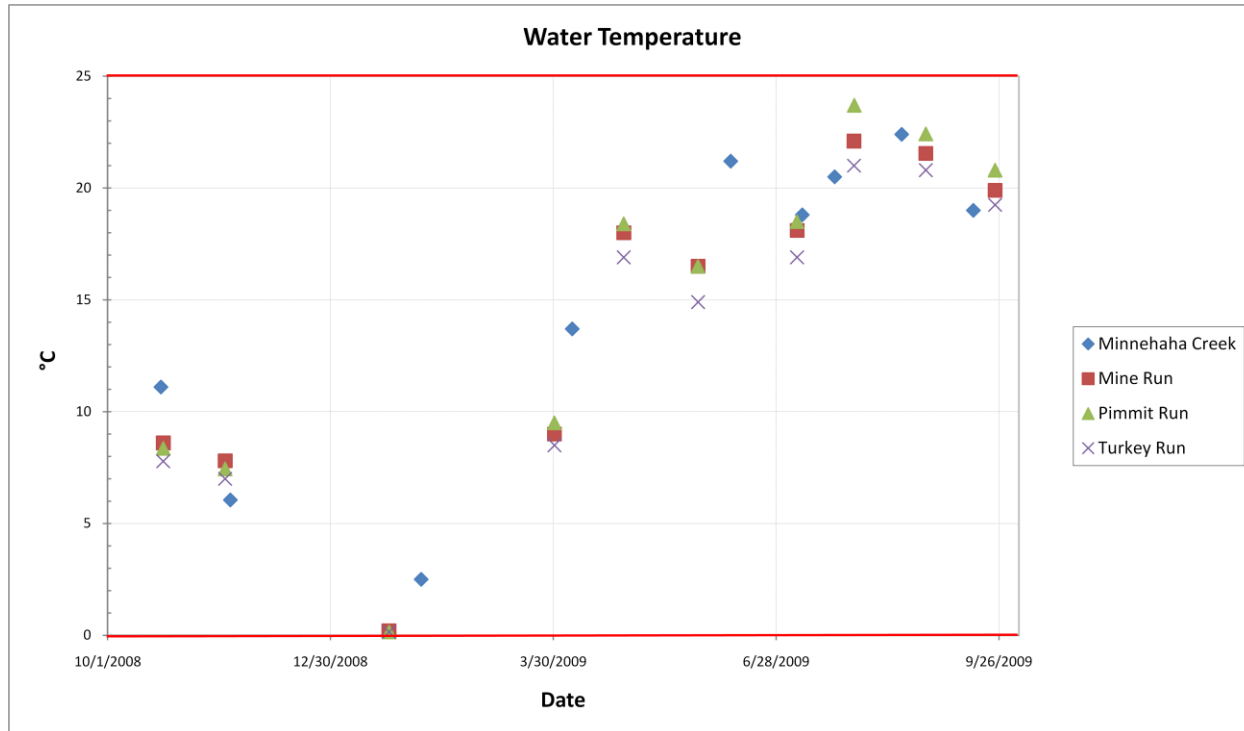


Figure 40: Temperatures in George Washington Memorial Parkway Streams FY 2009. Ideal temperatures for aquatic life are between 0 and 25 °C.

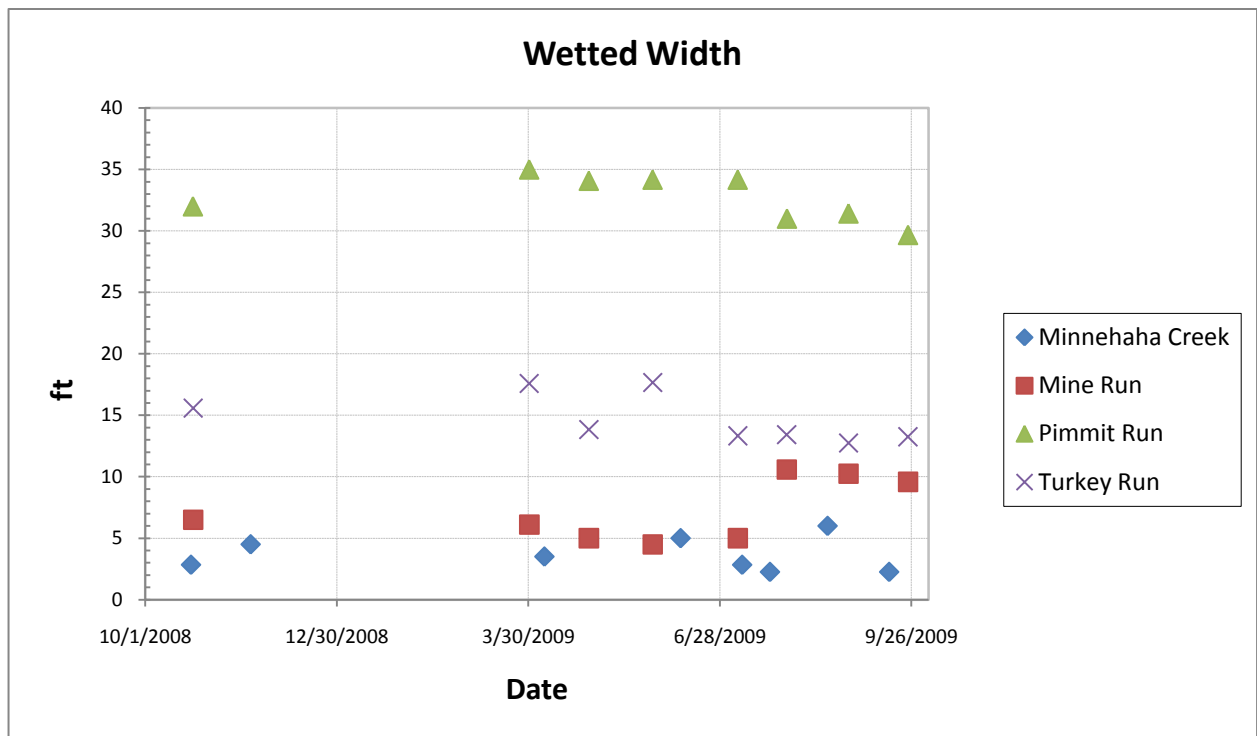


Figure 41: Wetted Width in George Washington Memorial Parkway Streams FY 2009.

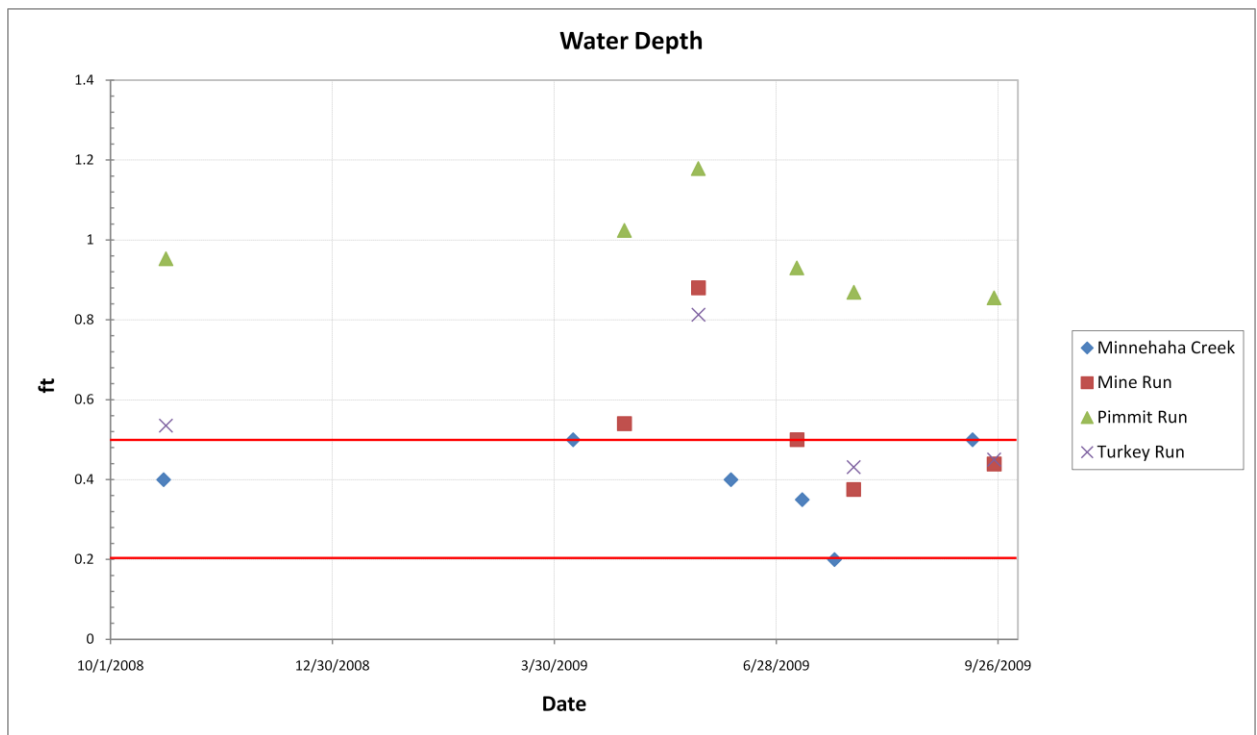


Figure 42: Average depth in George Washington Memorial Parkway Streams FY 2009. Required condition is above 0.2 foot for discharge measurements and 0.5 foot for continuous measurement with data sondes.

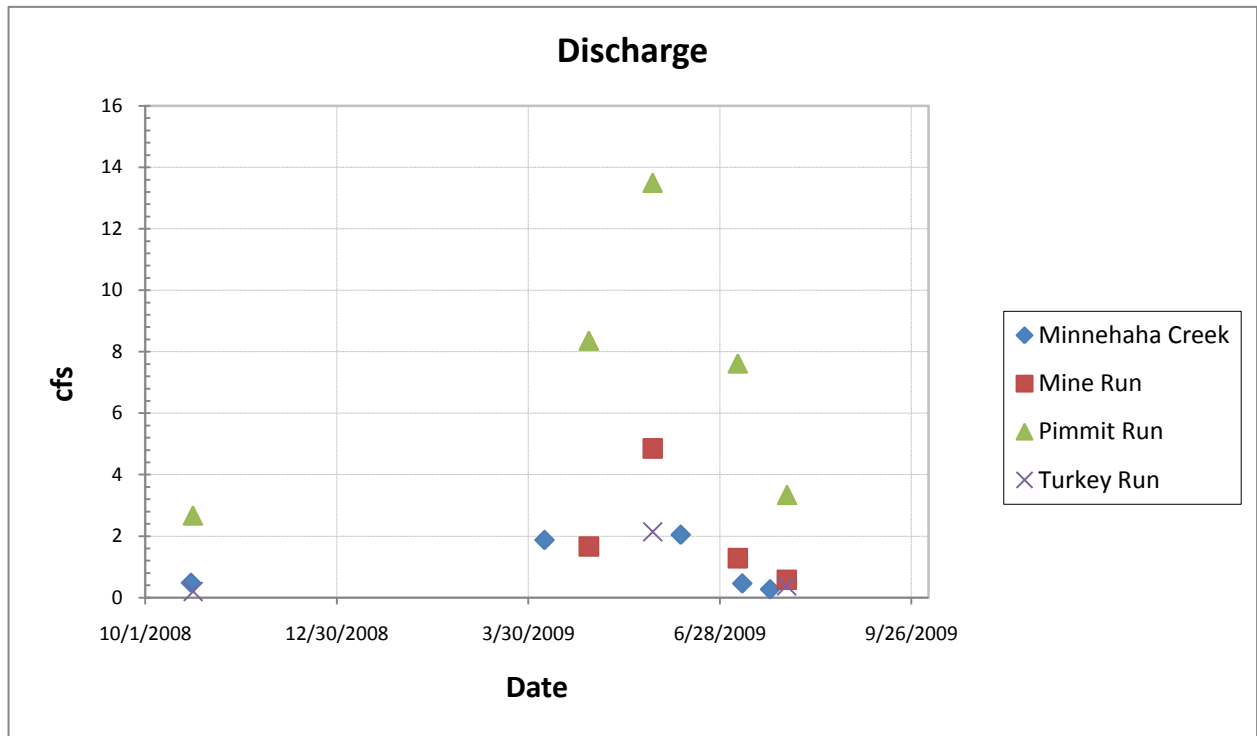


Figure 43: Discharge in George Washington Memorial Parkway Streams FY 2009.

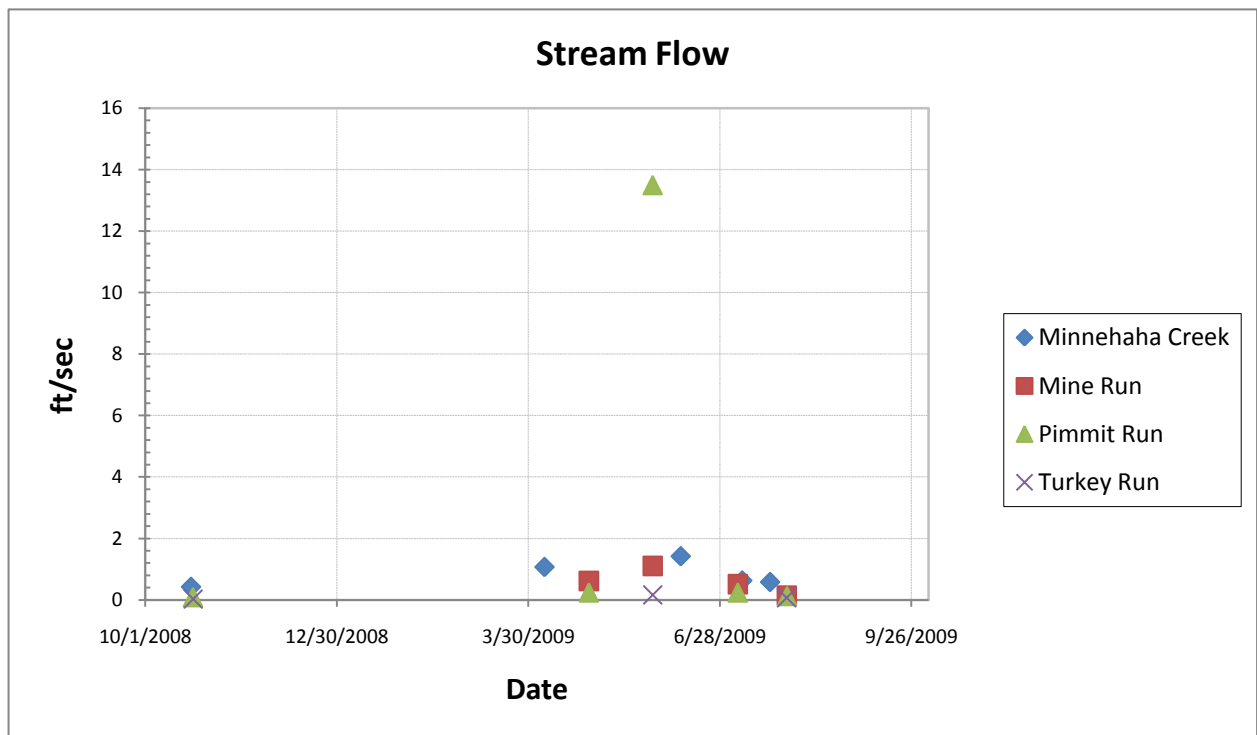


Figure 44: Flow in George Washington Memorial Parkway Streams, FY 2009.

Harpers Ferry National Historical Park (HAFE)

Harpers Ferry is located in the Great Valley subprovince of the Ridge and Valley physiographic province, within the Shenandoah and Potomac River Watersheds. It stretches across Jefferson County, West Virginia; Loudoun County, Virginia; and Frederick County, Maryland.

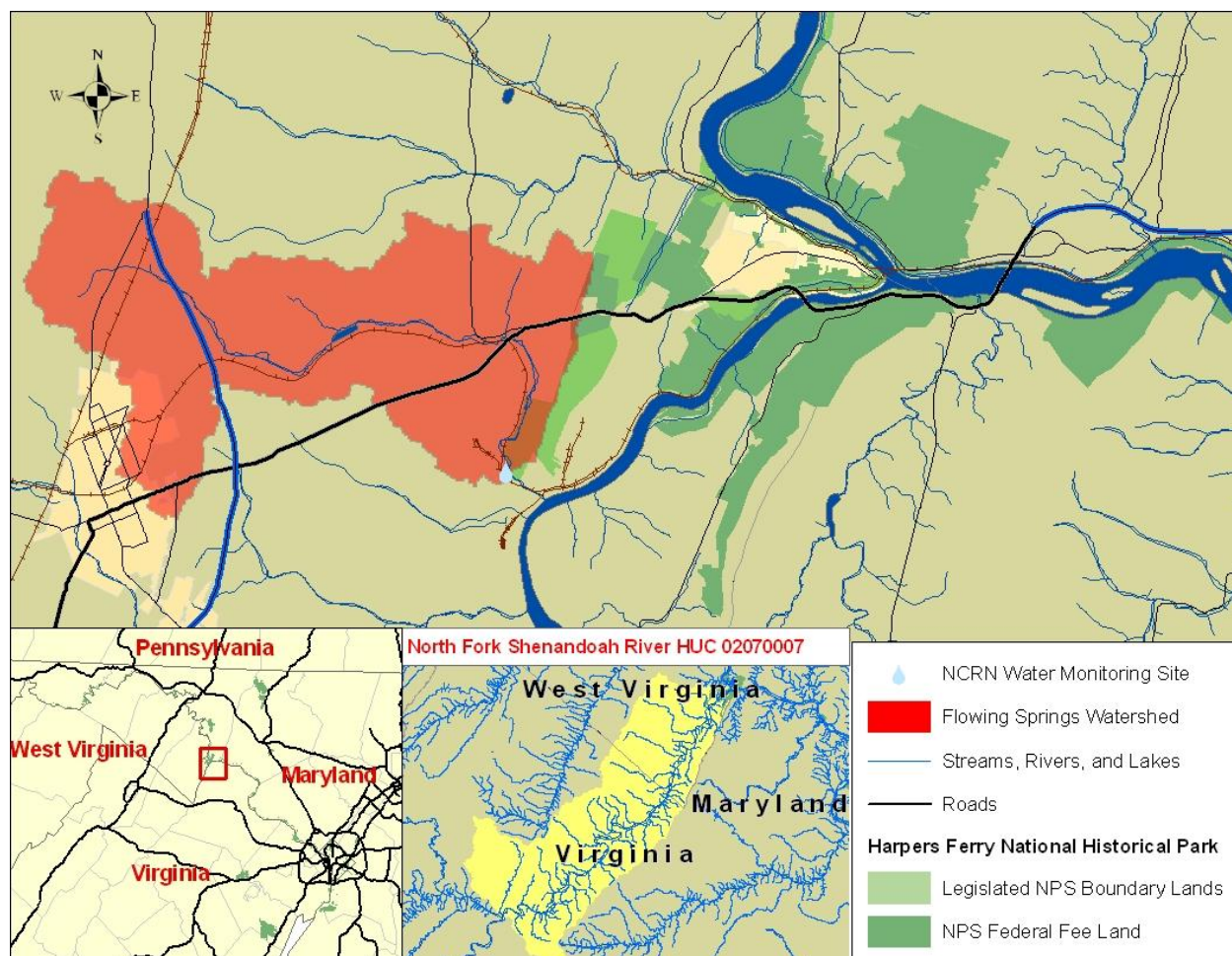


Figure 45: Relationship of the Flowing Springs monitoring site to the watershed and the park boundary.

The Potomac and Shenandoah Rivers run through the park but are not considered part of the park but there are some small tributaries that cross the park. Elk Run, for example, is the major water supply for the town and a 500-foot section runs through the park before it empties into the Potomac River. A short portion of Piney Run crosses the park before it also enters the Potomac. The only stream with any appreciable length on park property that would be affected by park management is Flowing Springs, which winds for about one mile along the park before it enters the Shenandoah. Wetlands/water are impacted by development including roads and possibly de-icing salts used in the winter. In addition, many homes have septic systems that drain into streams and probably affect water quality.

This report discusses data collected October 2008 through September 2009 in Flowing Springs (Figure 45). Summary statistics for the time period are shown in Table 5. One site was

monitored in the park on a monthly basis for dissolved oxygen, pH, specific conductance, temperature, acid neutralizing capacity, nitrate, ammonia, total phosphorus, depth, wetted width, flow and discharge. Data were not collected in Flowing Spring in December 2008, and February, March and May 2009 due to inclement weather or frozen or dry stream conditions.

Table 6: Date range, sample size (N), and data range for the vital signs data collected at Harper's Ferry National Historical Site.

Local Name	Units	Period of Record	N	Minimum	Maximum	Mean	Median	Standard Deviation
ANC	µeq/L	10/22/2008 - 9/15/2009	9	4460	6240	5233	5060	573
Discharge	cfs	10/22/2008 - 9/15/2009	4	1.76	4.37	3.51	---	1.21
Dissolved Oxygen	mg/l	10/22/2008 - 9/15/2009	8	5.61	11.90	7.79	---	2.29
Flow	ft/sec	10/22/2008 - 9/15/2009	4	0.7542	1.0200	0.8702	---	0.1308
Nitrate	mg/l	10/22/2008 - 9/15/2009	9	1.5	4.2	2.8	2.8	1.0
Ammonia	mg/l	10/22/2008 - 9/15/2009	6	0.046	0.151	0.092	---	0.034
pH	None	10/22/2008 - 9/15/2009	9	8.02	8.28	8.15	8.13	0.07
Total Phosphorus	mg/l	10/22/2008 - 9/15/2009	9	0.25	0.79	0.41	0.41	0.16
Salinity	ppt	10/22/2008 - 9/15/2009	9	0.29	0.50	0.37	0.36	0.07
Specific Conductance	µS/cm	10/22/2008 - 9/15/2009	9	597.5	1037.0	746.0	727.0	151.2
Water Depth	ft	10/22/2008 - 9/15/2009	4	0.258	0.379	0.334	---	0.052
Water Temperature	°C	10/22/2008 - 9/15/2009	9	2.7	24.7	15.1	19.5	8.0
Wetted Width	ft	10/22/2008 - 9/15/2009	8	6.50	21.58	12.06	---	5.23

Much of the park is maintained as agriculture to replicate the historical Civil War landscape. The agriculture lease agreements allow for fertilizer and pesticide applications and some fields are leased for livestock grazing. These are probably among the sources of nitrate and phosphorus. Other sources include acid rain and atmospheric deposition as well as background levels in groundwater.

Measurements of dissolved oxygen were always above the desired minimum of 5 mg/L to sustain aquatic life (Figure 53). Nitrate was only at or below threshold in April, July and September 2009 (Figure 51). Ammonia never exceeded threshold in 2009 (Figure 50). Total Phosphorus always exceeded threshold (Figure 52).

The pH was always within the range comfortable to aquatic life (Figure 47). ANC was always well above the desired level (Figure 46). The higher pH and acid neutralizing capacity of Flowing Spring Run are due to dissolution of the limestone and dolomite bedrock. This may also contribute to the higher specific conductance, though fertilizers, pesticides, and livestock runoff may also contribute. Limestone (CaCO_3) and dolomite ($\text{CaMg}(\text{CO}_3)_2$) are ionic salts that

dissociate in pure water to their constituent ions: Ca^{2+} and CO_3^{2-} ; $\text{Ca}^{2+} + \text{Mg}^{2+} + 2 \text{CO}_3^{2-}$. Groundwater in karst areas can also contain sulfate ions from gypsum beds and weathered sulfite materials, chlorides from deeper circulating ground water and seawater mining, sodium, potassium, dissolved oxygen. Hilderbrand et al. (2005) speculated the high pH recorded at some water quality sampling sites may be in response to agricultural lime applications in the area. This increase in dissolved ions also increases the specific conductance (White 1998). Specific conductance always exceeded the threshold (Figure 48). Throughout 2009, Flowing Springs was within the limits of 0.5 ppt salinity for a freshwater stream (Figure 49). Water temperature follows expected seasonal trends and stays in the comfort range of most aquatic organisms (Figure 54).

There was only sufficient depth (Figure 56) to measure flow (Figure 58) and discharge (Figure 57) in Flowing Springs in October 2008 and March, June, and July 2009. Wetted width of Flowing Springs fluctuates by less than 10 feet per month but 15 feet throughout the year (Figure 55).

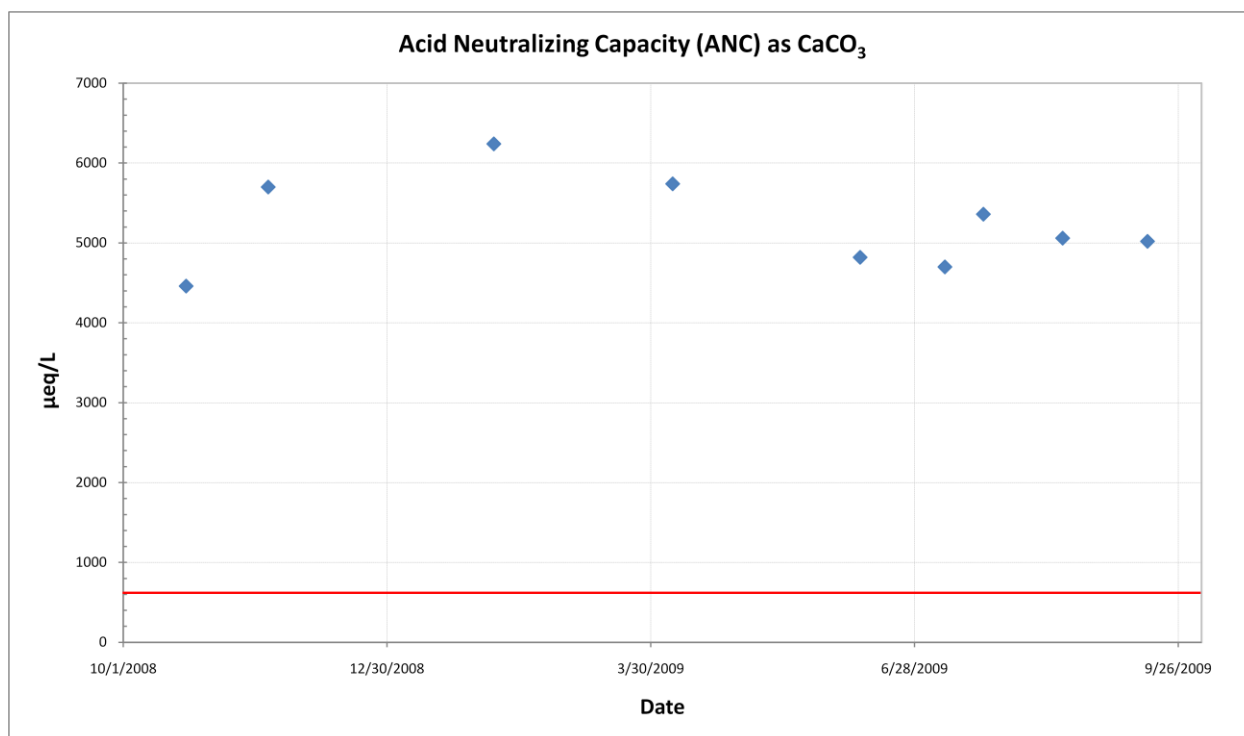


Figure 46: ANC in Flowing Springs in FY 2009. Desired condition is above the 600 ueq/L threshold for karst waters shown in red.

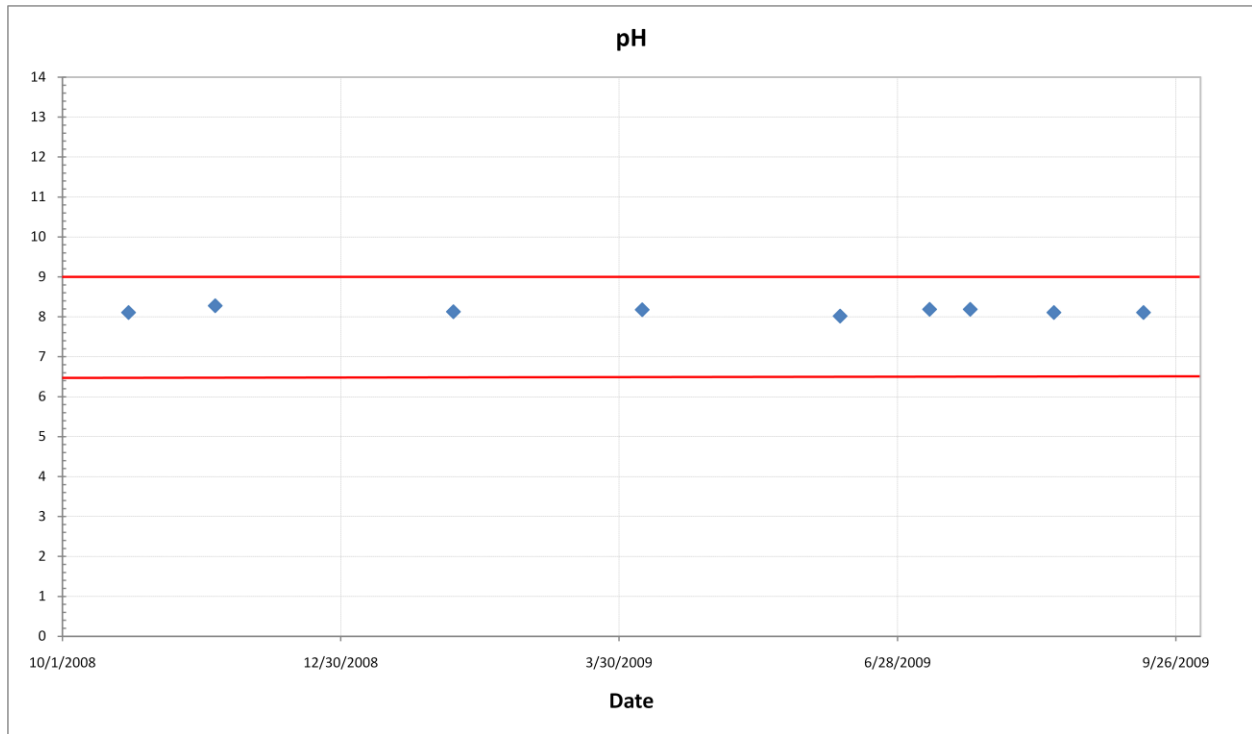


Figure 47: pH in Flowing Springs in FY 2009. Desired condition is between the 6.5 and 9.0 thresholds shown in red.

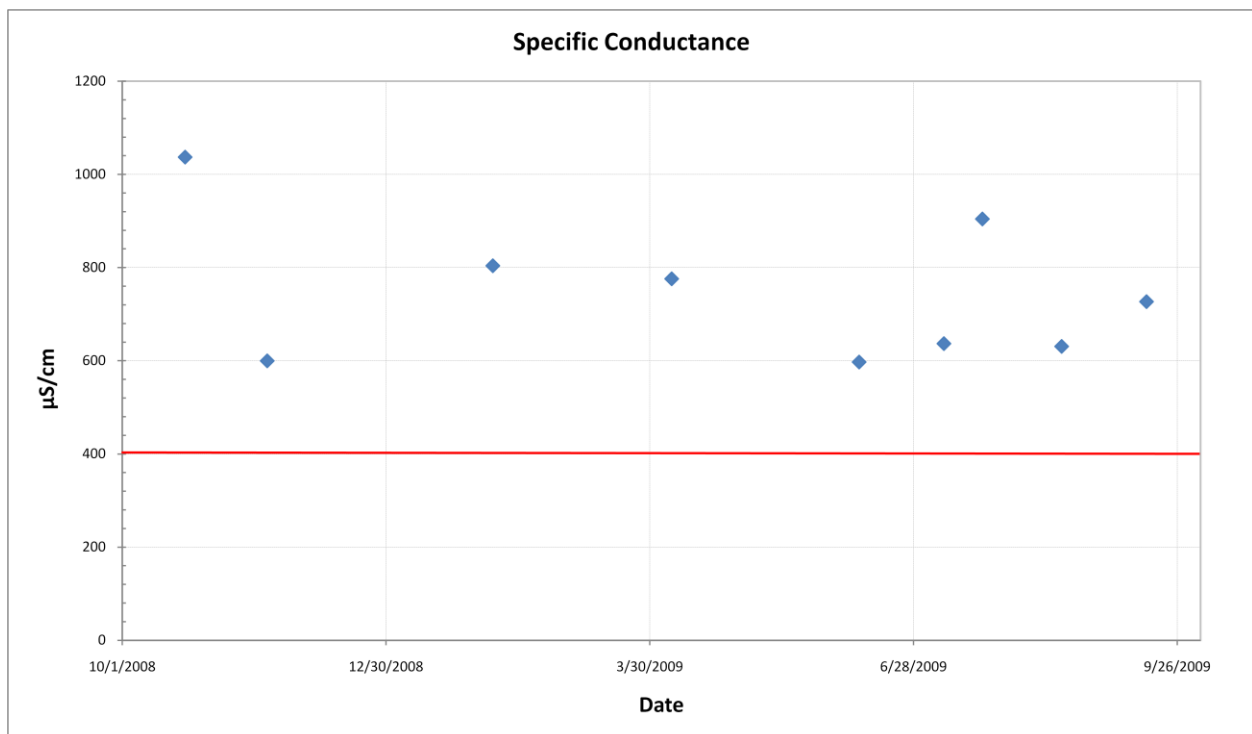


Figure 48: Specific Conductance in Flowing Springs, FY 2009. Desired condition is below the 400 µS/cm threshold shown in red.

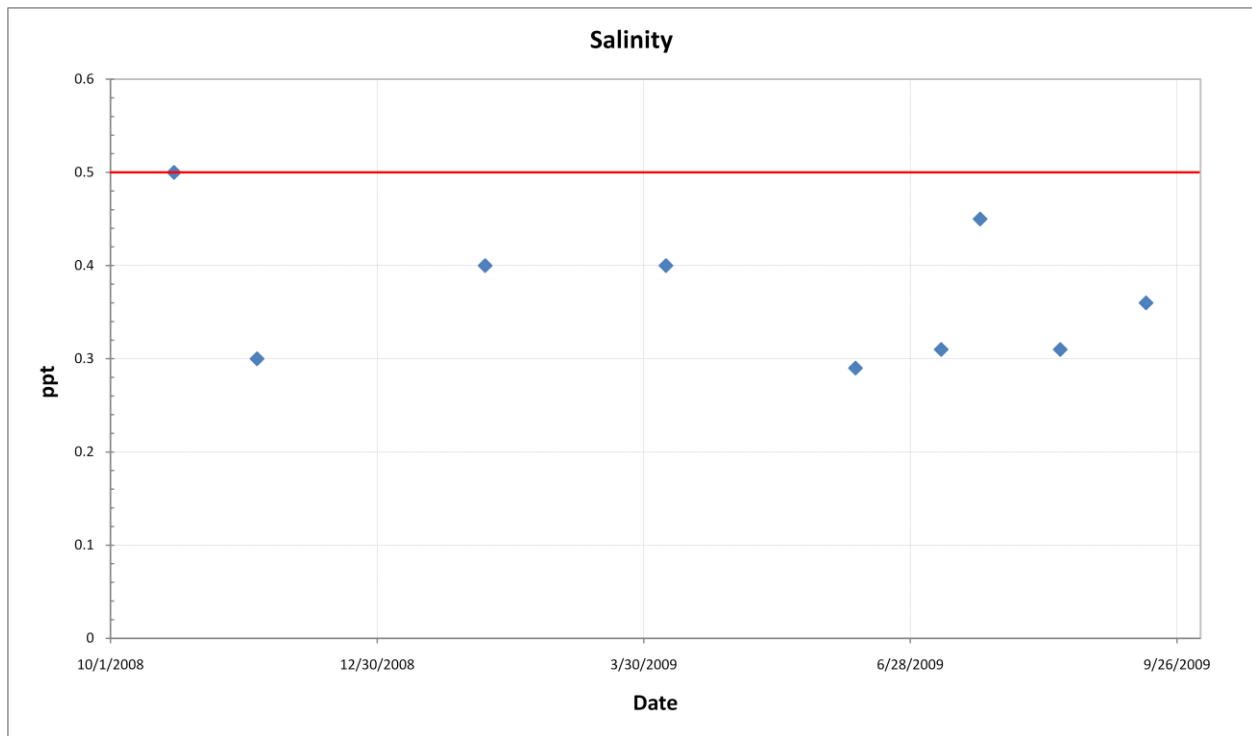


Figure 49: Salinity in Flowing Springs FY 2009. Desired condition is below the 0.5 ppt threshold shown in red.

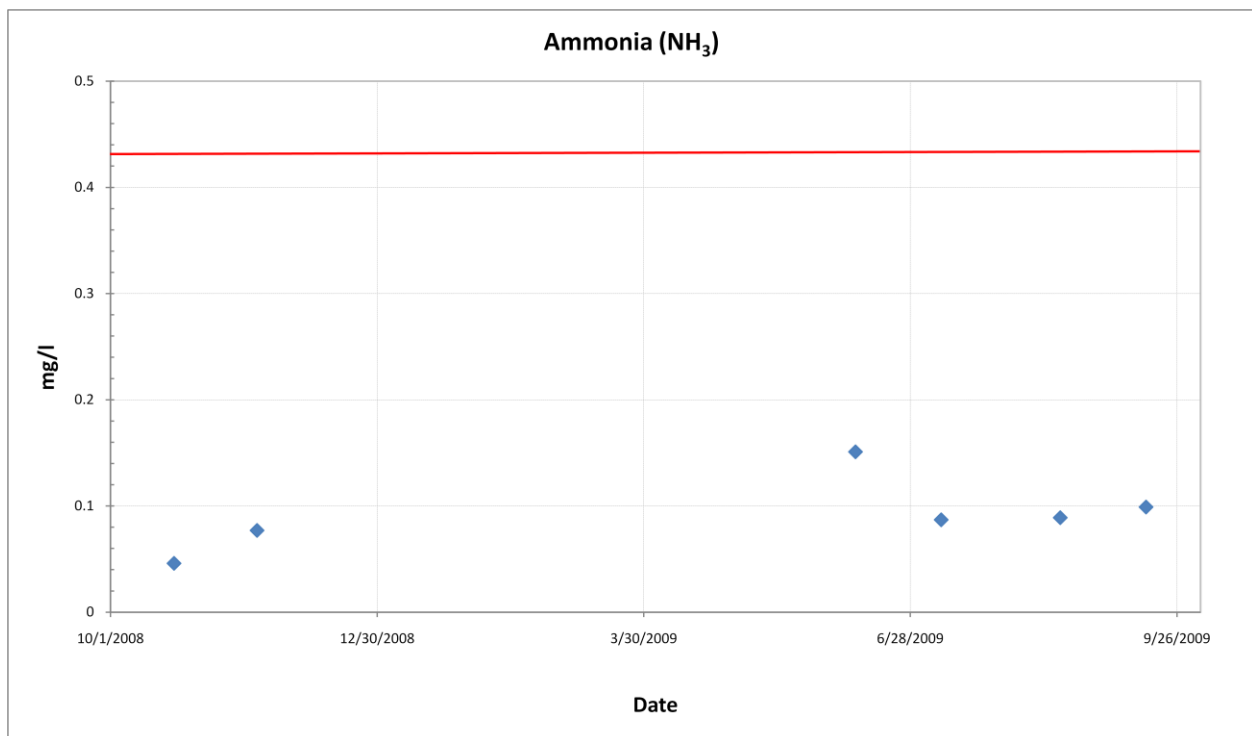


Figure 50: Ammonia in Flowing Springs, FY 2009. Desired condition is below the 0.443 threshold shown in red.

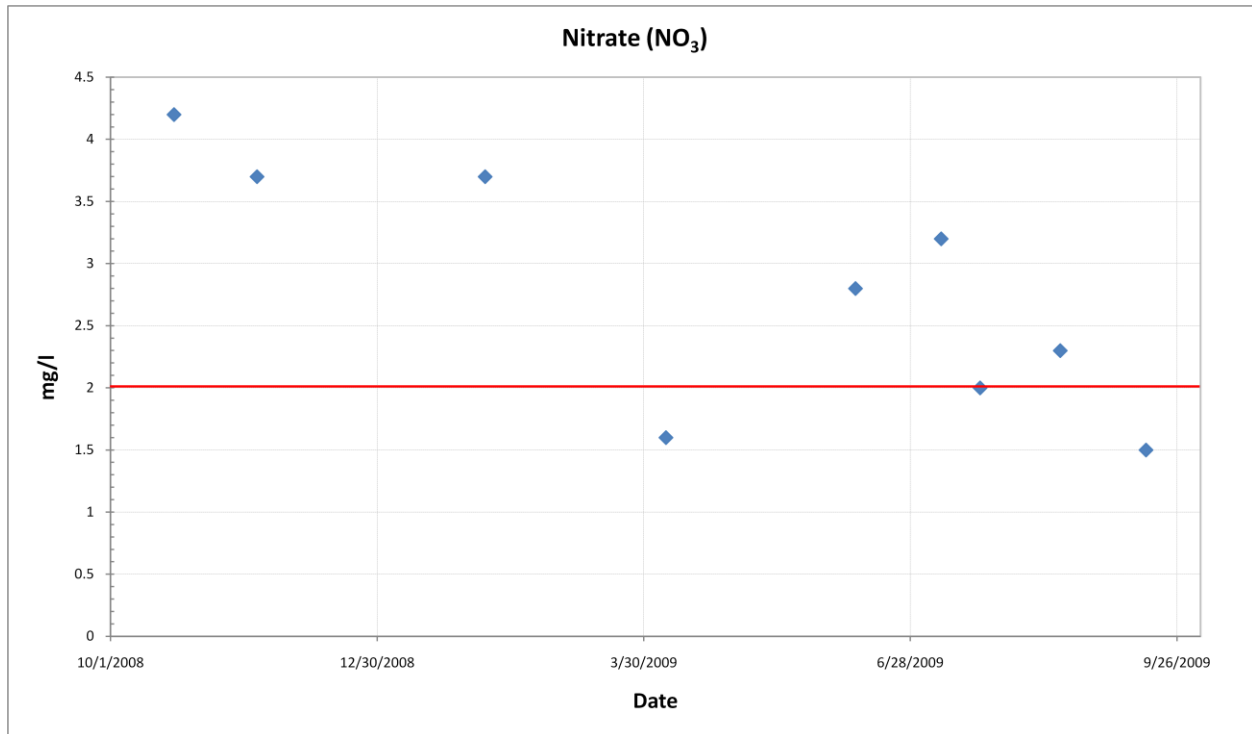


Figure 51: Nitrate in Flowing Springs, FY 2009. Desired condition is below the 2.0 mg/L threshold shown in red.

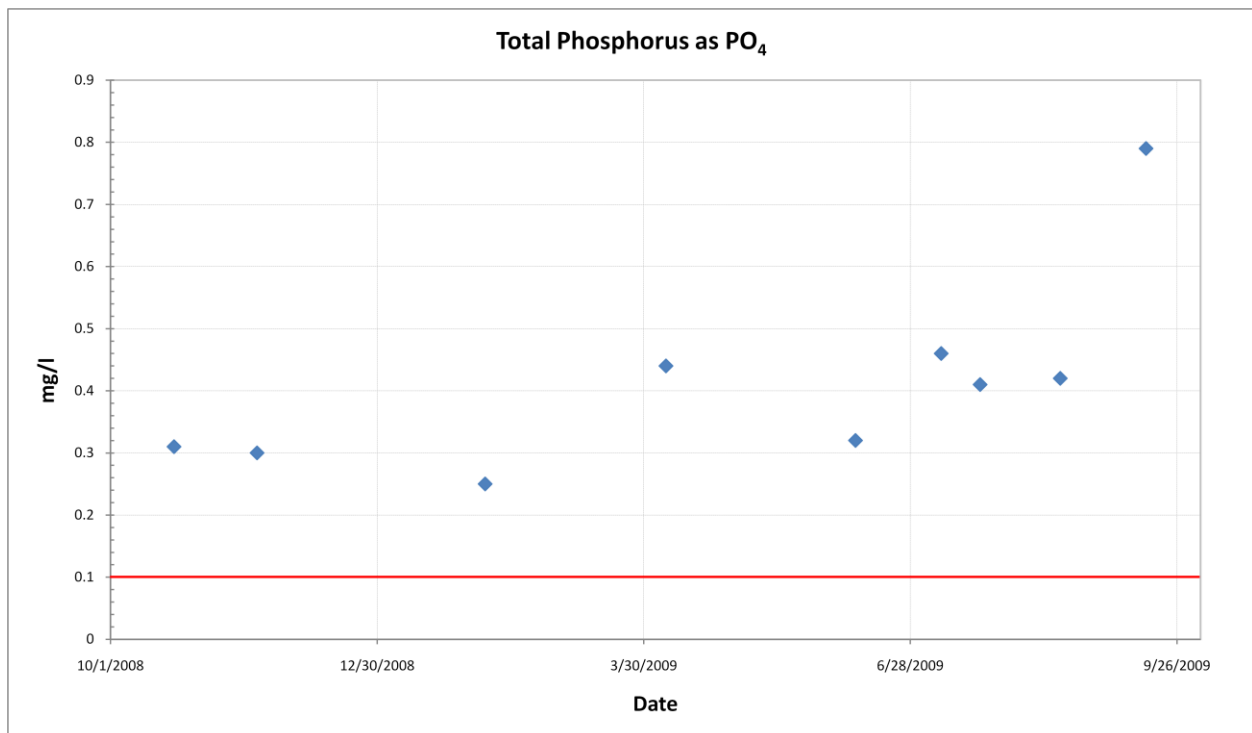


Figure 52: Total Phosphorus in Flowing Springs, FY 2009. Desired condition is below the 0.1 mg/L threshold shown in red.

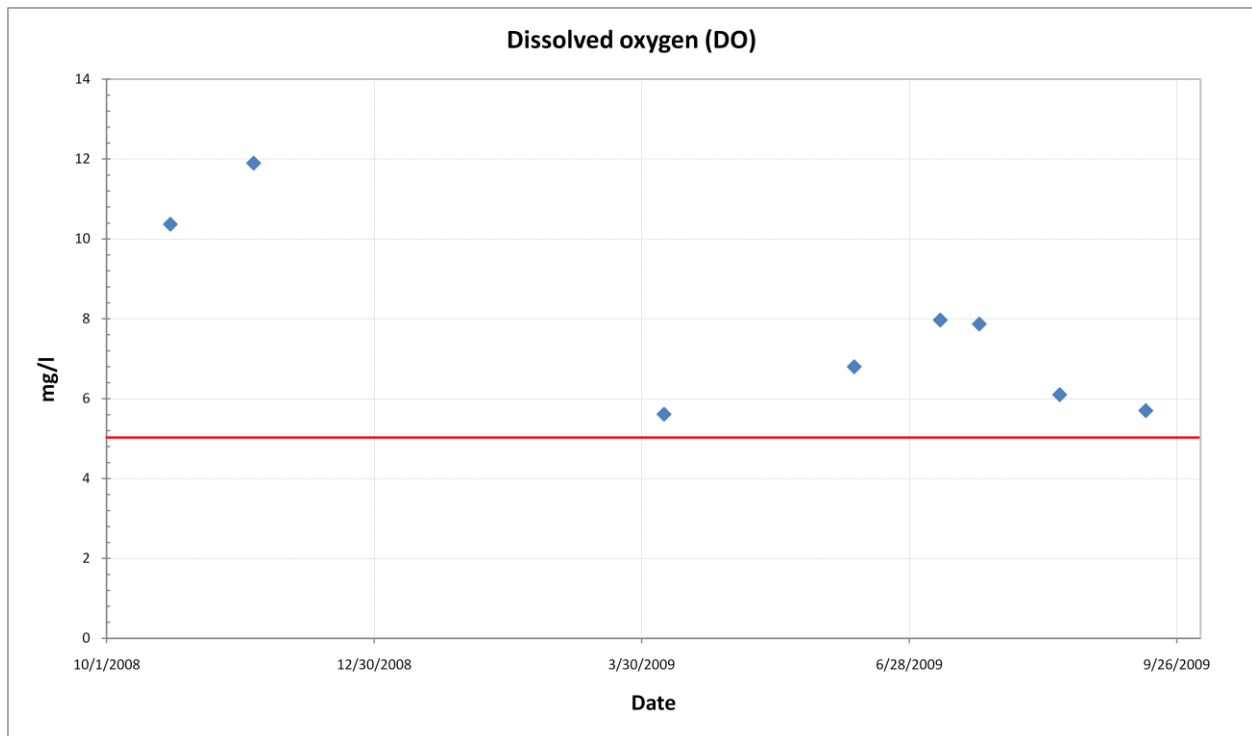


Figure 53: Dissolved Oxygen in Flowing Springs, FY 2009. Desired condition is above the 5.0 mg/L threshold shown in red.

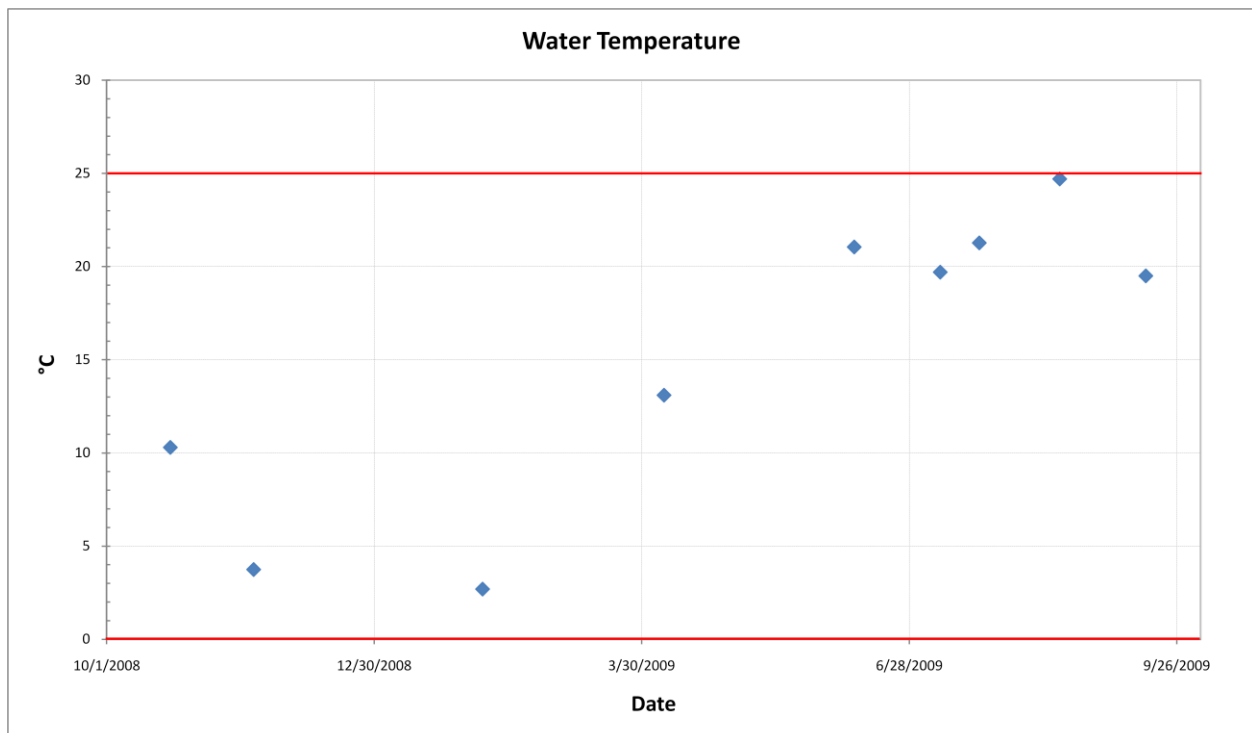


Figure 54: Temperatures in Flowing Springs, FY 2009. Ideal temperatures for aquatic life are 0 to 25 °C.

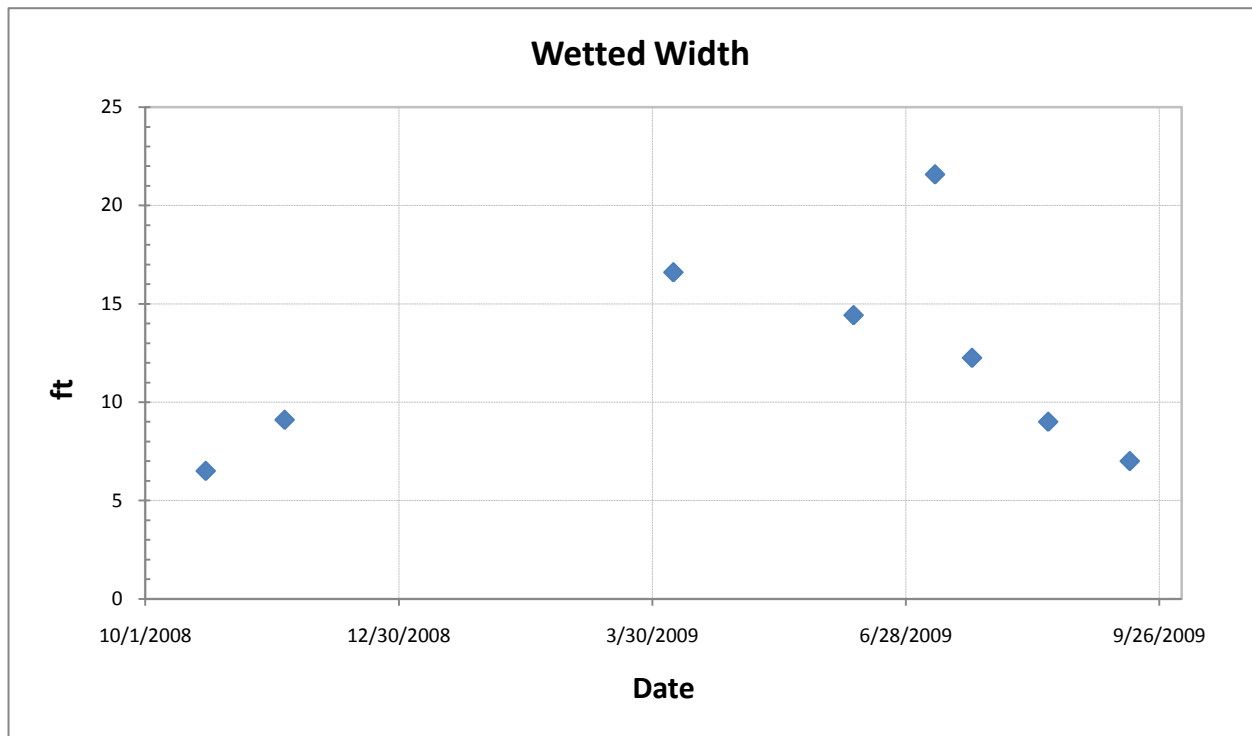


Figure 55: Wetted Width in Flowing Springs, FY 2009.

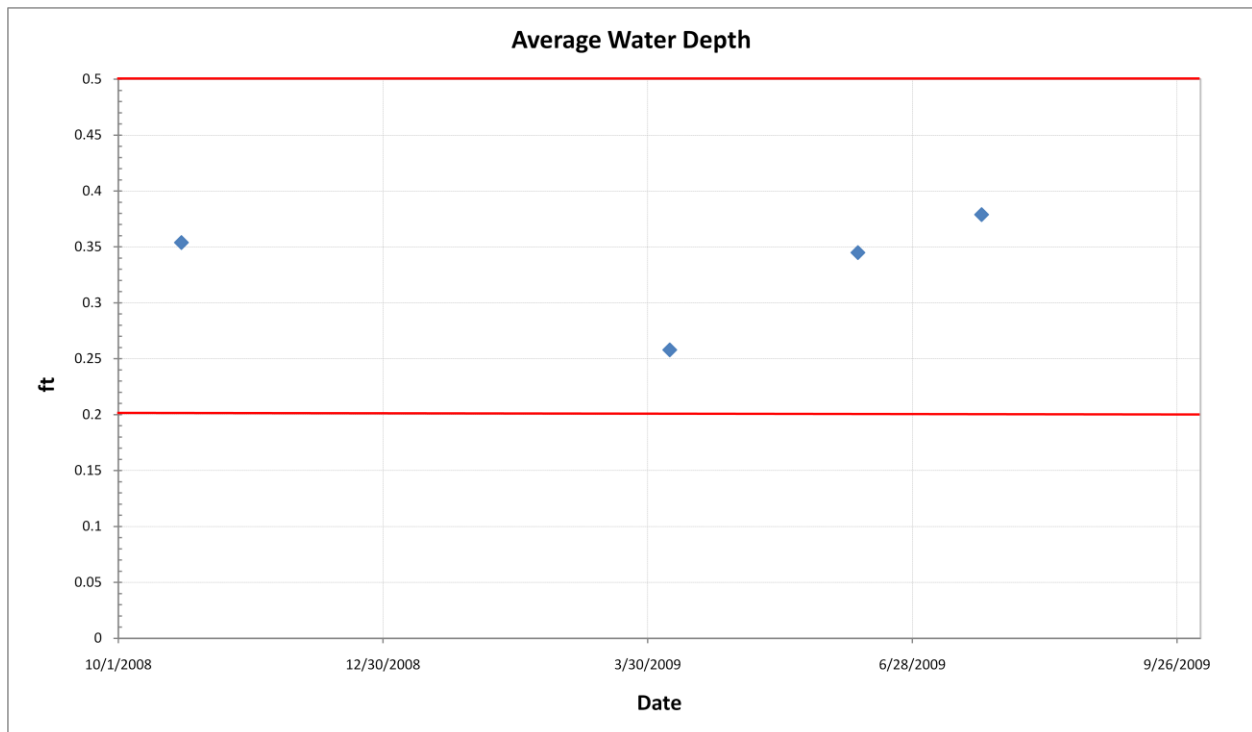


Figure 56: Average depth in Flowing Springs, FY 2009. Required condition is above 0.2 foot for discharge measurements and 0.5 foot for continuous measurement with data sondes.

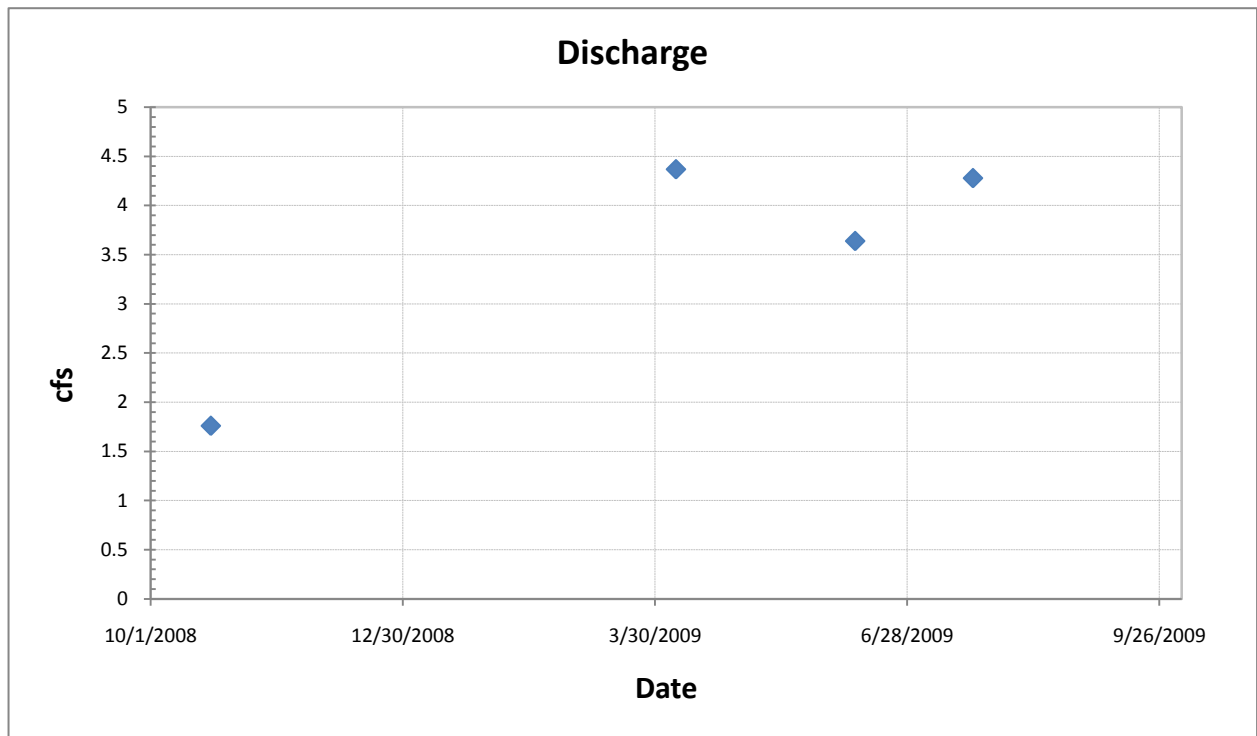


Figure 57: Discharge in Flowing Springs, FY 2009

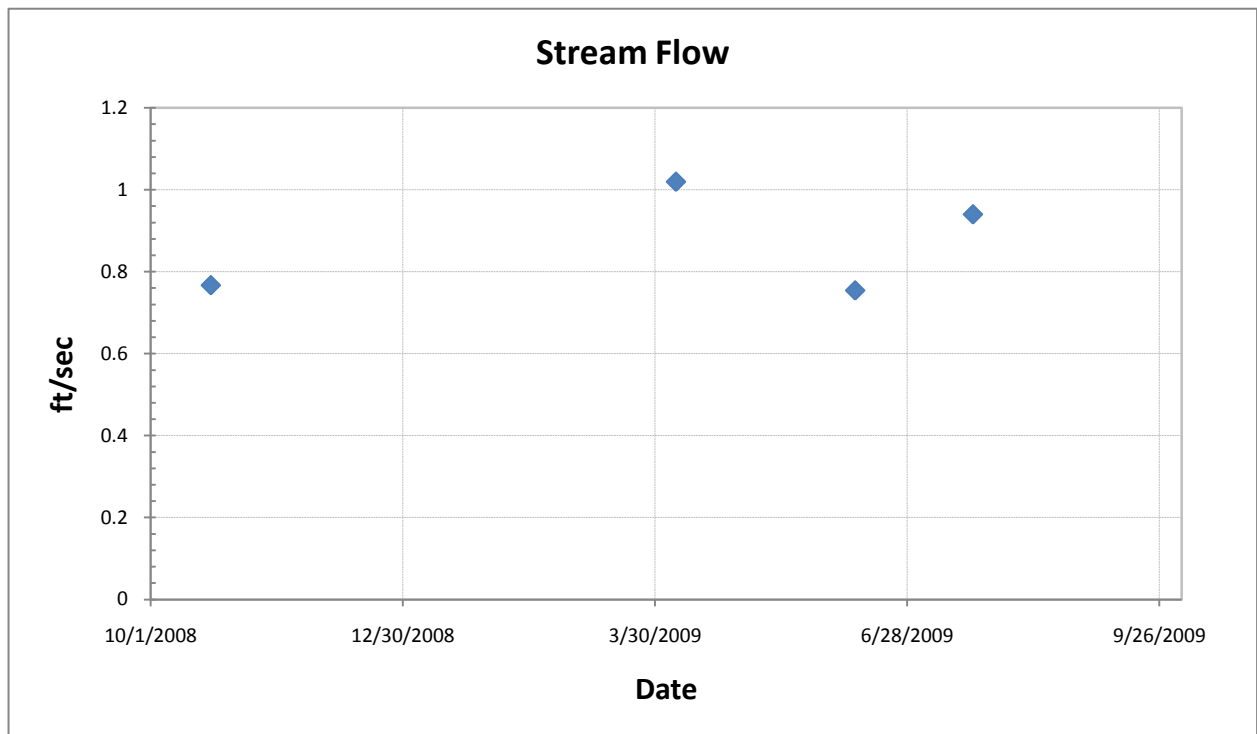


Figure 58: Flow in Flowing Springs, FY 2009

Manassas National Battlefield Park (MANA)

MANA was established in 1940 to preserve the scene of two major Civil War battles that took place a few miles north of the prized railroad junction of Manassas, Virginia, in 1861 and 1862. The 2,064 ha park is located approximately 72 km southwest of Washington, D.C. in Manassas County, Virginia within the Piedmont physiographic province. The Piedmont is characterized by a gently rolling topography of deeply weathered bedrock, with some solid outcrop. MANA is characterized by gently rolling hills with a patchwork of open fields and forests with riparian vegetation along the streams. A variety of igneous and metamorphic rocks make up the bedrock of the Piedmont province. Most streams are of moderate slope with rock or bedrock bottoms (Fenneman 1938, Thornbury 1968, Blomquist et al. 1996, William & Mary 2000). MANA's streams are lined with dark red siltstone. The park contains about 16 miles of named streams and several unnamed watercourses. The eastern boundary of the park is Bull Run. Young's Branch is a tributary of Bull Run and most of its watershed is contained within the battlefield (Figure 59).

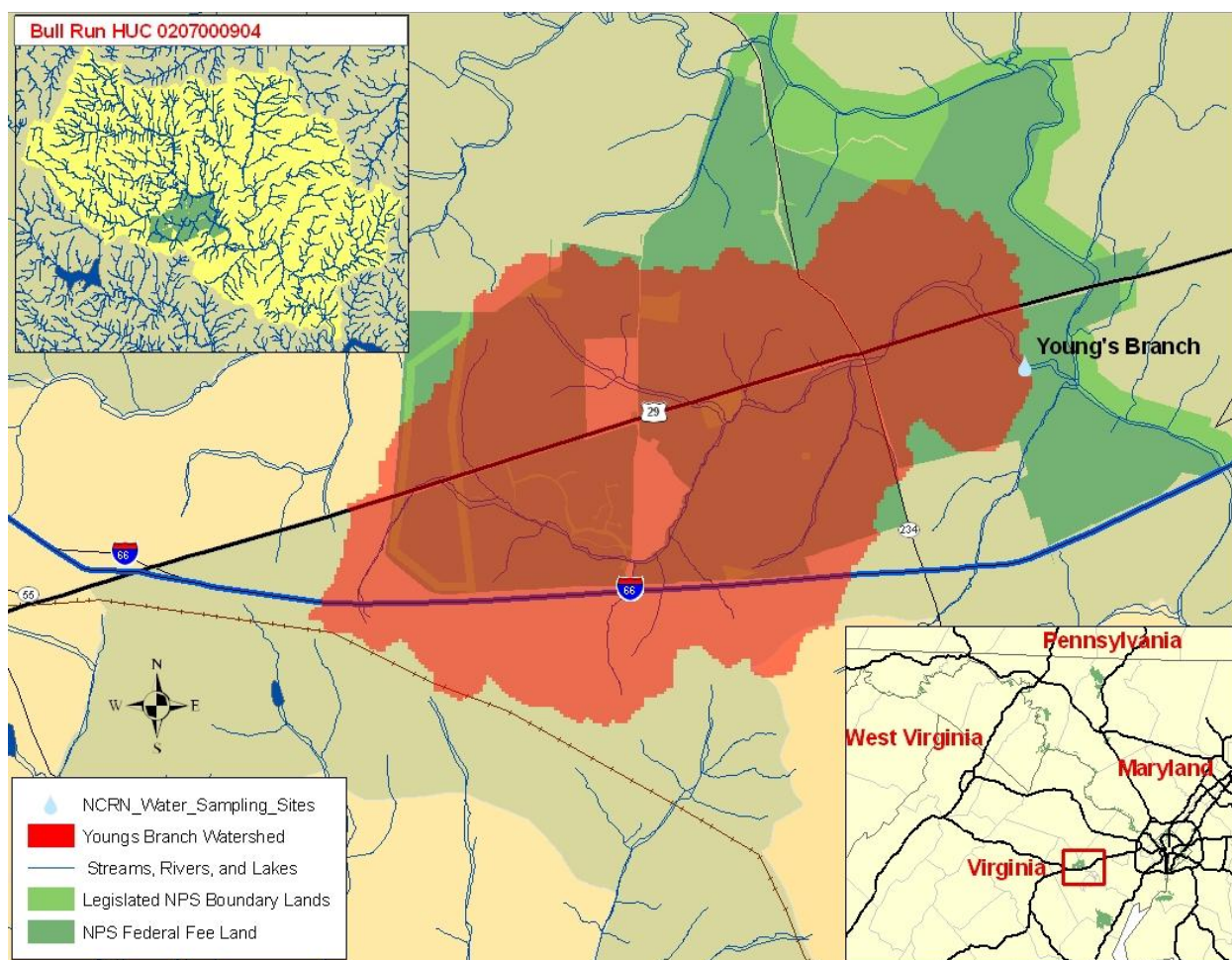


Figure 59: Relationship of MANA stream monitoring sites to their watersheds and the park boundary.

This report discusses data collected October 2008 through September 2009 in Youngs Branch. Summary statistics for the time period are shown in Table 6. One site was monitored in the park on a monthly basis for dissolved oxygen, pH, specific conductance, temperature, acid

neutralizing capacity, nitrate, ammonia, total phosphorus, depth, wetted width, flow and discharge. Data were not collected in December 2008, and March, May, or September 2009 due to inclement weather or frozen or dry stream conditions.

Table 7: Date range, sample size (N), and data range for the vital signs data collected at Manassas National Battlefield Park.

Local Name	Units	Period of Record	N	Minimum	Maximum	Mean	Standard Deviation
ANC	µeq/L	10/15/2008 - 9/22/2009	7	1112	2472	1777	501
Discharge	cfs	10/15/2008 - 9/22/2009	2	0.32	0.41	0.37	0.06
Dissolved Oxygen	mg/l	10/15/2008 - 9/22/2009	7	5.10	12.85	7.68	2.88
Flow	ft/sec	10/15/2008 - 9/22/2009	2	0.0268	0.0351	0.0310	0.0059
Nitrate	mg/l	10/15/2008 - 9/22/2009	8	0.7	1.1	0.9	0.2
Ammonia	mg/l	10/15/2008 - 9/22/2009	4	0.046	1.304	0.367	0.625
pH	None	10/15/2008 - 9/22/2009	8	7.20	8.75	7.60	0.48
Total Phosphorus	mg/l	10/15/2008 - 9/22/2009	8	0.13	0.29	0.20	0.05
Salinity	ppt	10/15/2008 - 9/22/2009	8	0.1	0.4	0.2	0.1
Specific Conductance	µS/cm	10/15/2008 - 9/22/2009	8	322.5	797.0	469.5	146.7
Water Depth	ft	10/15/2008 - 9/22/2009	2	0.363	0.626	0.495	0.186
Water Temperature	°C	10/15/2008 - 9/22/2009	8	0.15	22.73	12.88	8.15
Wetted Width	ft	10/15/2008 - 9/22/2009	8	0	32.42	23.48	9.96

ANC in Young's Branch was always well above the desired condition of 200 µeq/l (Figure 60). The pH of young's Branch was always within desired condition for aquatic life (Figure 61). Young's Branch almost always exceeds the specific conductance threshold at some time (Figure 62), which would coincide with the application of fertilizer. Young's Branch was always a freshwater stream with a salinity less than 0.5 ppt (Figure 63).

Youngs Branch exceeded the total phosphorus threshold in October 2008, and July and August 2009 (Figure 66). Measurement of dissolved oxygen was always above the desired minimum of 5mg/L to sustain aquatic life (Figure 67). Ammonia only exceeded threshold in Youngs Branch in April 2009 (Figure 64). Nitrate was always below the threshold (Figure 65). Water Temperatures followed expected seasonal trends and stayed within the comfort range of most freshwater organisms (Figure 68).

There was only sufficient depth (Figure 70) to measure flow (Figure 72) and discharge (Figure 71) in July and August 2009. The stream went dry in September 2009. Wetted width in Youngs Branch fluctuates less than 10 feet per month (Figure 69).

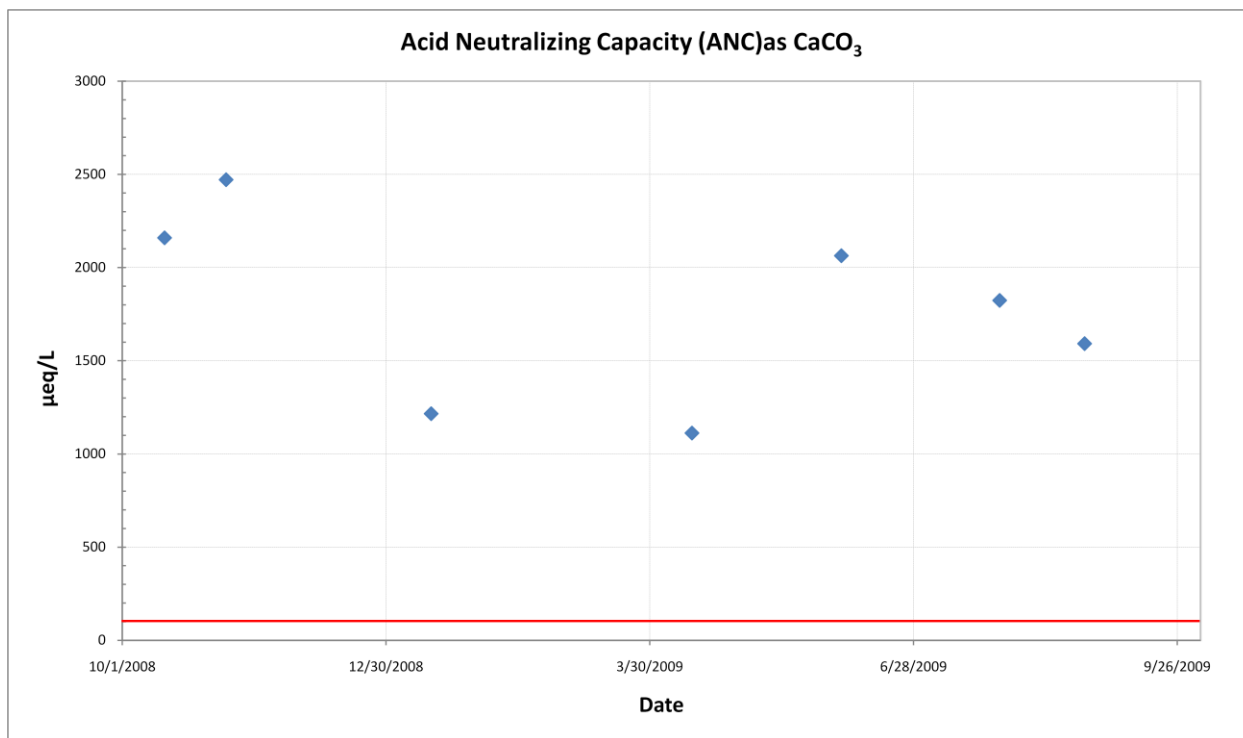


Figure 60: ANC in Youngs Branch in FY 2009. Desired condition is above the 200 ueq/L threshold for non-karst waters shown in red.

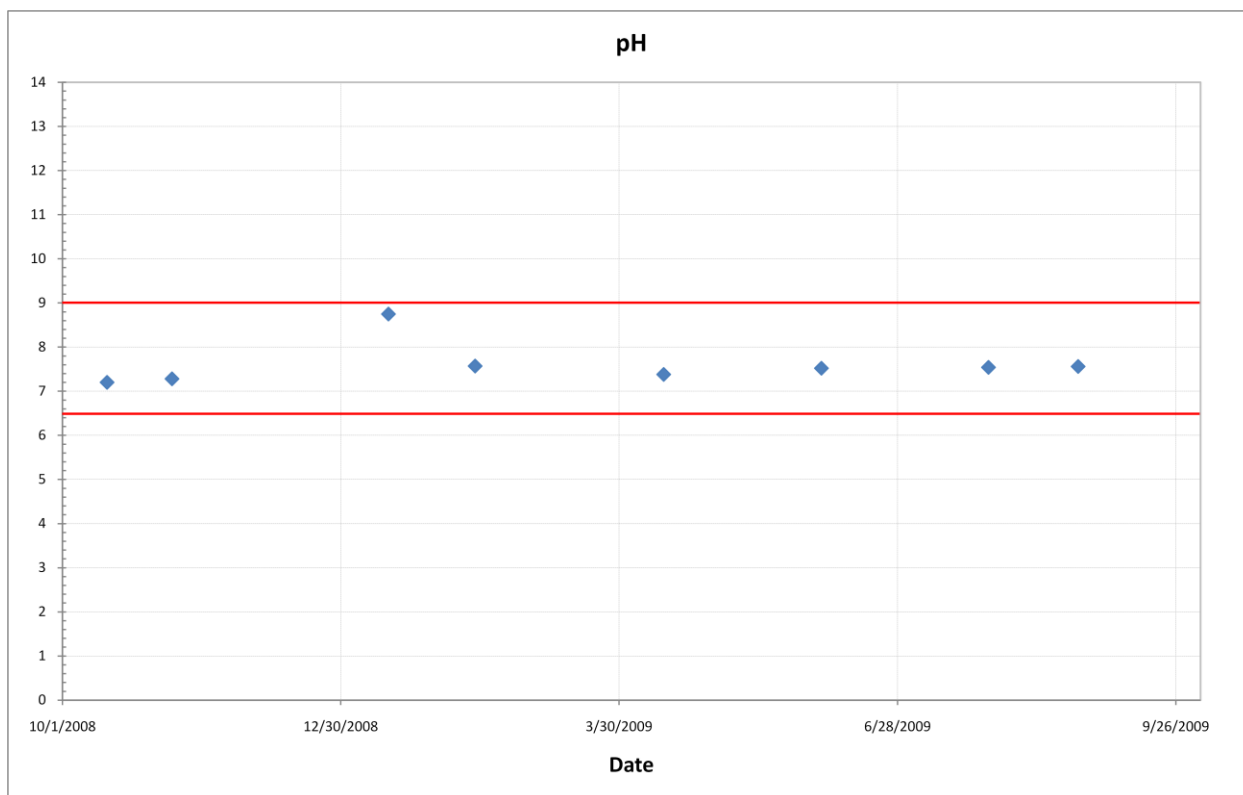


Figure 61: pH in Youngs Branch in FY 2009. Desired condition is between the 6.5 and 9.0 thresholds shown in red.

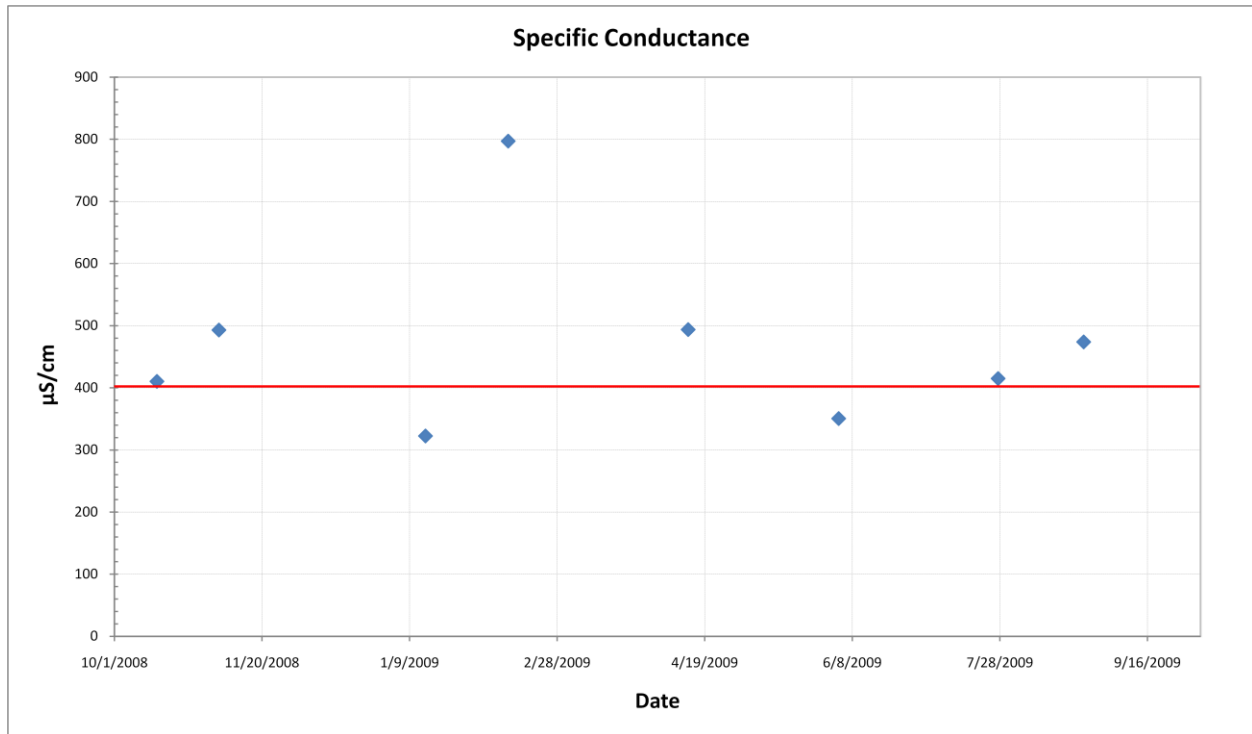


Figure 62: Specific Conductance in Youngs Branch FY 2009. Desired condition is below the 400 µS/cm threshold shown in red.

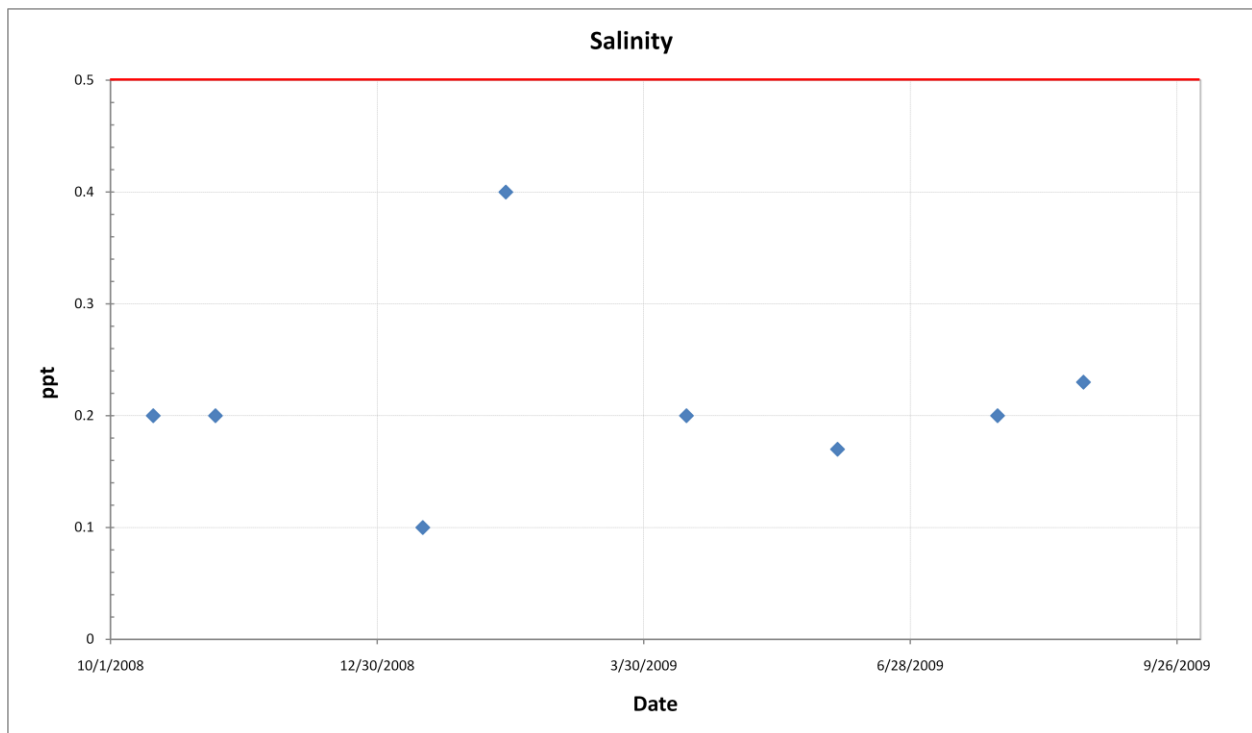


Figure 63: Salinity in Youngs Branch in FY 2009. Desired condition is below the 0.5 ppt threshold shown in red.

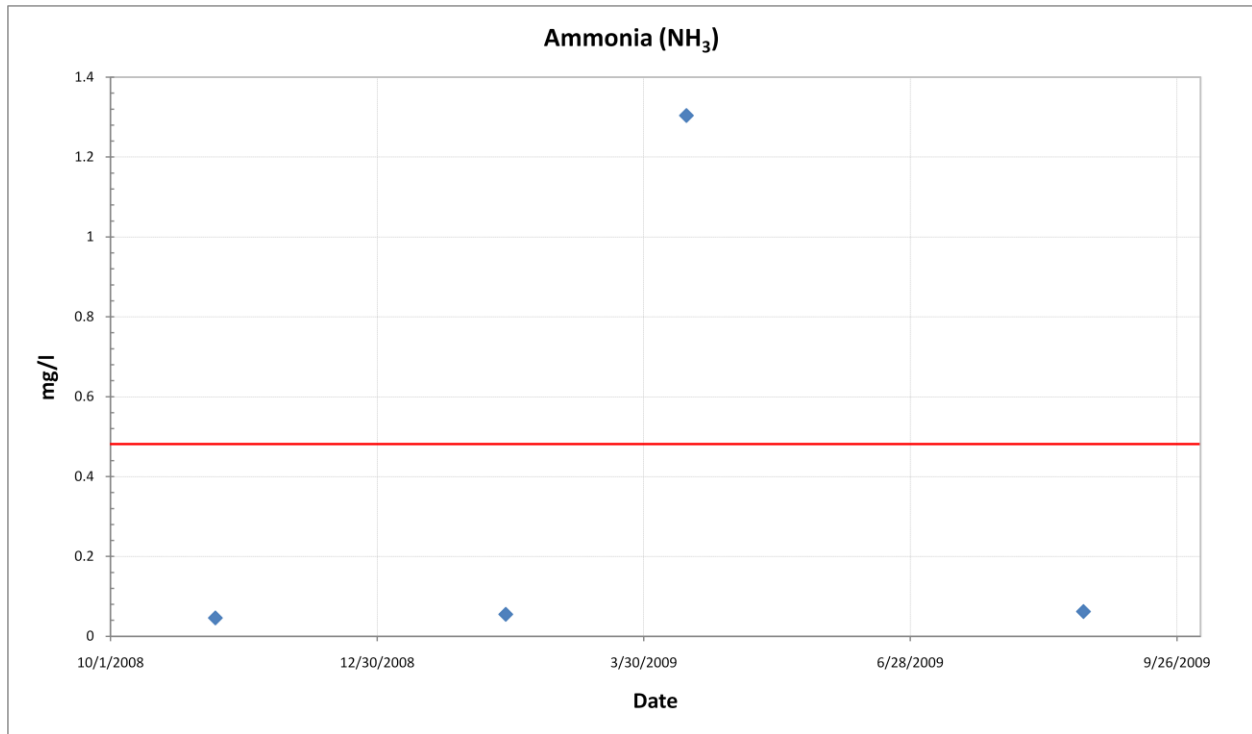


Figure 64: Ammonia in Youngs Branch in FY 2009. Desired condition is below the 0.443 threshold shown in red.

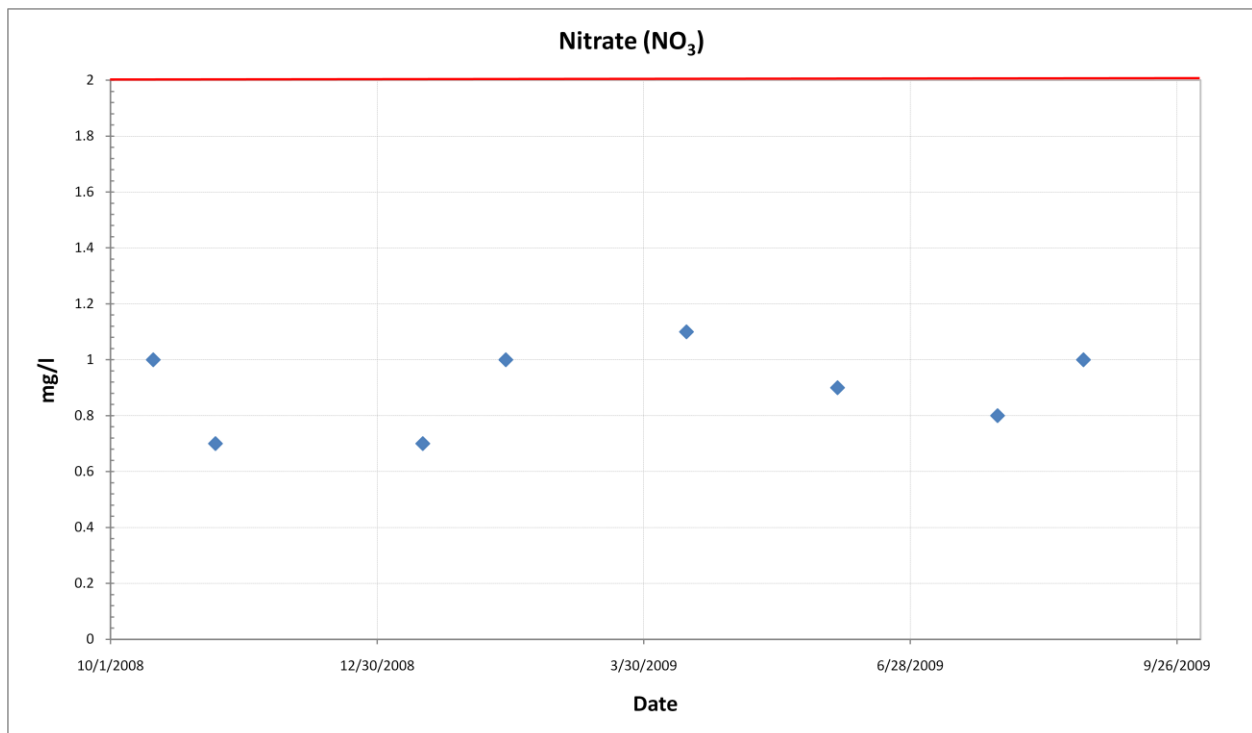


Figure 65: Nitrate in Youngs Branch in FY 2009. Desired condition is below the 2.0 mg/L threshold shown in red.

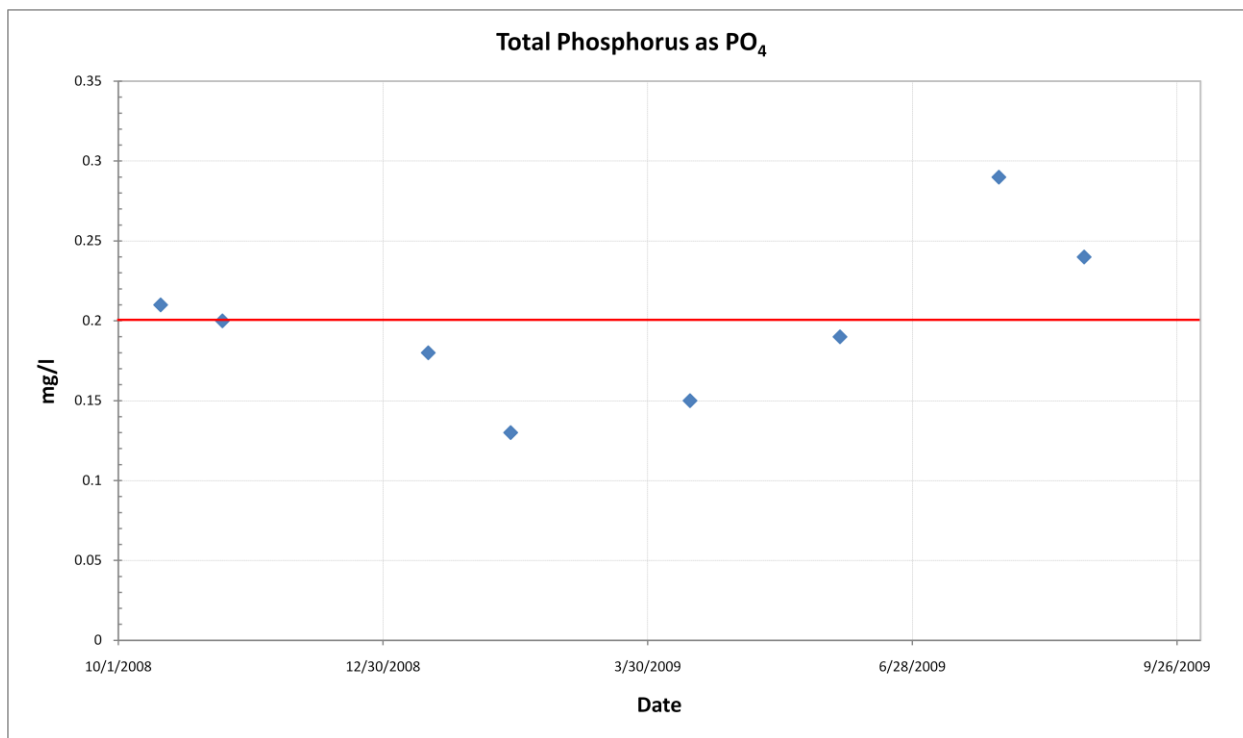


Figure 66: Total Phosphorus in Youngs Branch in FY 2009. Desired condition is below the 0.1 mg/L threshold shown in red.

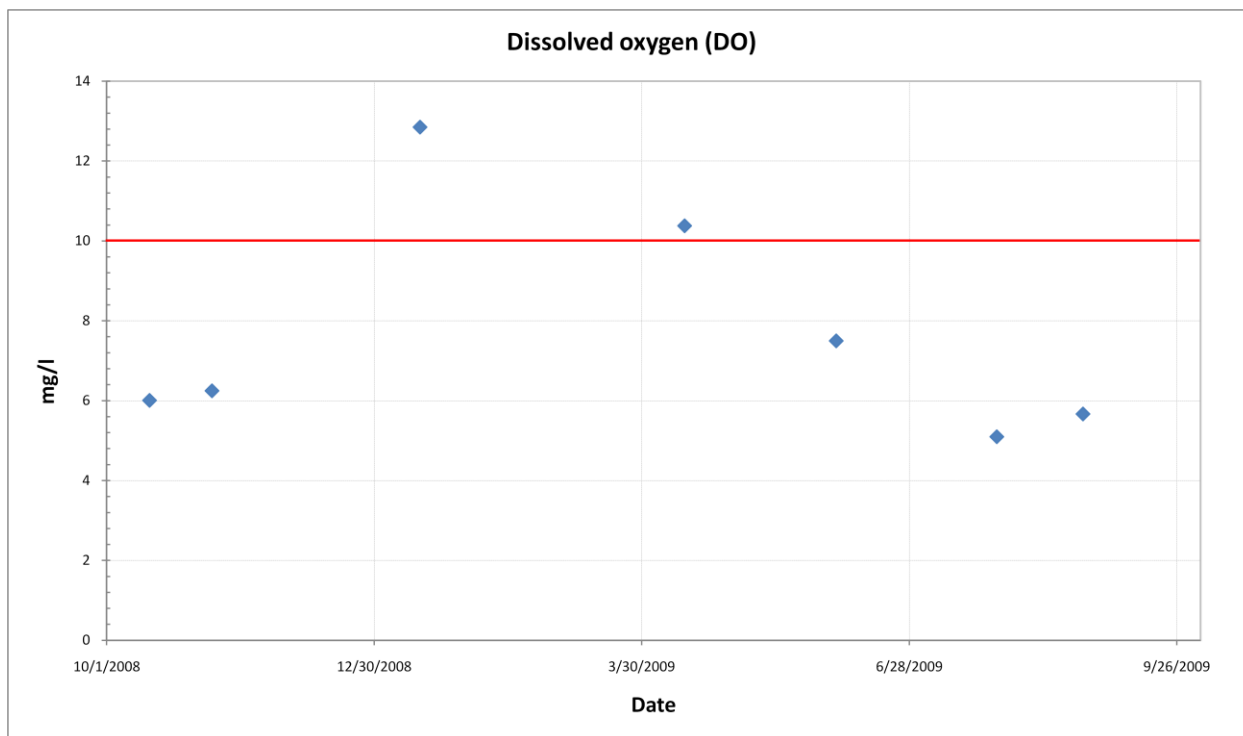


Figure 67: Dissolved Oxygen in Youngs Branch in FY 2009. Desired condition is above the 5.0 mg/L threshold shown in red.

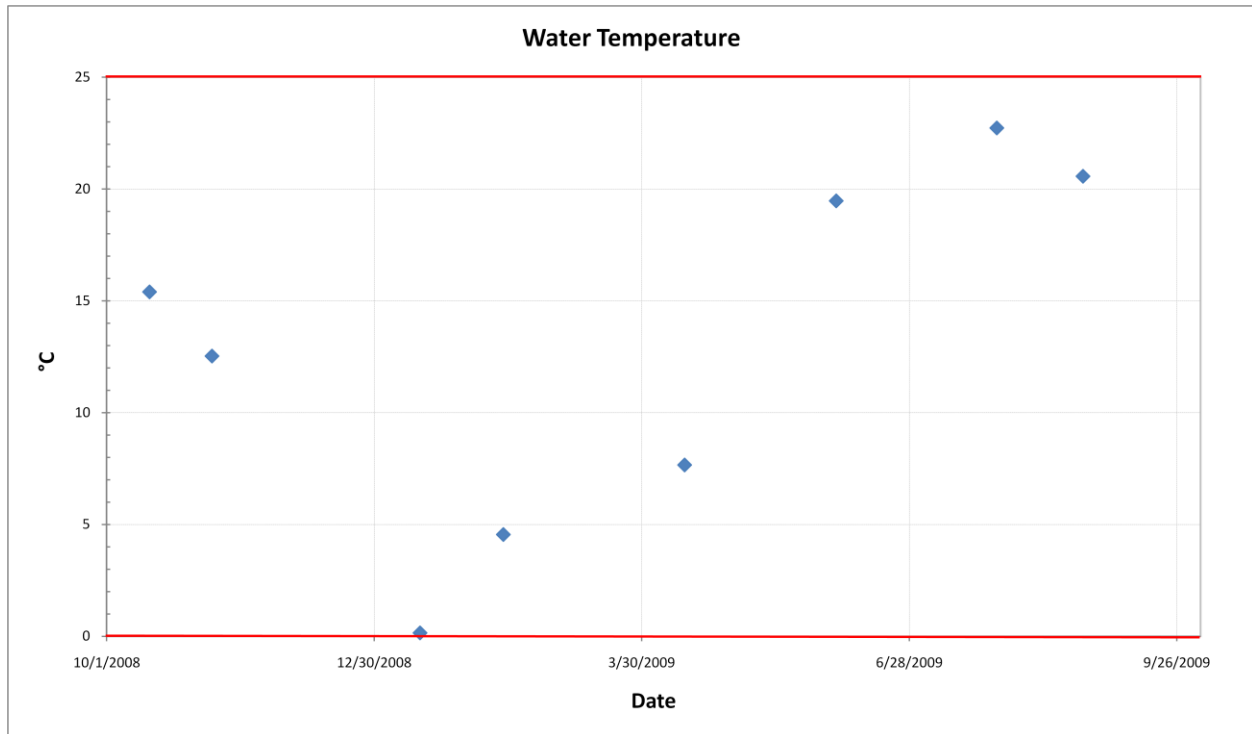


Figure 68: Temperature in Youngs Branch, FY 2009. Ideal temperatures for aquatic life are 0 to 25 °C.

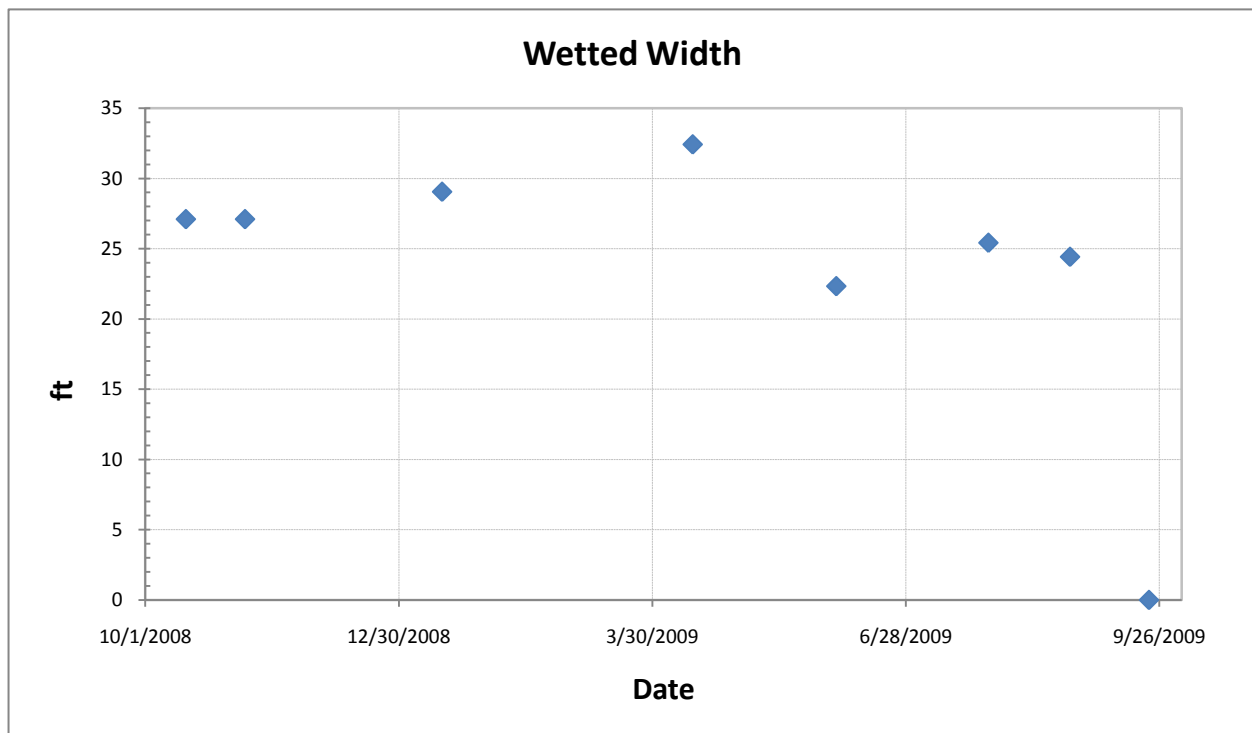


Figure 69: Wetted Width in Youngs Branch, FY 2009.

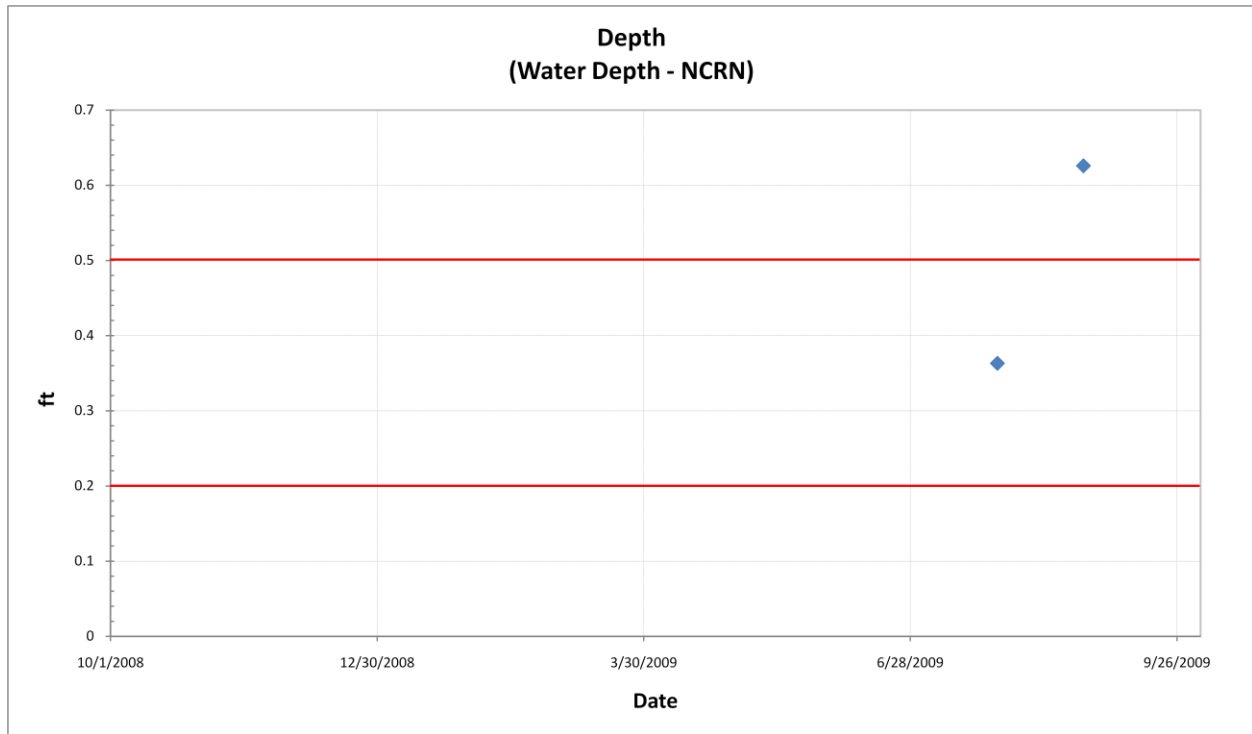


Figure 70: Average depth in Youngs Branch FY 2009. Required condition is above 0.2 foot for discharge measurements and 0.5 foot for data sondes.

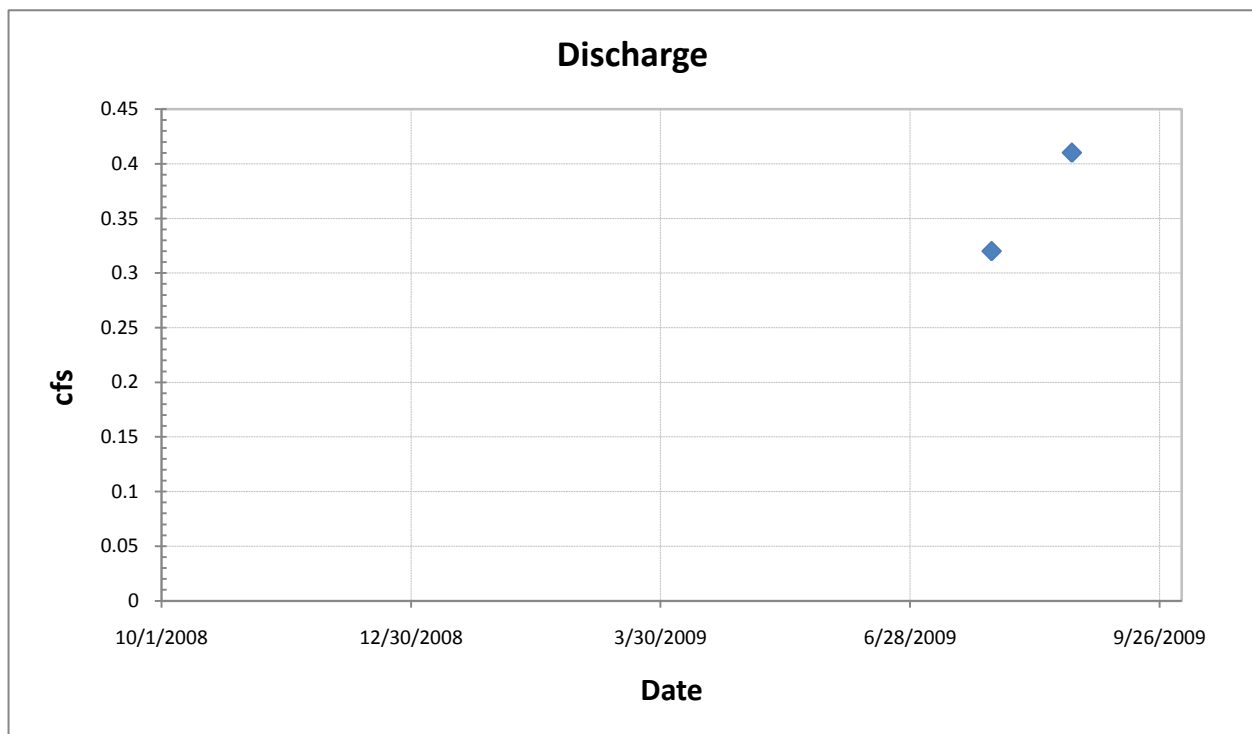


Figure 71: Discharge in Youngs Branch FY 2009.

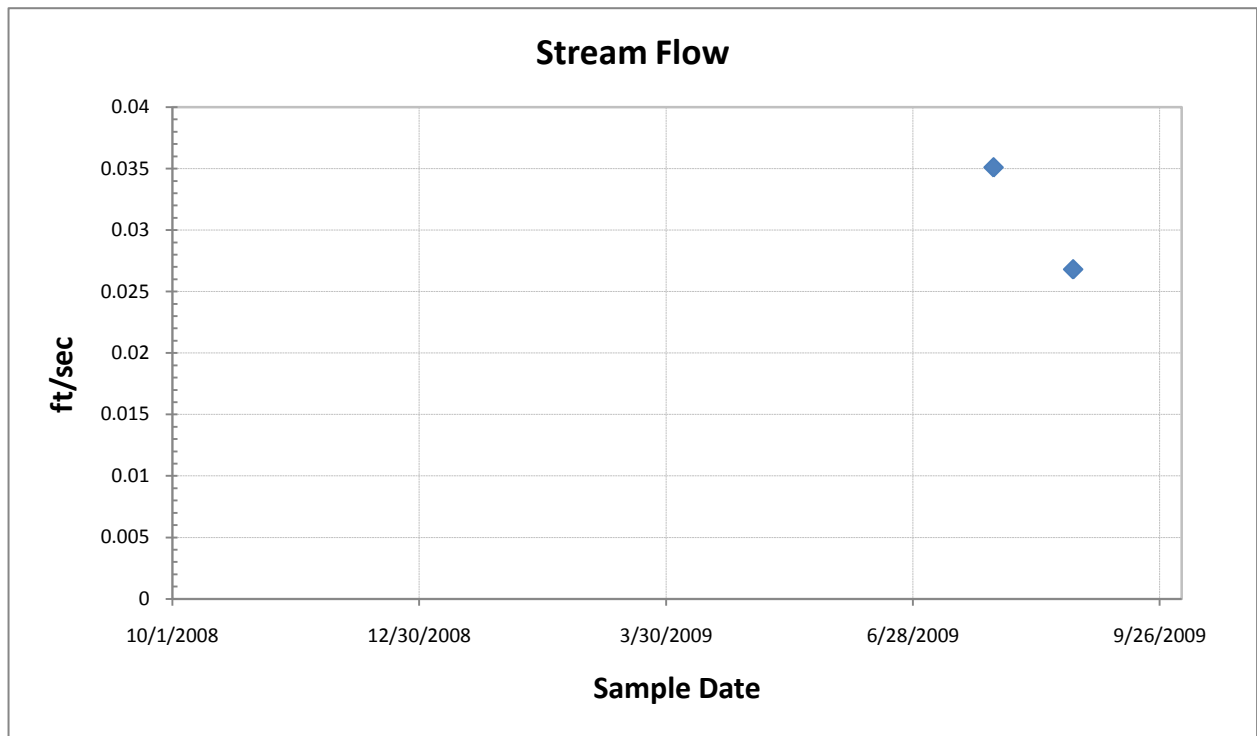


Figure 72: Flow in Youngs Branch FY 2009.

Monocacy National Battlefield (MONO)

The battlefield is located near the town of Urbana in Frederick County, Maryland along the eastern side of the Frederick Valley within the Northern Piedmont physiographic province. The landscape of MONO consists of the broad Monocacy River valley and ridges of less resistant geology. The river is confined to the west side of the Frederick Valley and tends to flow along the west base of the resistant ridges. These ridges, like Brooks Hill, are underlain by plunging anticlines of hard rock. Uplift and erosion has produced “valley and ridge” topography, with linear ridges and intervening valleys. To the west of the national battlefield, the landscape is a broad, open valley underlain by carbonate rocks that are susceptible to chemical erosion producing the local karst features (i.e., sinkholes and springs). To the east, the landscape is an elevated plateau underlain by fine-grained metamorphic rocks. Most of the battlefield is on the flat land which consists of terrace deposits overlying rocks of the Frederick Formation, just north of Interstate Highway 270 (Southworth and Denenny 2005). MONO is underlain by limestone bedrock which has developed karst topography. The karst topography affects water quality in the park similarly to the effects on ANTI and HAFE detailed previously.

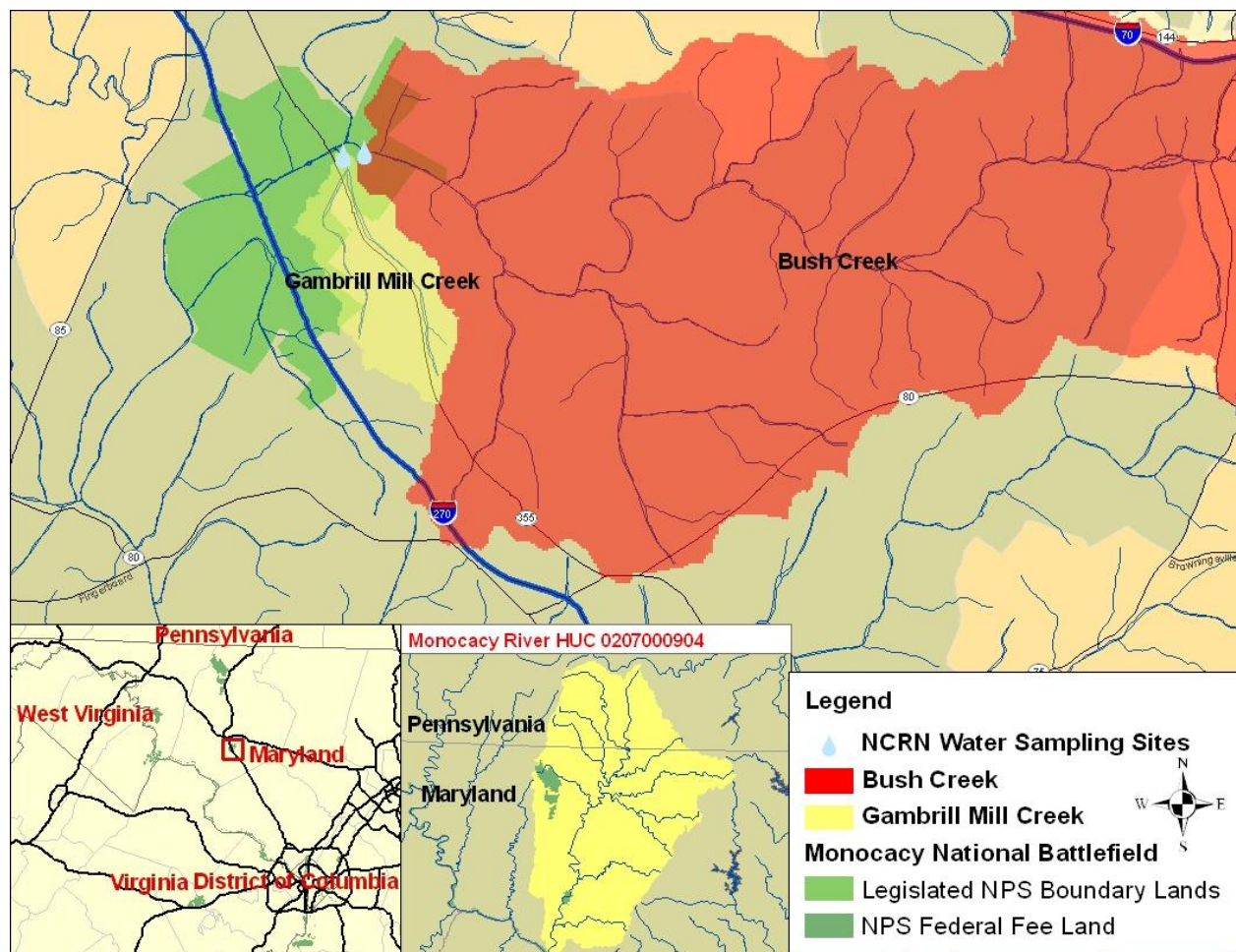


Figure 73: Relationship of the MONO stream monitoring sites to their watersheds and the park boundary.

Streams in MONO are all part of the Lower Monocacy River drainage (Figure 73) that drains 194,700 acres before emptying into the Potomac River (Maryland Department of Natural Resources 2003). The Monocacy River is the largest Maryland tributary of the Potomac River (Monocacy Scenic River Local Advisory Board 1990). The perennial streams in the park are Bush Creek, Harding's Run, and Thomas Farm Creek/Gambrill Mill Creek. Two ephemeral streams, Best Farm Creek and an unnamed drainage also feed into the river. The Monocacy River flows directly through and along the boundary of the national battlefield for approximately 2.5 miles. Approximately 0.8 miles of Bush Creek passes through the north central part of the national battlefield. Bush Creek is the largest Monocacy River tributary within the national battlefield, a moderately narrow, rapidly flowing creek with a cobble/gravel bottom with scoured sections of banks and cobble beds from periodic high flows (Motivans 1995). As the creek nears its confluence with the river, the stream channel becomes incised and much of the stream bank is undercut.

Agriculture is the dominate land use within the Bush Creek watershed with approximately a third of the watershed still forested. Given the long history of human habitation and agricultural land use in the region, streams are far from pristine; however, much of lower Bush Creek and its tributaries appear to be in reasonably good condition at present.

This report discusses data collected October 2008 through September 2009 in Bush Creek and Gambrill Mill Creek (Figure 73). Summary statistics for the time period are shown in Table 7. Two sites were monitored in the park on a monthly basis for dissolved oxygen, pH, specific conductance, temperature, acid neutralizing capacity, nitrate, ammonia, total phosphorus, depth, wetted width, flow and discharge. Data was not collected in December 2008 or February 2009 due to inclement weather or frozen stream conditions.

Table 8: Date range, sample size (N), and data range for the vital signs monitored in Monocacy National Battlefield.

Local Name	Units	Period of Record	N	Minimum	Maximum	Mean	Median	Standard Deviation
ANC	µeq/L	10/21/2008 - 9/15/2009	20	1280	3384	1958	1680	660
Discharge	cfs	10/21/2008 - 9/15/2009	6	6.88	57.96	24.14	---	20.24
Dissolved Oxygen	mg/l	10/21/2008 - 9/15/2009	20	8.07	17.17	10.37	9.09	2.54
Flow	ft/sec	10/21/2008 - 9/15/2009	6	0.689	2.012	1.170	---	0.527
Nitrate	mg/l	10/21/2008 - 9/15/2009	20	2.2	7.1	4.2	3.9	1.4
Ammonia	mg/l	10/21/2008 - 9/15/2009	7	0.036	0.178	0.0803	---	0.050
pH	None	10/21/2008 - 9/15/2009	20	7.71	8.27	7.86	7.86	0.13
Total Phosphorus	mg/l	10/21/2008 - 9/15/2009	20	0.09	0.96	0.28	0.22	0.20
Salinity	ppt	10/21/2008 - 9/15/2009	20	0.14	0.30	0.20	0.20	0.04
Specific Conductance	µS/cm	10/21/2008 - 9/15/2009	20	295.8	613.0	422.5	381.2	96.1
Water Depth	ft	10/21/2008 - 9/15/2009	8	0.15	0.87	0.52	---	0.22

Local Name	Units	Period of Record	N	Minimum	Maximum	Mean	Median	Standard Deviation
Water Temperature	°C	10/21/2008 - 9/15/2009	20	0.5	21.3	12.7	15.0	6.0
Wetted Width	ft	10/21/2008 - 9/15/2009	19	3.11	33.42	18.56	12.42	11.54

Much of the park is maintained as agriculture to replicate the historical Civil War landscape. The agriculture lease agreements allow for fertilizer and pesticide applications and some fields are leased for livestock grazing. These are probably among the sources of the nitrate and phosphorus. Other sources include acid rain and atmospheric deposition as well as background levels in groundwater. Measurements of dissolved oxygen were always above the desired minimum of 5 mg/L to sustain aquatic life (Figure 81). Ammonia never exceeded the threshold of 0.443 mg/L in either stream (Figure 78). Nitrate always exceeded threshold in both streams (Figure 79). Total phosphorus always exceeded the threshold except for Gambrill Mill Creek in June 2009 (Figure 80).

ANC in Gambrill Mill and Bush Creek was always well above the 600 µeq/l threshold (Figure 74). Whereas pH in Bush Creek and Gambrill stream exceeded threshold a number of times. The higher pH of Bush Creek and Gambrill stream are due to dissolution of the limestone and dolomite bedrock (Figure 75). This may also contribute to the higher specific conductance (Figure 76), though fertilizers, pesticides, and livestock runoff may also contribute. Limestone (CaCO_3) and dolomite ($\text{CaMg}(\text{CO}_3)_2$) are ionic salts that dissociate in pure water to their constituent ions: Ca^{2+} and CO_3^{2-} ; $\text{Ca}^{2+} + \text{Mg}^{2+} + 2 \text{CO}_3^{2-}$. Groundwater in karst areas can also contain sulfate ions from gypsum beds and weathered sulfite materials, chlorides from deeper circulating ground water and seawater mining, sodium, potassium, dissolved oxygen. Specific conductance is lower in Monocacy streams than it is in HAFE or ANTI. This may be due to differences in the chemistry and physical extent of the two areas of karst terrain. The threshold exceedances for Gambrill Mill Creek may be due to adjacent pollution sources (former Visitor's Center septic field for Gambrill Mill Creek). Specific Conductance should be closely monitored and sources determined. Salinity for both sites was always less than the freshwater limit of 0.5 ppt (Figure 77).

Water temperature followed expected seasonal patterns and stayed within the comfort range of most freshwater organisms (Figure 82). There was only sufficient depth (Figure 83) to measure flow (Figure 85) and discharge (Figure 86) in Bush Creek in October 2008 and April through August 2009. Wetted width of Bush Creek fluctuated less than 5 feet per month and less than 10 feet throughout the year (Figure 84). Gambrill Mill Creek fluctuated up to 5 feet per month and 10 feet throughout the year.

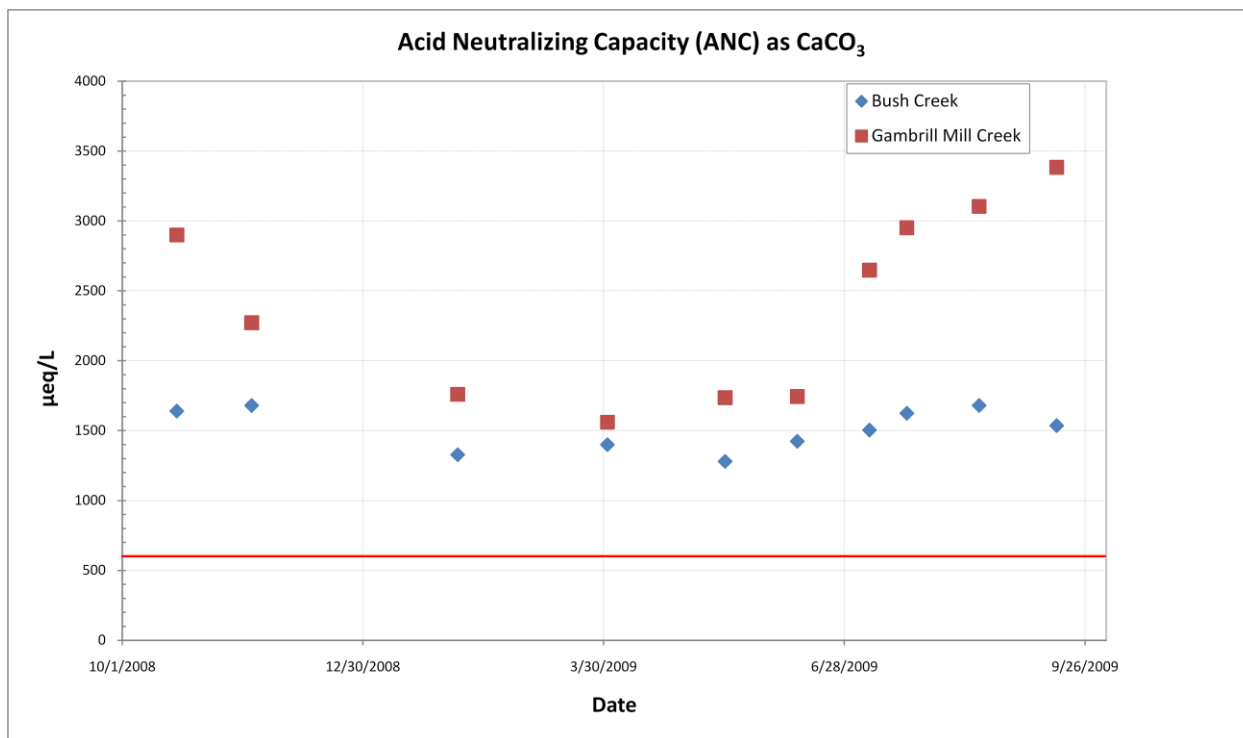


Figure 74: ANC in Monocacy National Battlefield streams in FY 2009. Desired condition is above the 600 $\mu\text{eq/L}$ threshold for karst waters shown in red.

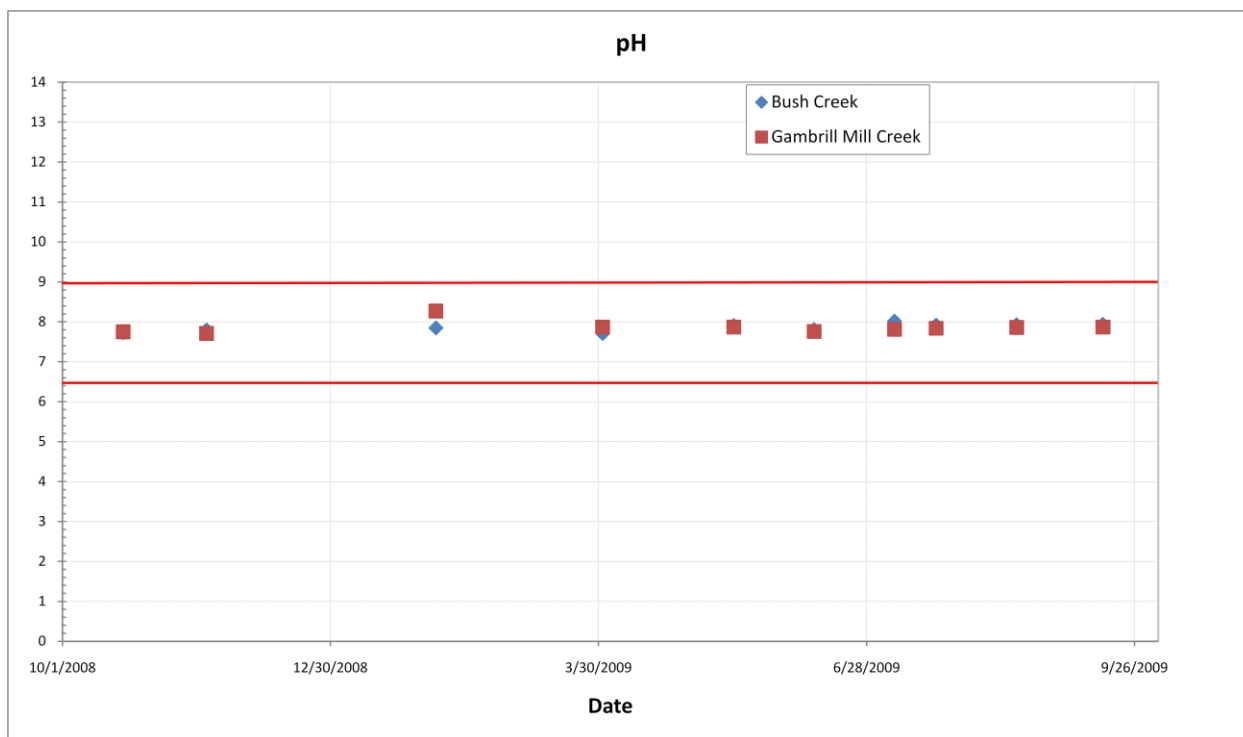


Figure 75: pH in Monocacy National Battlefield streams in FY 2009. Desired condition is between the 6.5 and 9.0 thresholds shown in red.

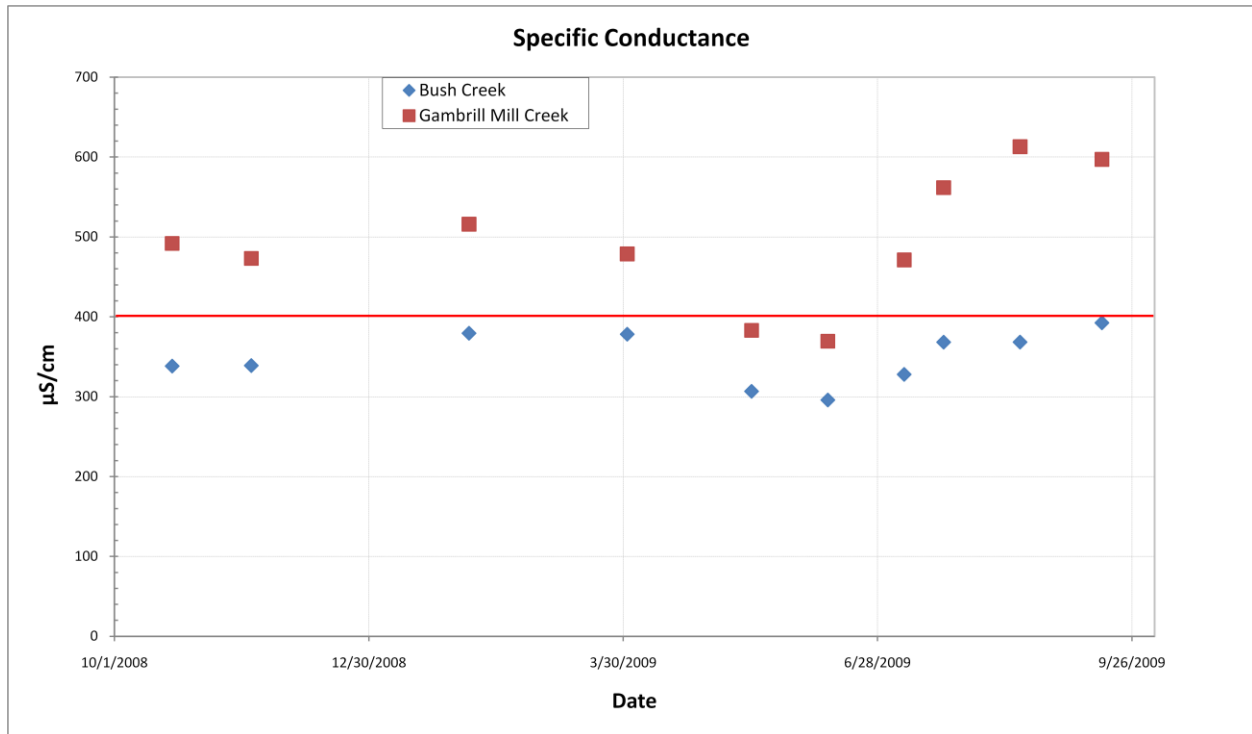


Figure 76: Specific Conductance in Monocacy National Battlefield streams, FY 2009. Desired condition is below the 400 µS/cm threshold shown in red.

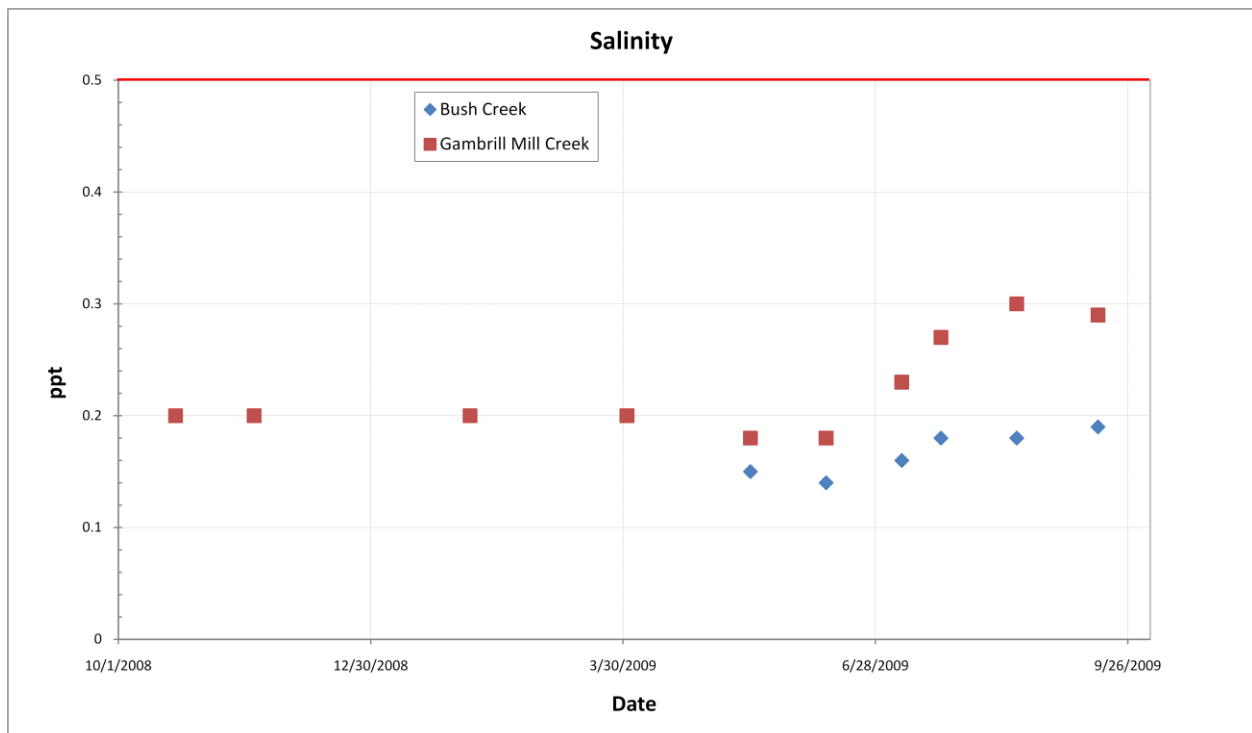


Figure 77: Salinity in Streams of Monocacy National Battlefield FY 2009. Desired condition is below the 0.5 ppt threshold shown in red.

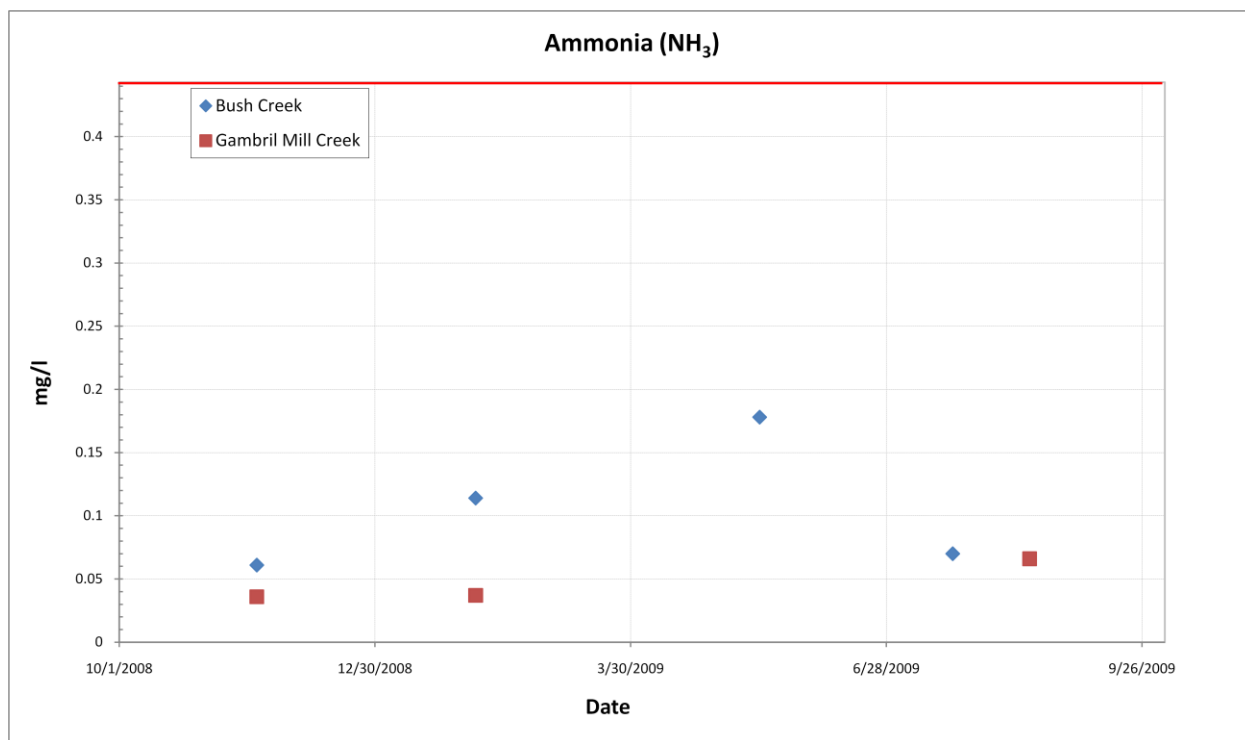


Figure 78: Ammonia in Monocacy National Battlefield streams, FY 2009. Desired condition is below the 0.443 threshold shown in red.

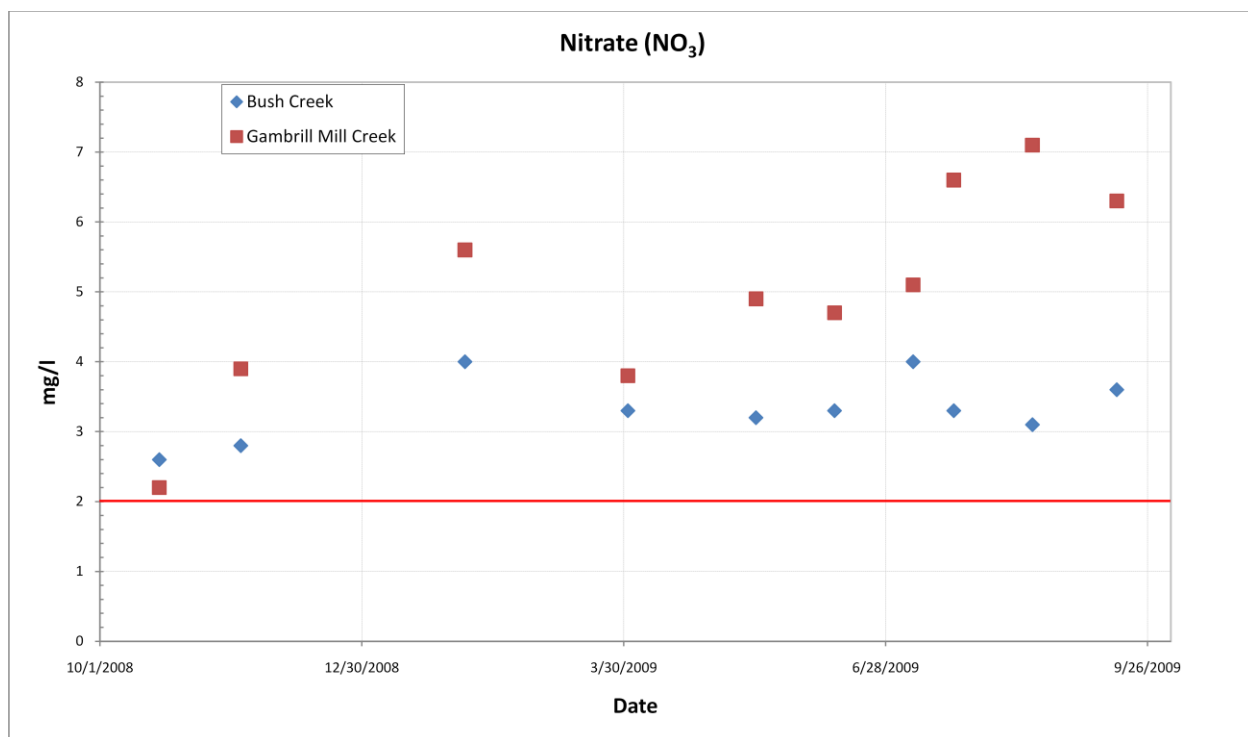


Figure 79: Nitrate in Monocacy National Battlefield streams, FY 2009. Desired condition is below the 2.0 mg/L threshold shown in red.

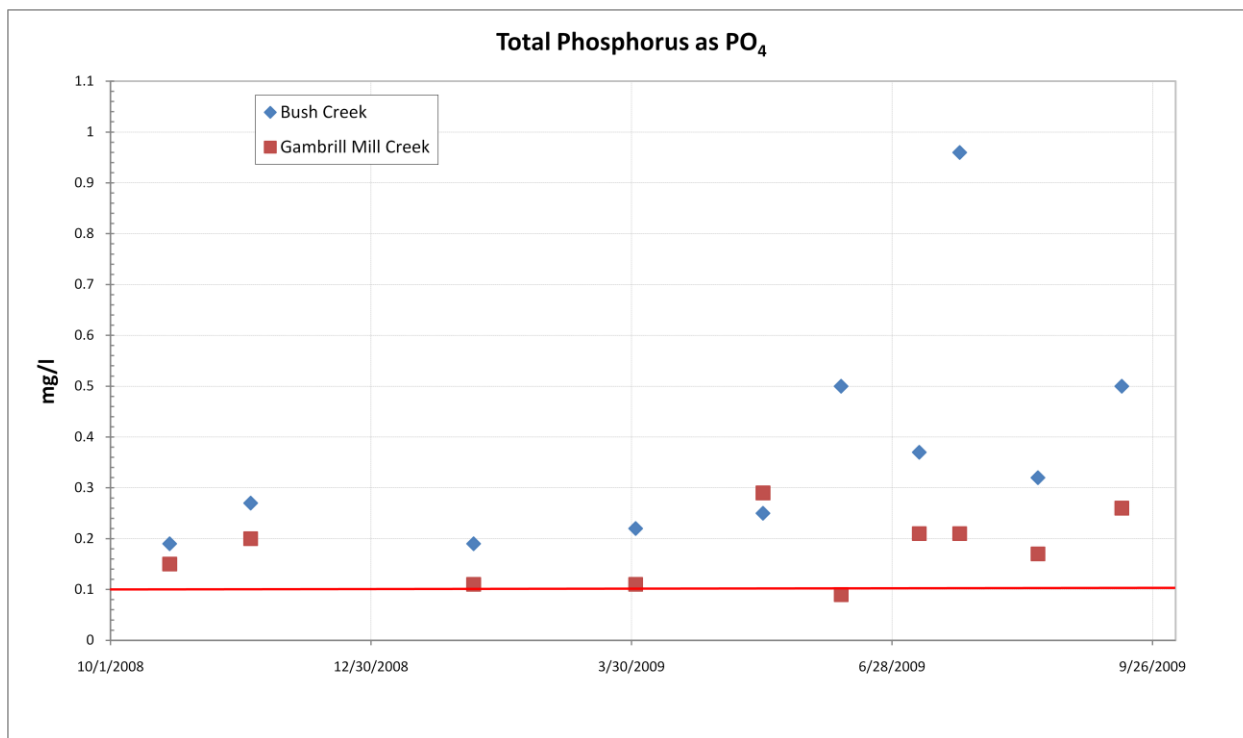


Figure 80: Total Phosphorus in Monocacy National Battlefield streams, FY 2009. Desired condition is below the 0.1 mg/L threshold shown in red.

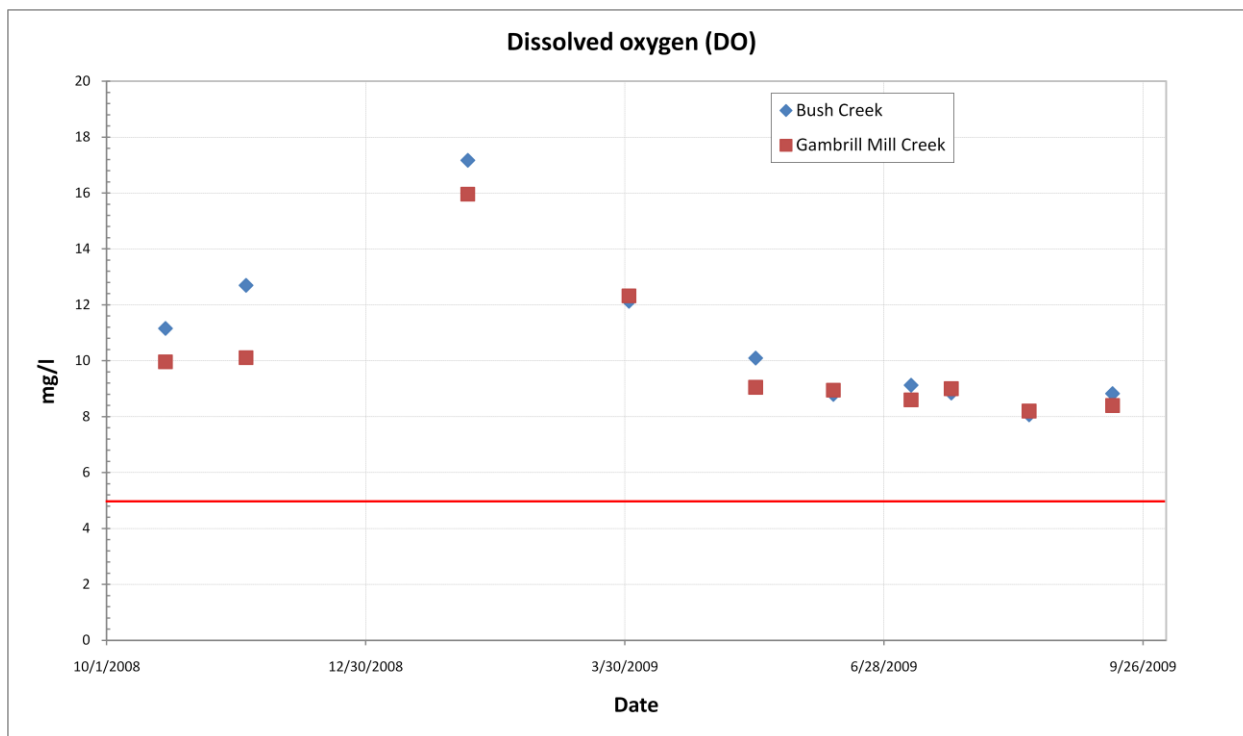


Figure 81: Dissolved Oxygen in Monocacy National Battlefield streams, FY 2009. Desired condition is above the 5.0 mg/L threshold shown in red.

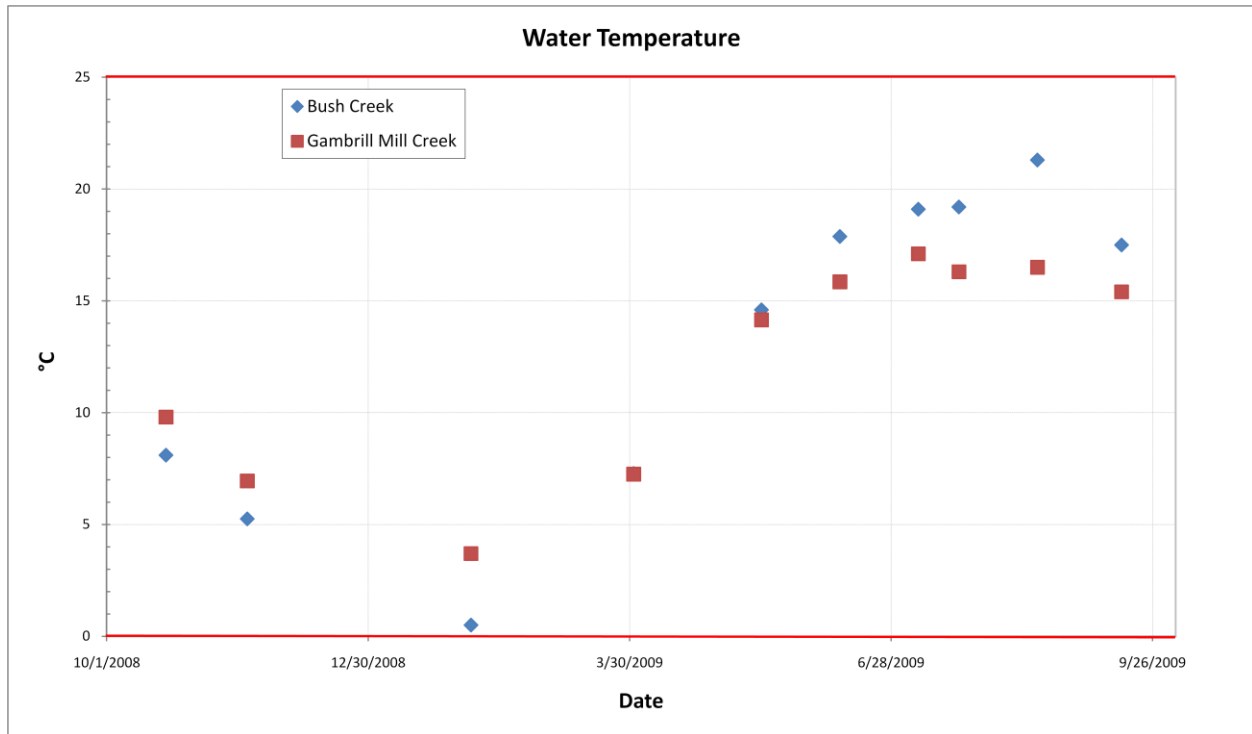


Figure 82: Temperatures of Monocacy National Battlefield Streams, FY 2009. Ideal temperatures for aquatic life are 0 to 25 °C.

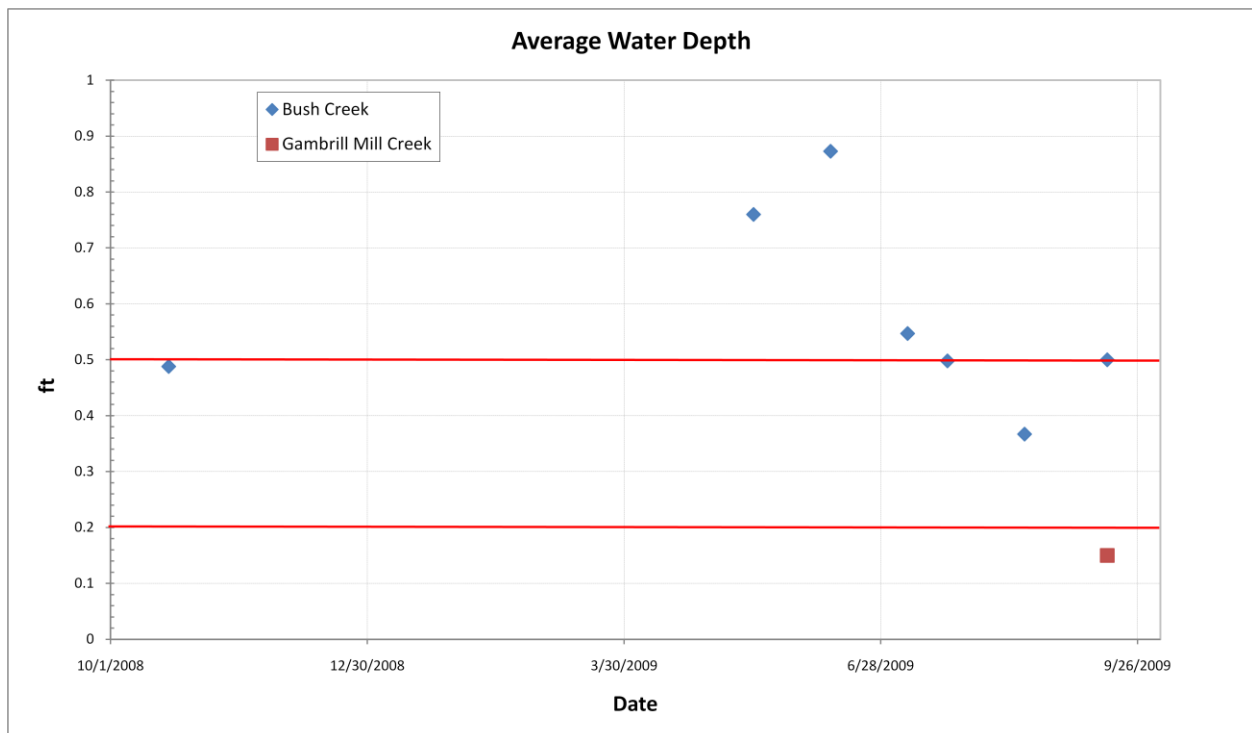


Figure 83: Average depth of Monocacy National Battlefield Streams, FY 2009. Required condition is above 0.2 foot for discharge measurements and 0.5 foot for data sondes.

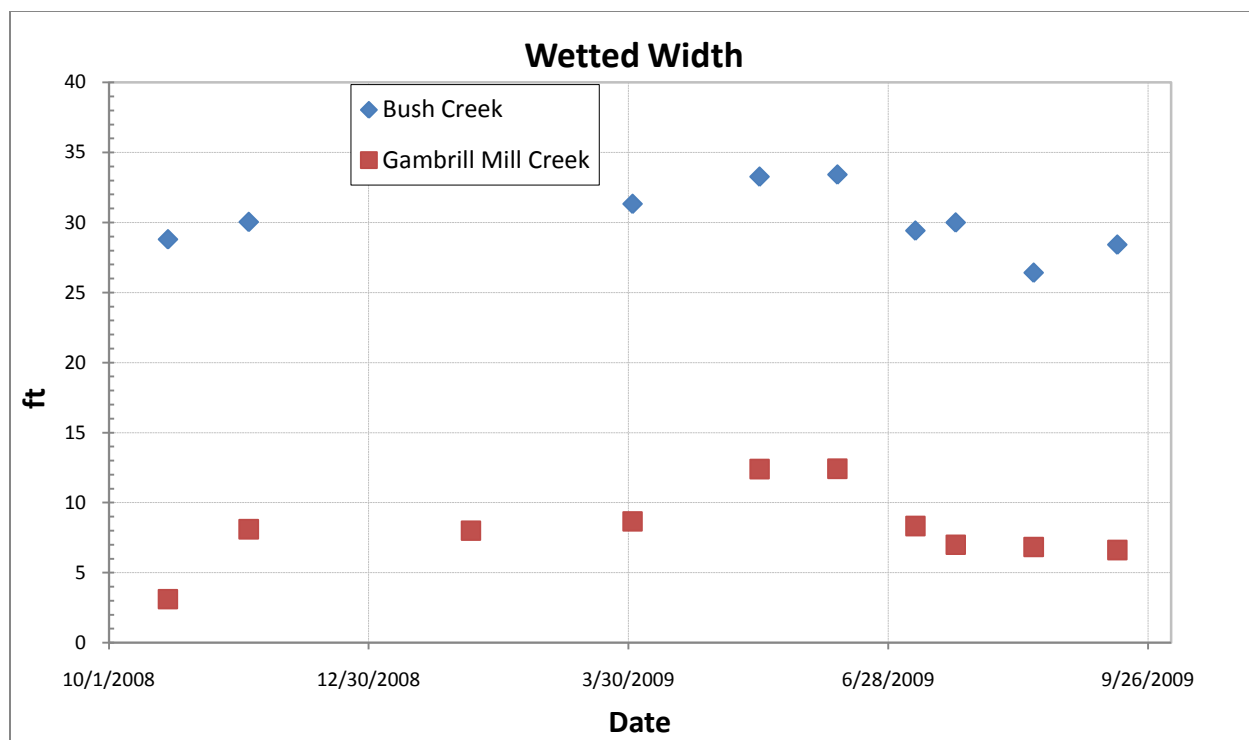


Figure 84: Wetted Width of Monocacy National Battlefield Streams, FY 2009.

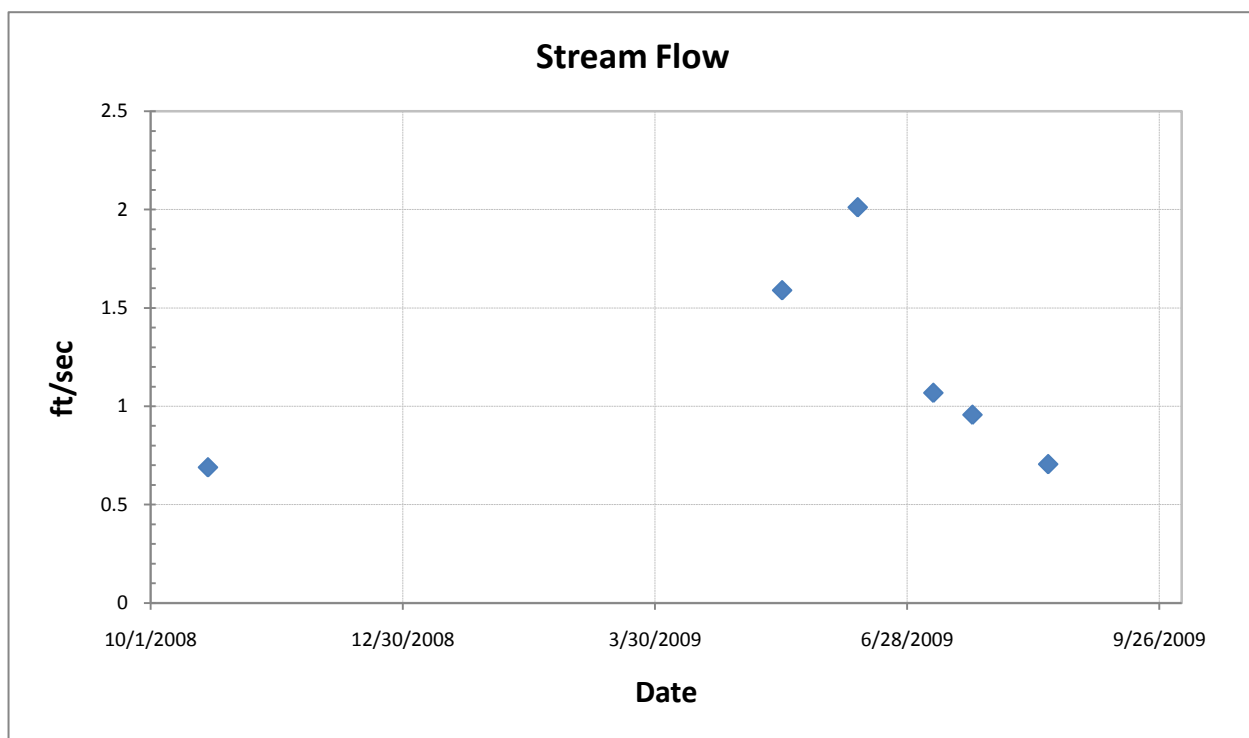


Figure 85: Flow of Bush Creek, Monocacy National Battlefield, FY 2009.

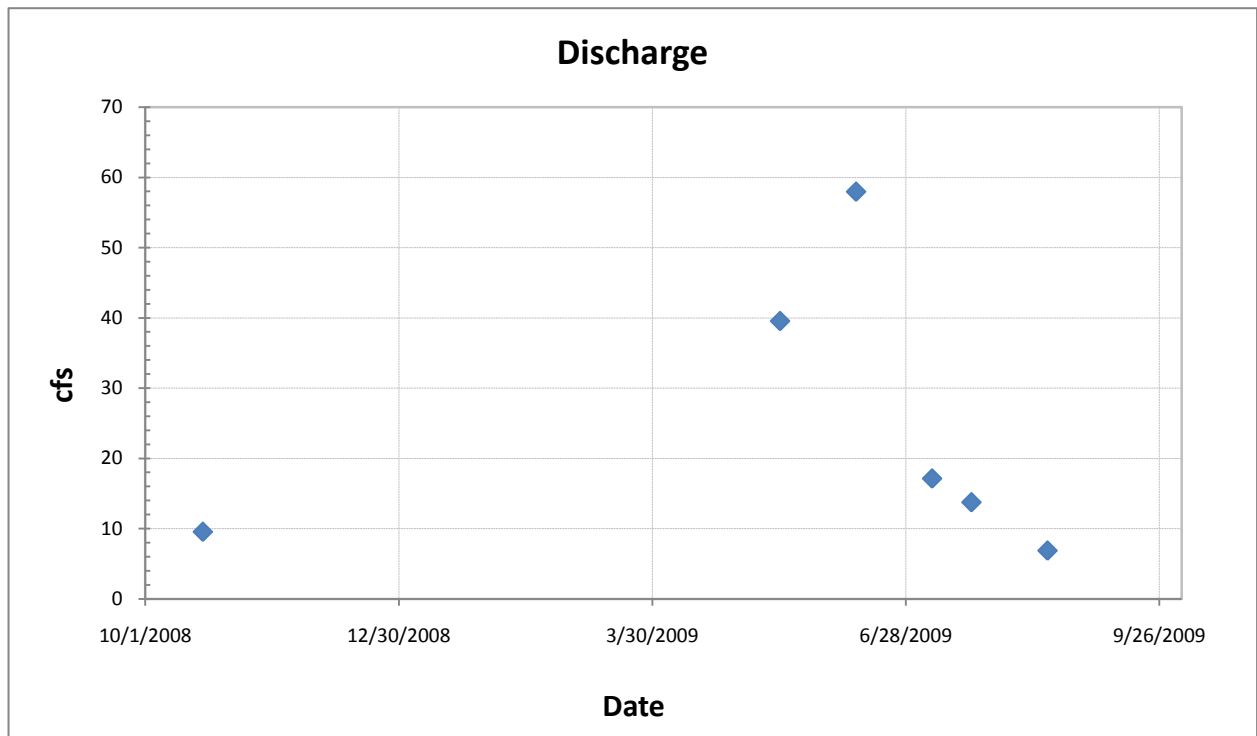


Figure 86: Discharge of Bush Creek, Monocacy National Battlefield, FY 2009.

National Capital Parks – East (NACE)

National Capital Parks-East includes 11 major park areas covering 4,378 ha within the District of Columbia and three nearby counties in Maryland. The park lies entirely within the upper Coastal Plain physiographic province and is managed for a variety of natural, cultural, and recreational resources. Most of the park units are within the Potomac River Watershed, with the exception of parts of Suitland Parkway and Baltimore and Washington Parkway which are in the Patuxent River watershed.

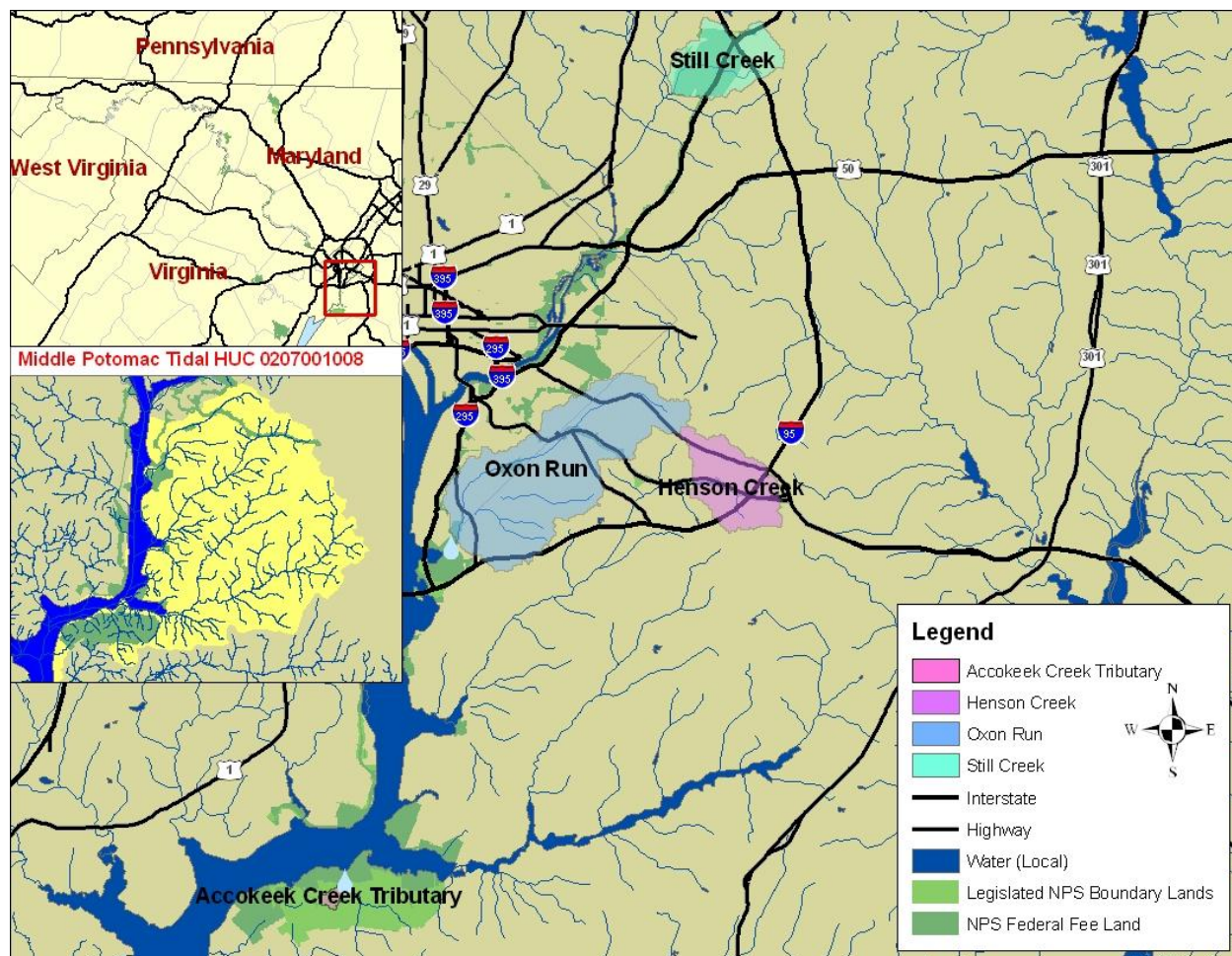


Figure 87: Relationship of the Stream monitoring sites in NACE to their watersheds and the park subunit boundaries.

This report discusses data collected October 2008 through September 2009 for an unnamed tributary of Accokeek Creek (Piscataway Park), Henson Creek (Suitland Parkway), Oxon Run (Oxon Cove Farm Park), and Still Creek (Greenbelt Park) (Figure 87). Summary statistics for the timeperiod are shown in Table 8.

Four sites were monitored in the park on a monthly basis for dissolved oxygen, pH, specific conductance, temperature, acid neutralizing capacity, nitrate, ammonia, and total phosphorus. In FY 2009 data was not collected at any sites in December 2008 and February 2009 due to inclement weather or frozen stream conditions. January 2009 data was only collected at Henson Creek because it was the only safely accessible, non-frozen stream.

Table 9: Date range, sample size (N), and data range for the vital signs data collected at National Capital Parks – East.

Local Name	Units	Period of Record	N	Minimum	Maximum	Mean	Median	Standard Deviation
ANC	µeq/L	10/7/2008 - 9/3/2009	33	612	2328	1163	1104	416
Discharge	cfs	10/7/2008 - 9/3/2009	13	0.50	22.02	4.87	2.66	5.76
DO	mg/l	10/7/2008 - 9/3/2009	36	5.38	19.41	9.39	8.56	2.68
Flow	ft/sec	10/7/2008 - 9/3/2009	13	0.137	1.368	0.637	0.481	0.450
Nitrate	mg/l	10/7/2008 - 9/3/2009	33	0.2	2.2	1.1	1.1	0.5
Ammonia	mg/l	10/7/2008 - 9/3/2009	14	0.032	0.428	0.126	0.069	0.131
pH	None	10/7/2008 - 9/3/2009	33	6.77	9.04	7.67	7.56	0.56
Salinity	ppt	10/7/2008 - 9/3/2009	36	0.09	1.85	0.23	0.18	0.30
Specific Conductance	µS/cm	10/7/2008 - 9/3/2009	36	175	3490	476	368	561
Total Phosphorus	mg/l	10/7/2008 - 9/3/2009	33	0.09	1.07	0.22	0.19	0.17
Water Depth	ft	10/7/2008 - 9/3/2009	13	0.197	0.519	0.346	0.324	0.087
Water Temperature	°C	10/7/2008 - 9/3/2009	36	3.5	25.9	15.5	16.3	5.8
Wetted Width	ft	10/7/2008 - 9/3/2009	32	2	32	16	18	9

Acid neutralizing capacity always exceeded the desired minimum for non-karst waters at all sites (Figure 88). All sites met the dissolved oxygen threshold in 2009 (Figure 89). pH was in the desired range for aquatic life at all sites in FY 2009 (Figure 90). Specific conductance is usually above the current threshold of 400 µS for Oxon Run, Henson Creek, and Still Creek in 2009 (Figure 94). The unnamed tributary of Accokeek Creek was never above threshold. Henson Creek and Oxon Run were at or above the threshold October through April and again in August. Still Creek was at or above threshold March and April. Henson Creek showed a typical stream response to wintry weather with a spike of 3500 µS/cm in January 2009, most likely due to road salt or other deicing compounds. Salinity was well below the freshwater defining point of 0.5 ppt, except in January in Henson Creek and March in Still Creek (Figure 95). Water temperature follows expected seasonal patterns. Oxon Run exceeded 25° C in July (Figure 96). The sampling site on Henson Creek is downstream from a military landing strip. It is possible that the stream is receiving runoff of airplane and other vehicle deicing compounds in the winter.

Ammonia was within desired condition in FY 2009 (Figure 92) except Henson Creek in January 2009. Henson Creek was the only stream not iced over during that site visit. Total phosphorus is consistently above the desired range of 0.1 mg/L at all sites; only Still Creek met the threshold in October and November 2008 and Henson Creek in March 2009 (Figure 92). In 2009 only Oxon Run exceeded nitrate threshold in April (Figure 93).

We only had sufficient depth (Figure 99) to collect flow (Figure 97) and discharge (Figure 98) at

Oxon Run in April, May and July, and in Henson Creek and Still Creek in April through July. Oxon Run and Still Creek, which have the largest stream channels, also had the widest range of widths (17-32, 13-23; Figure 100). Wetted width of the unnamed tributary of Accokeek Creek and Henson Creek were less than 10 feet.

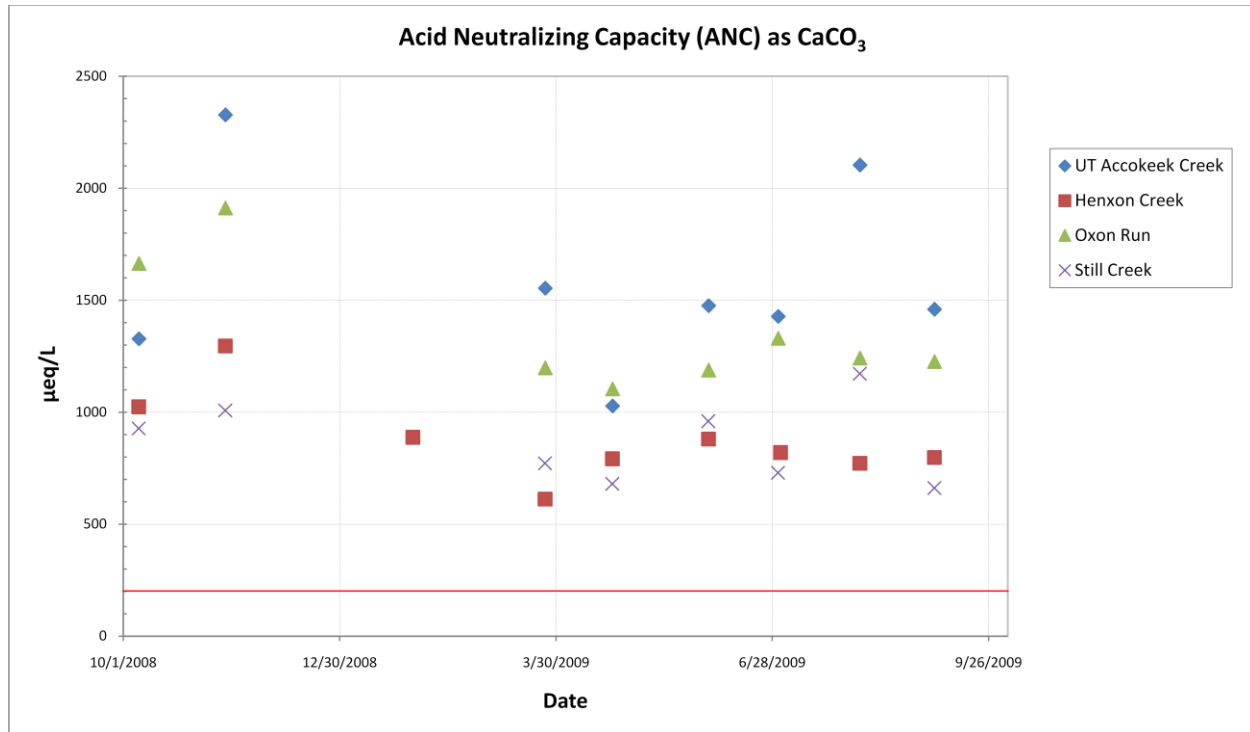


Figure 88: ANC in National Capital Parks - East Streams in FY 2009. Desired condition is above the 200 ueq/L threshold for non-karst waters is shown in red.

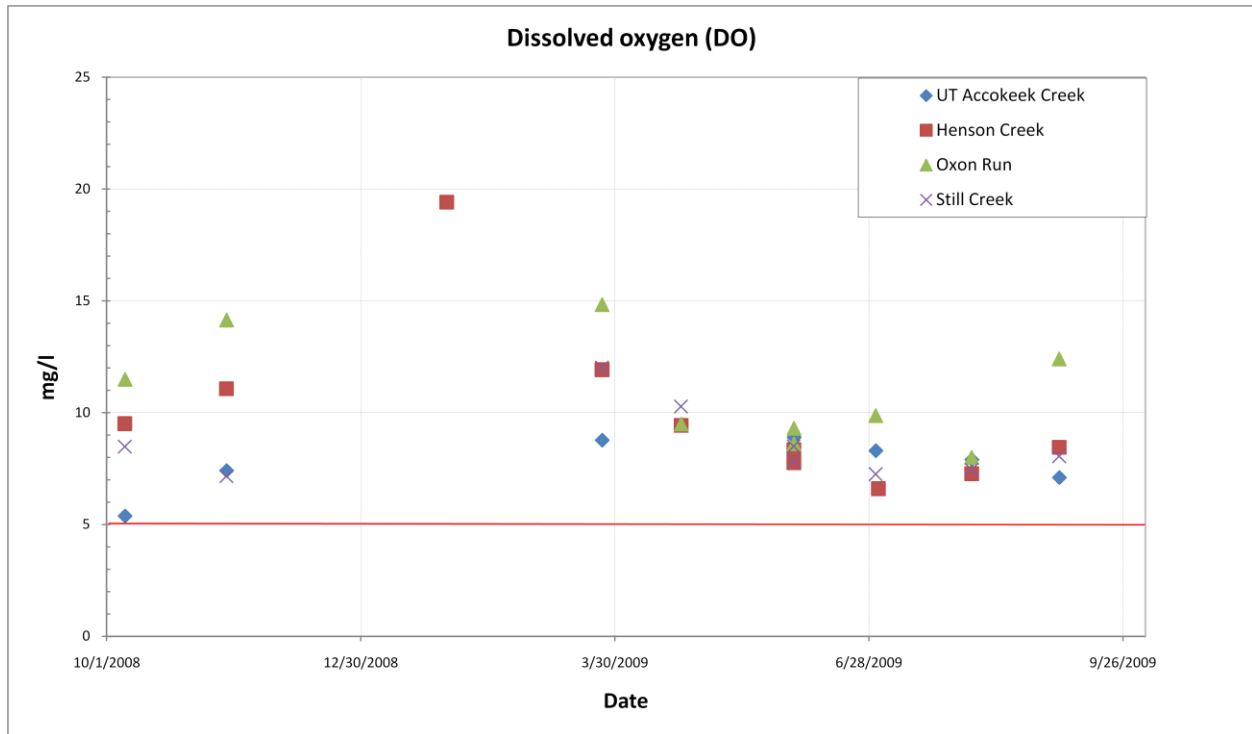


Figure 89: Dissolved Oxygen in National Capital Parks - East Streams in FY 2009. Desired condition is above the 0.5 mg/L threshold shown in red.

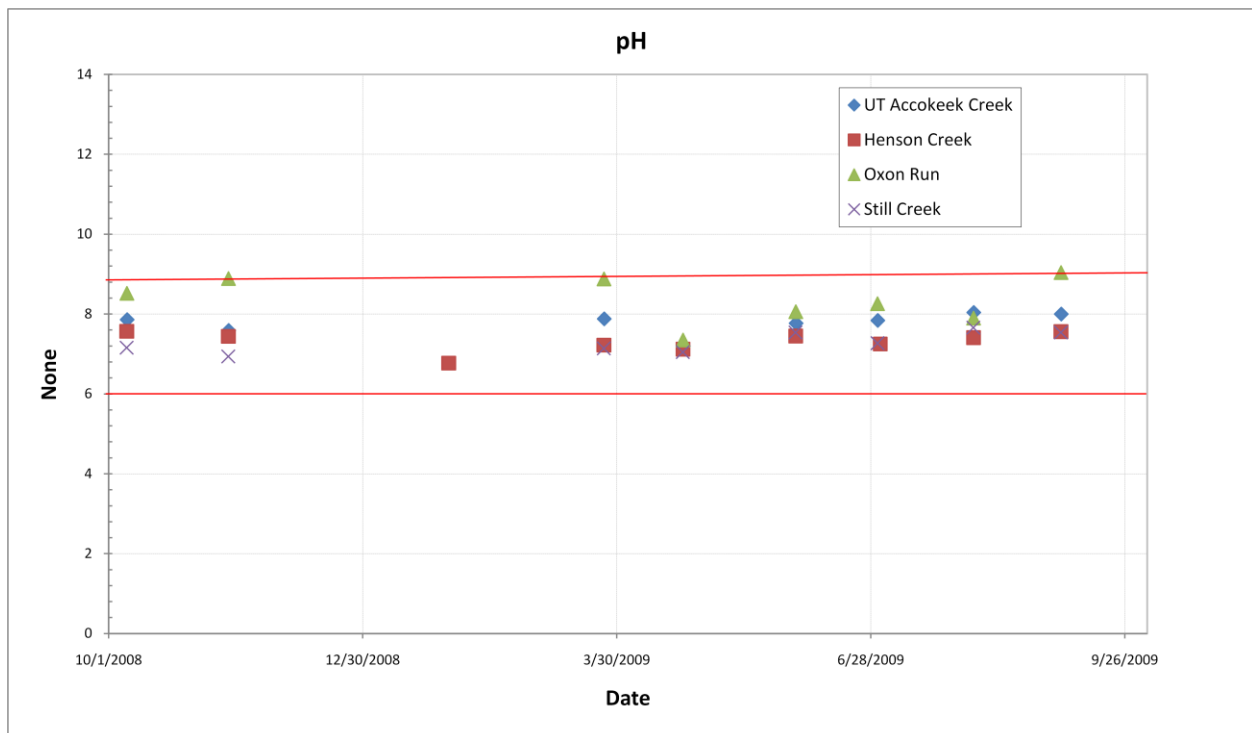


Figure 90: pH in National Capital Parks - East Streams in FY 2009. Desired condition is between the 6.5 and 9.0 thresholds shown in red.

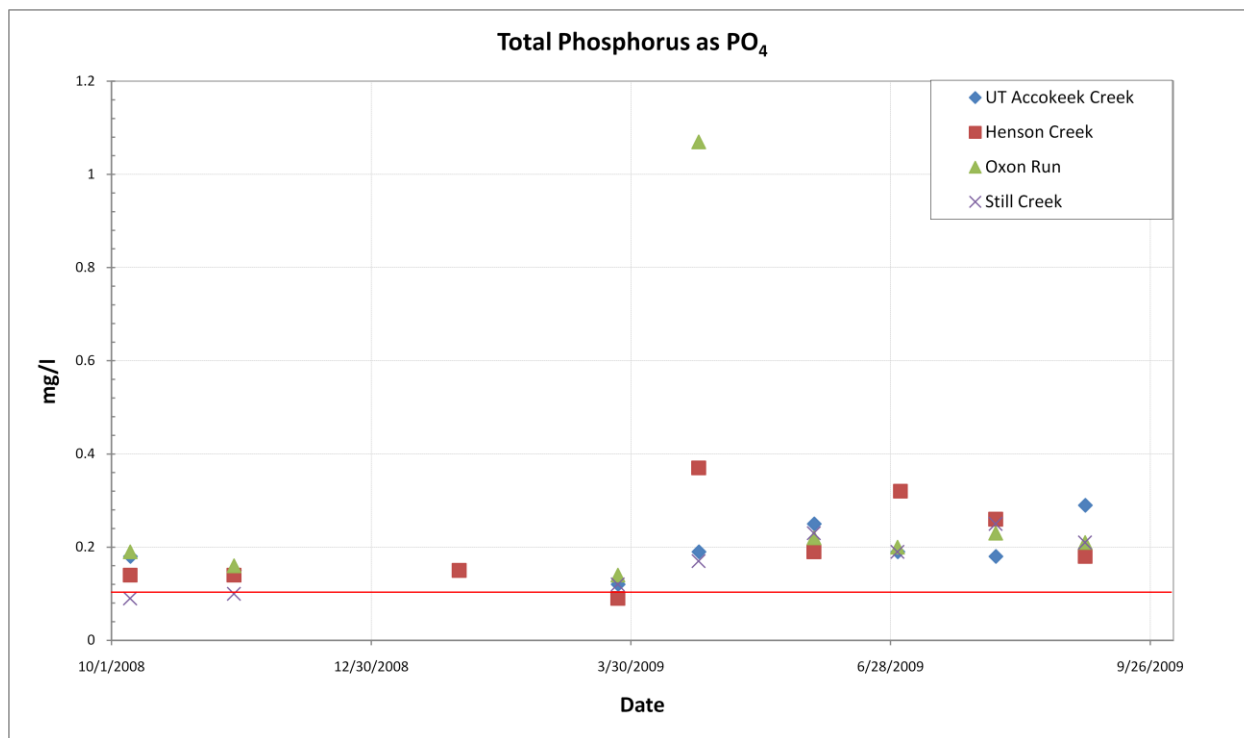


Figure 91: Phosphorus in National Capital Parks - East Streams in FY 2009. Desired conditions is below the 0.1 mg/L threshold shown in red.

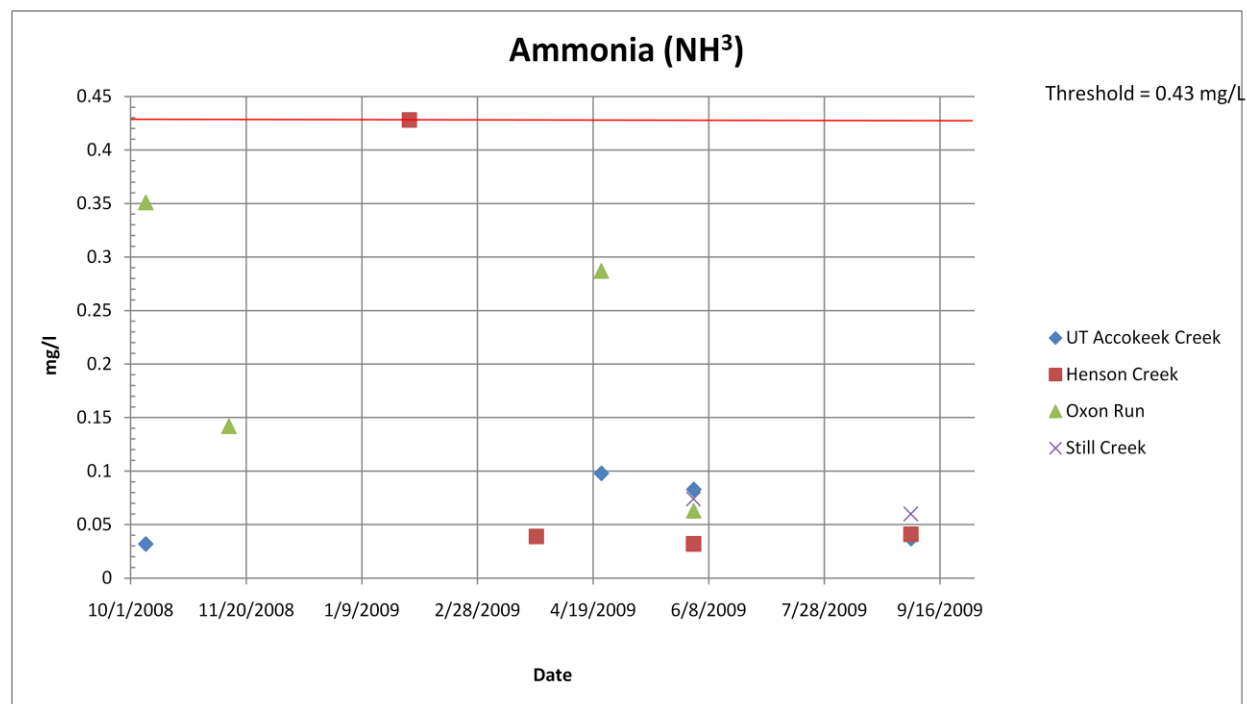


Figure 92: Ammonia in National Capital Parks - East streams FY 2009. Desired condition is below the 0.443 mg/L threshold shown in red.

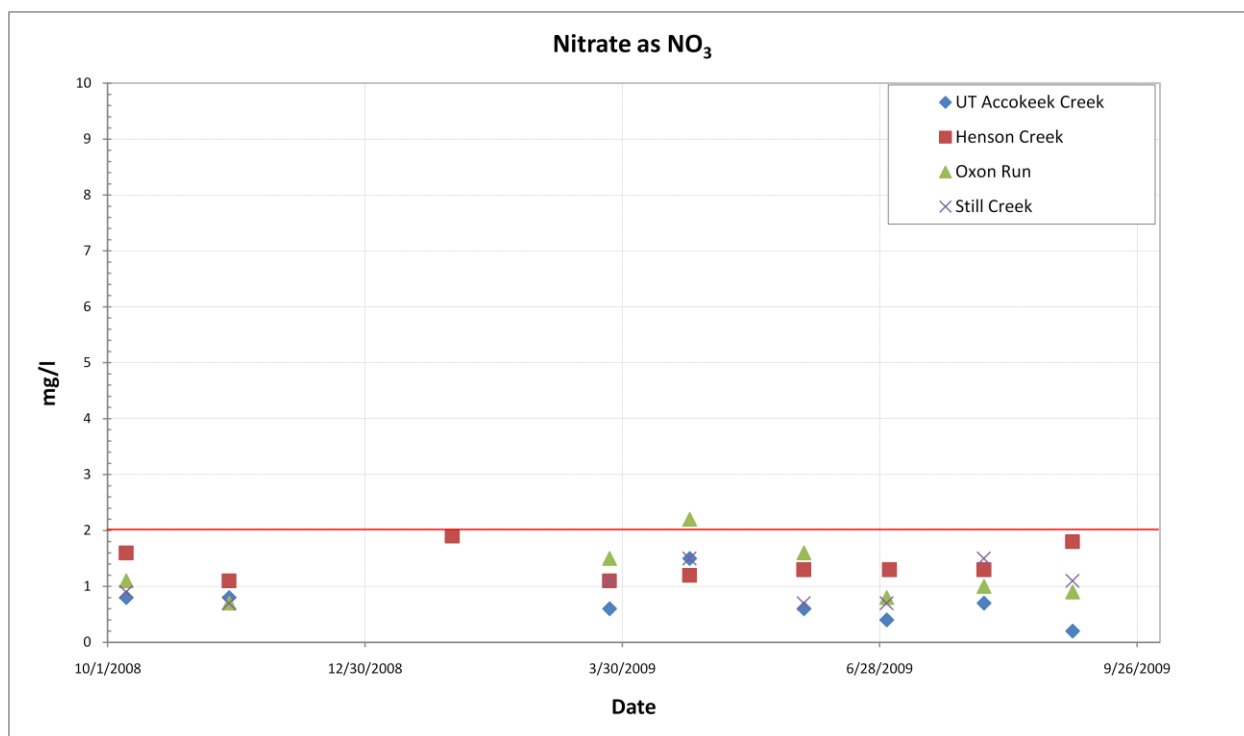


Figure 93: Nitrate in National Capital Parks - East streams FY 2009. Desired condition is below the 2.0 mg/L threshold shown in red.

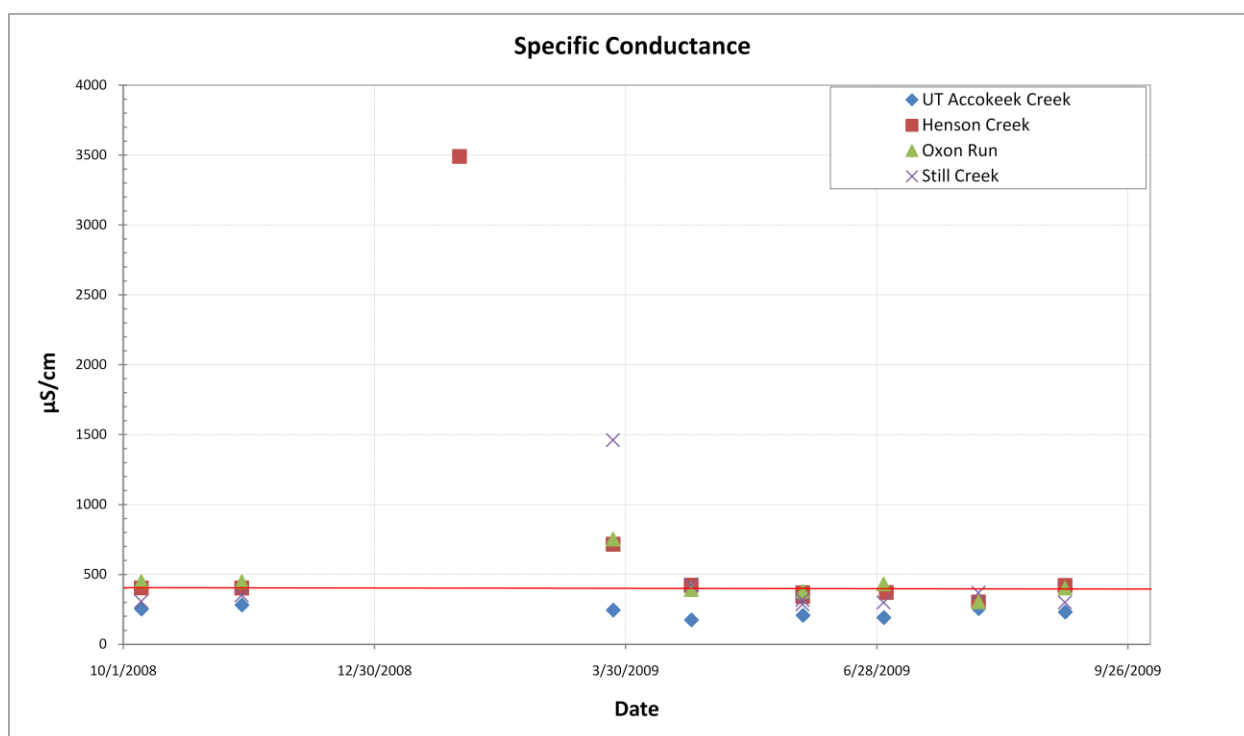


Figure 94: Specific Conductance in National Capital Parks - East streams FY 2009. Desired condition is below the 400 µS/cm threshold shown in red.

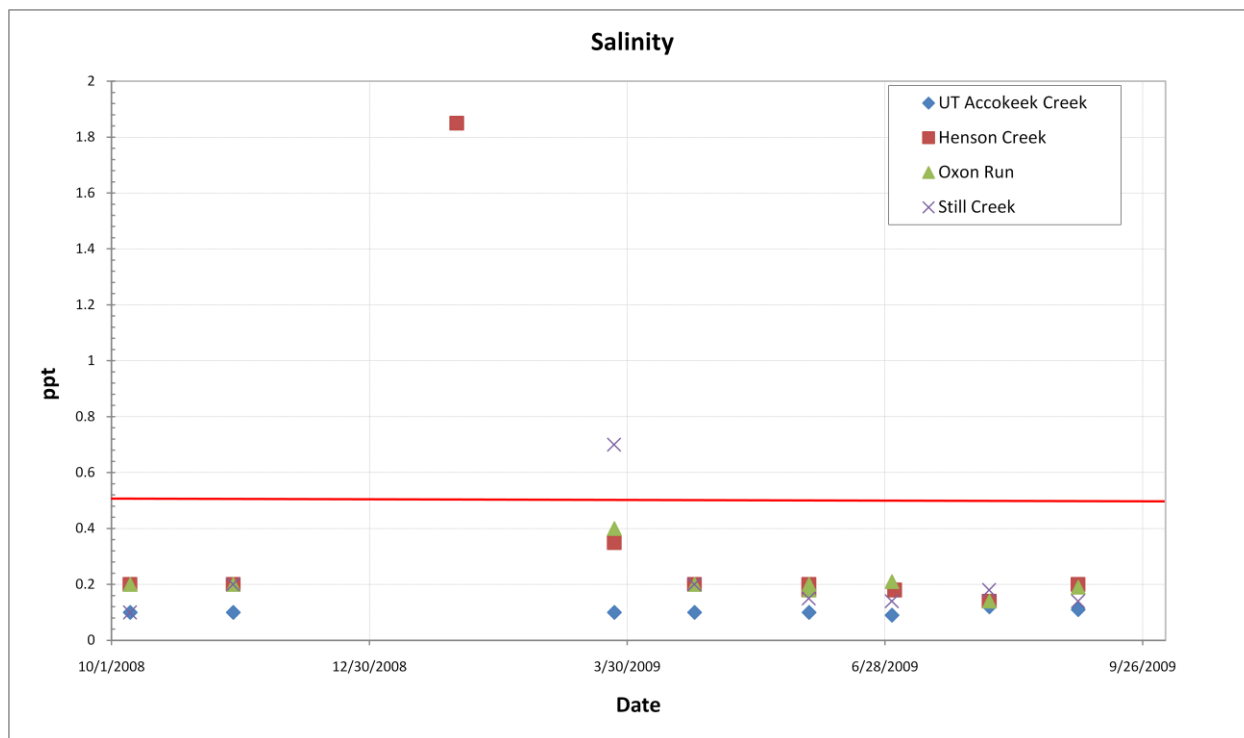


Figure 95: Salinity in National Capital Parks - East streams, FY 2009. Desired condition is below the 0.5 ppt threshold shown in red.

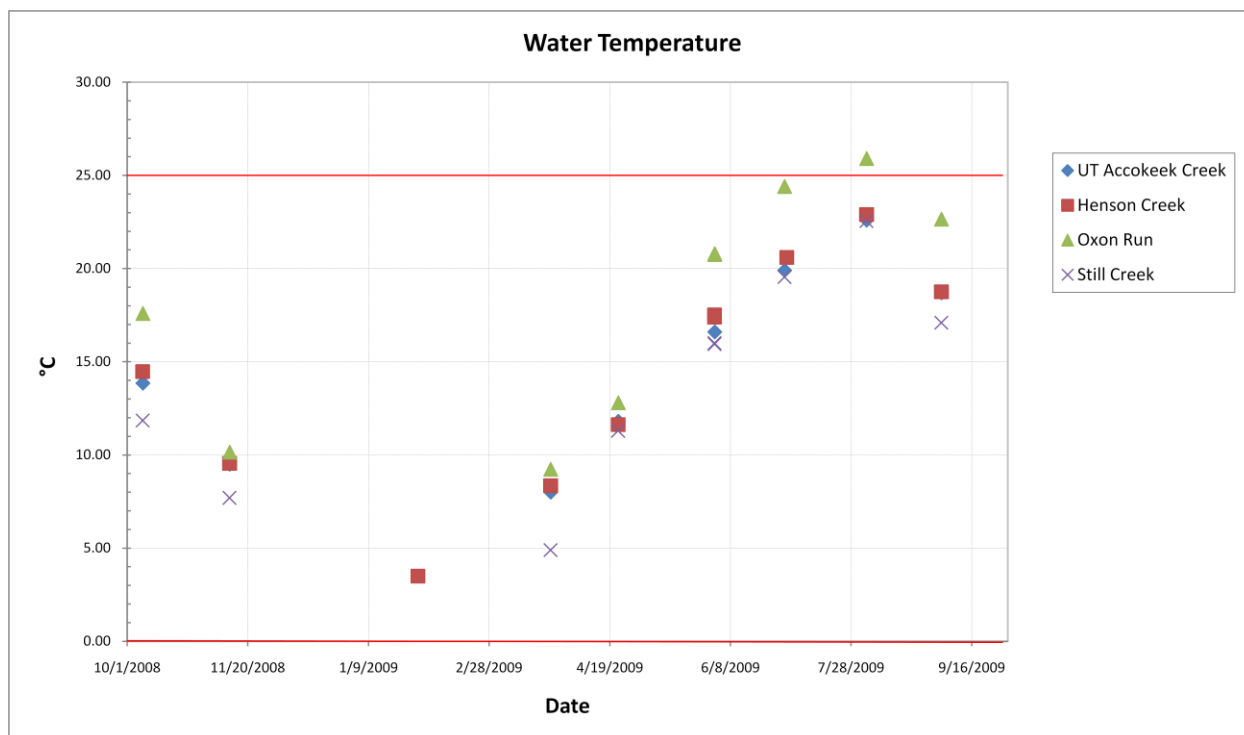


Figure 96: Water Temperature in National Capital Parks - East streams, FY 2009. Ideal condition for aquatic life is between the 0°C and 25°C thresholds shown in red.

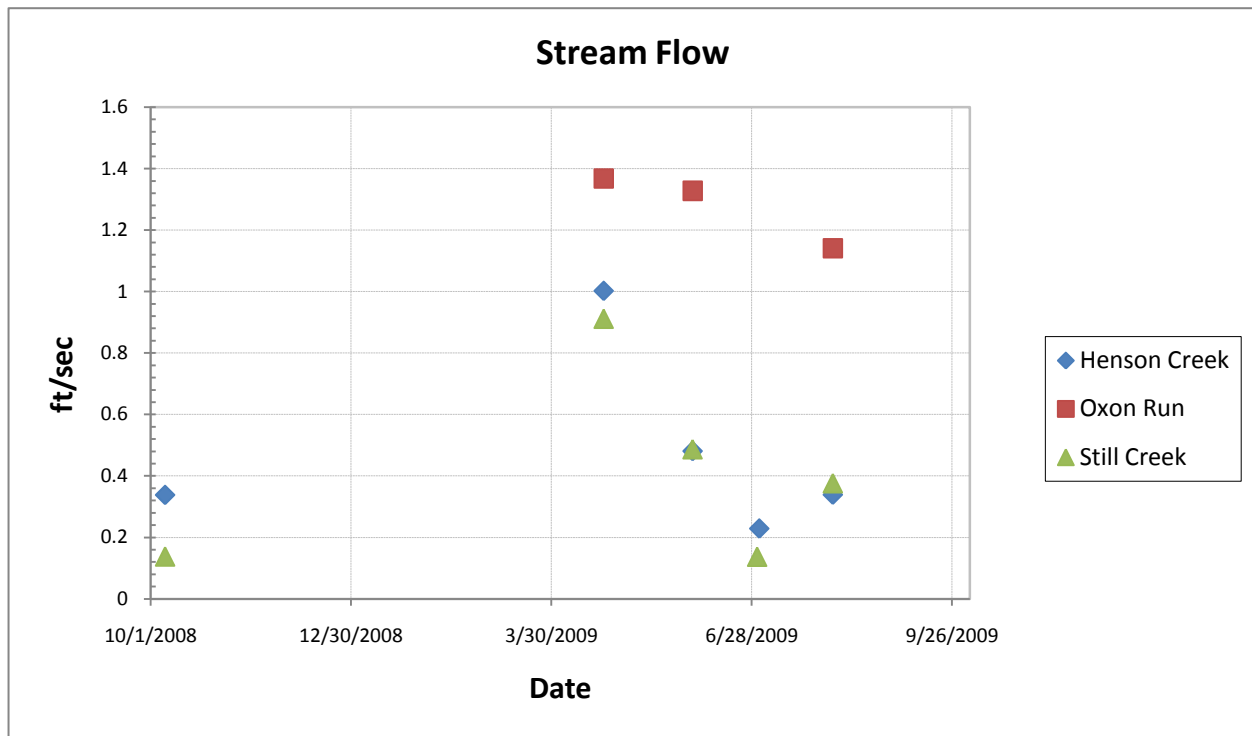


Figure 97: Flow in National Capital Parks - East streams in FY 2009.

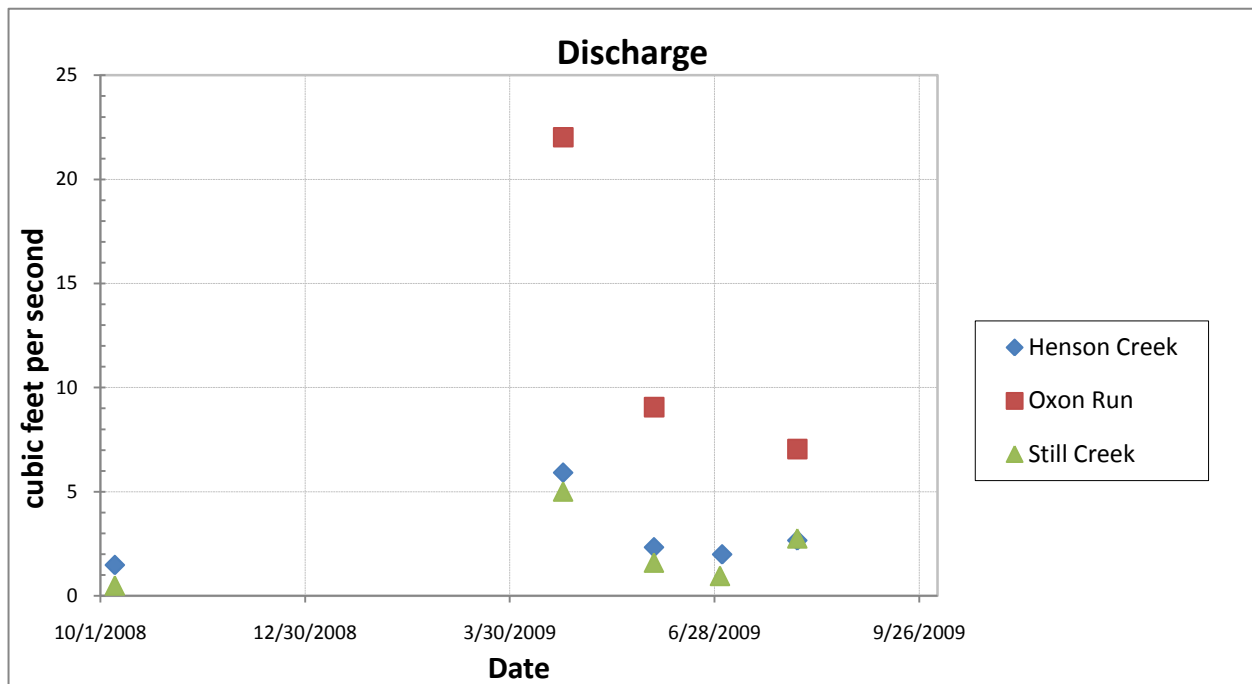


Figure 98: Discharge in National Capital Parks - East streams in FY 2009.

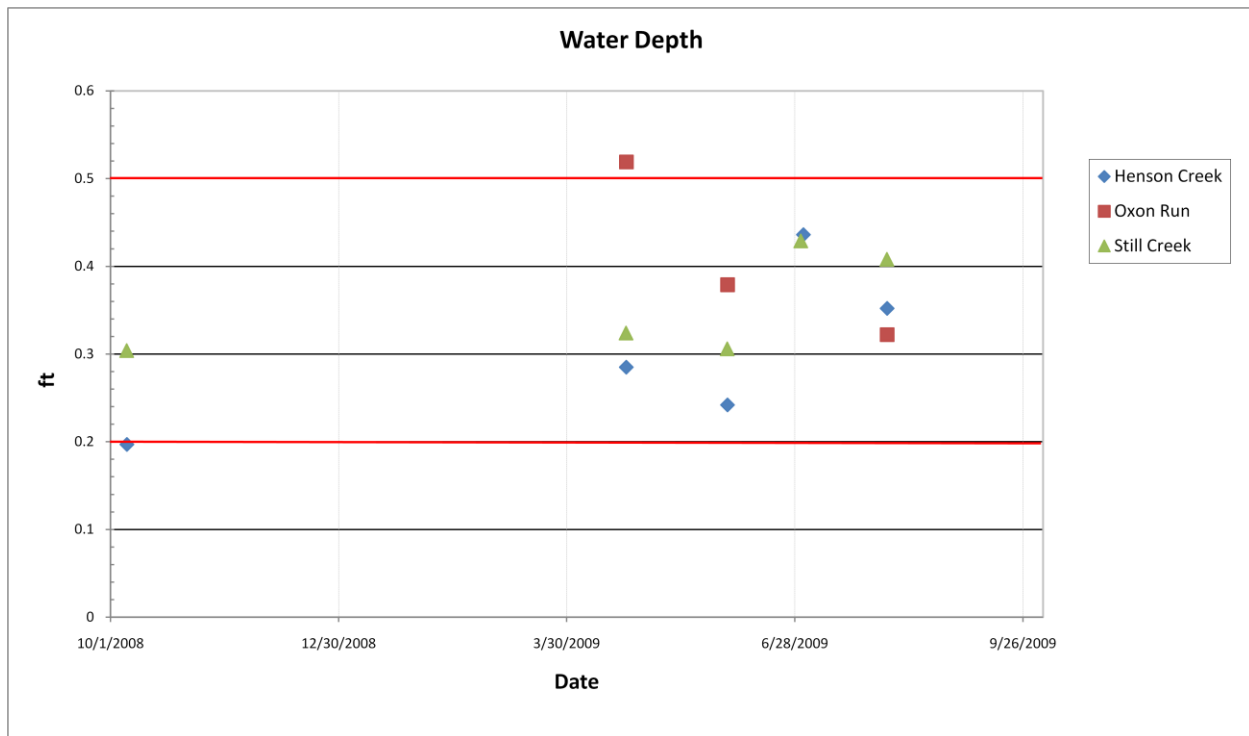


Figure 99: Average Water Depth in National Capital Parks - East streams in FY 2009. Required condition is above 0.2 foot for discharge measurements and 0.5 foot for data sondes.

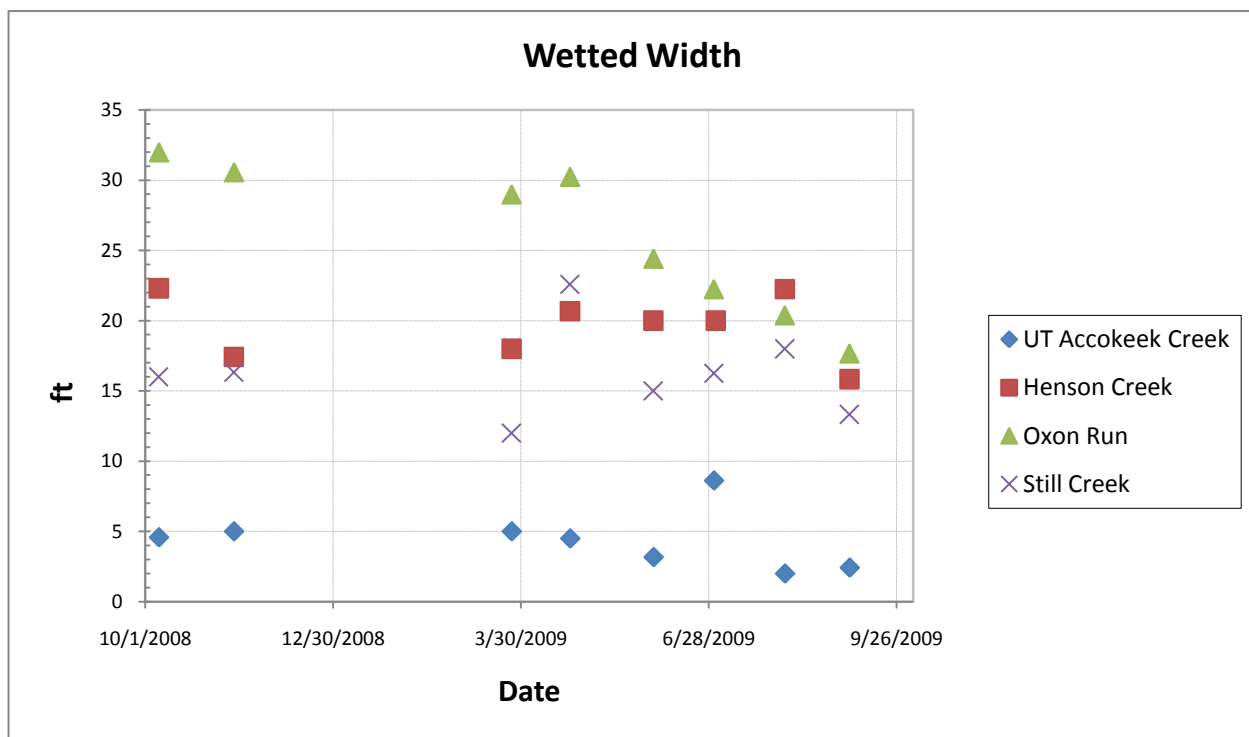


Figure 100: Wetted Width of National Capital Parks - East streams in FY 2009.

Prince William Forest Park (PRWI)

The park is located in Prince William and Stafford Counties, Virginia and crosses the Piedmont and Coastal Plain physiographic regions. PRWI contains portions of two stream systems: Quantico Creek and Chopawamsic Creek (Figure 101). The 30-square mile watershed of Quantico Creek is almost entirely forested. The headwaters of South Fork Quantico Creek, 9 square miles, lie within Quantico Marine Corps Base, while 4 square miles of watershed are in private ownership. The remaining 17 square miles of the watershed lie within the 7,518 ha Prince William Forest Park. Thus, the park has the unique opportunity to preserve and protect a large portion of this ecosystem. Because the park includes two physiographic provinces (Piedmont and Coastal Plain) and lies in the transition zone between northern and southern climates, it exhibits a wide range of habitat and vegetative communities. It is now the only natural area in the National Park System that contains a significant expanse of piedmont forest.

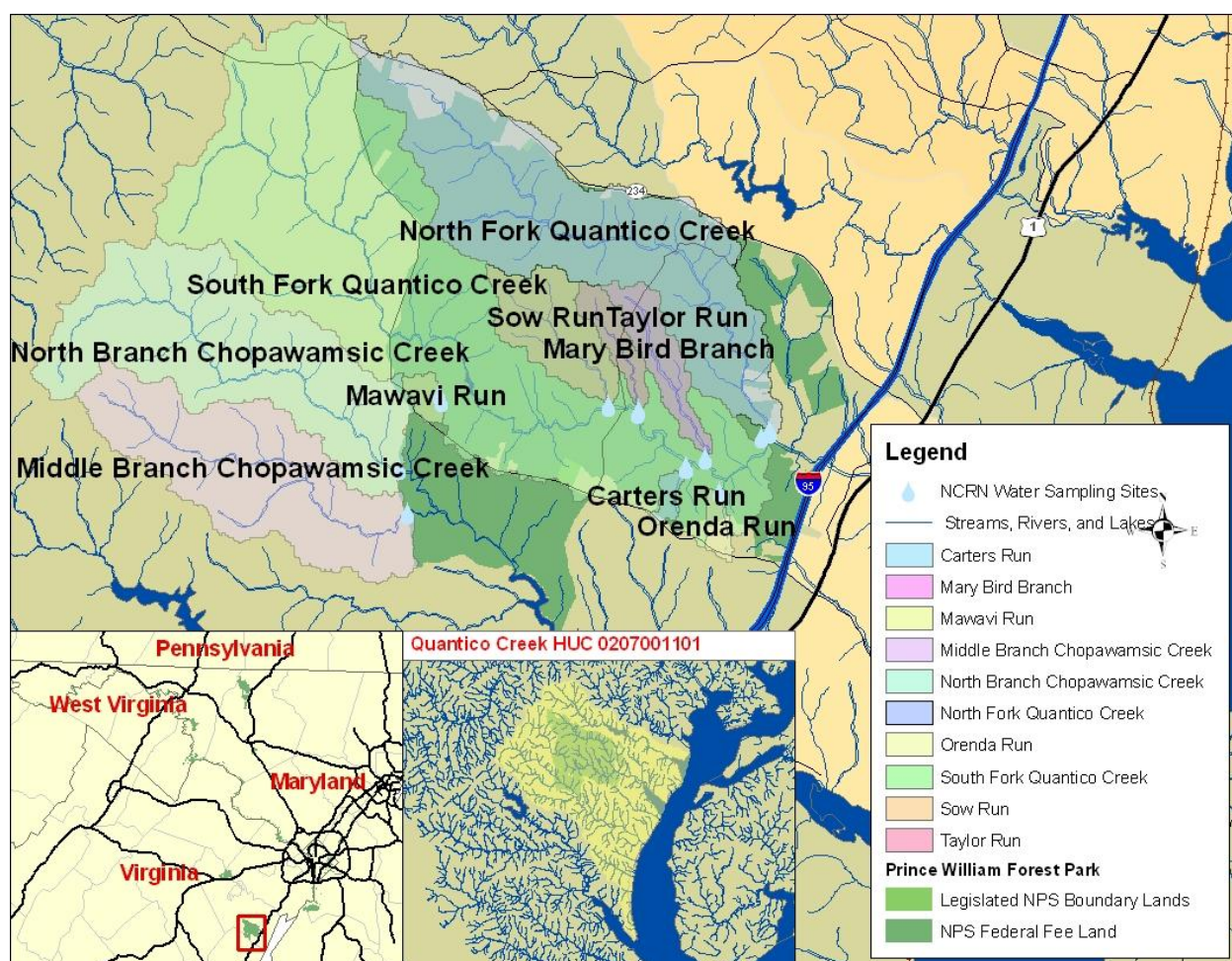


Figure 101: Relationship of PRWI stream monitoring sites to their watersheds and the park boundary.

This report discusses data collected October 2008 through September 2009 for Middle Branch Chopawamsik, North Branch Chopawamsik, North Fork Quantico Creek, South Fork Quantico Creek, Sow Run, Mary Bird Branch, Mawavi Run, Taylors Run, Carters Run, and Orenda Run. Summary statistics for the time period are shown in Table 9.

Table 10: Date range, sample size (N), and data range for the vital signs data collected at Prince William Forest Park.

Local Name	Units	Period of Record	N	Minimum	Maximum	Mean	Median	Standard Deviation
ANC	µeq/L	10/7/2008 - 9/3/2009	33	612	2328	1163	1104	416
Discharge	cfs	10/7/2008 - 9/3/2009	13	0.50	22.02	4.87	2.66	5.76
DO	mg/l	10/7/2008 - 9/3/2009	36	5.38	19.41	9.39	8.56	2.68
Flow	ft/sec	10/7/2008 - 9/3/2009	13	0.1372	1.3680	0.6365	0.4809	0.4503
Nitrate	mg/l	10/7/2008 - 9/3/2009	33	0.2	2.2	1.1	1.1	0.5
Ammonia	mg/l	10/7/2008 - 9/3/2009	14	0.032	0.428	0.126	0.069	0.131
pH	None	10/7/2008 - 9/3/2009	33	6.77	9.04	7.67	7.56	0.56
Total Phosphorus	mg/l	10/7/2008 - 9/3/2009	33	0.09	1.07	0.22	0.19	0.17
Salinity	ppt	10/7/2008 - 9/3/2009	36	0.09	1.85	0.23	0.18	0.30
Specific Conductance	µS/cm	10/7/2008 - 9/3/2009	36	175	3490	476	368	561
Water Depth	ft	10/7/2008 - 9/3/2009	13	0.197	0.519	0.346	0.324	0.087
Water Temperature	°C	10/7/2008 - 9/3/2009	36	3.5	25.9	15.5	16.3	5.8
Wetted Width	ft	10/7/2008 - 9/3/2009	32	2	32	17	18	9

Ten sites were monitored in the park on a monthly basis for dissolved oxygen, pH, specific conductance, temperature, acid neutralizing capacity, nitrate, ammonia, total phosphorus, width, depth, flow and discharge. Orrenda Run was added for sampling year 2009.

Acid Neutralizing Capacity was always above the threshold of 200 ueq/L except in Carter's Run and Orrenda Run, where it was never above the detection limit of 10 ueq/L (Figure 102). pH tends to be at the low end of desirable condition in PRWI streams (Figure 103). Carter's Run is always acidic and below the lower threshold of 6.5. Mawavi Run and Taylor Run were below the 6.5 threshold for the first half of FY09. North and Middle Branches of Chopawamsik were less than 6.5 on one occasion each in 2009. This is of special concern due to the lower ANC in the park and the recent realization that streams in Shenandoah are acidified to the point of losing native trout populations. There are 2 incidents of unusually high pH, South Fork Quantico Creek in September 2006 and Mary Bird Branch in August 2006. Specific conductance always meets the threshold of 400 uS/cm (Figure 104). Salinity was always very low in PRWI streams in FY 2009 (Figure 105) except Carter's Run in January 2009.

Ammonia is frequently below the detection limit. Ammonia was only measured above threshold during FY09 in April 2009 at Carter's Run, Mawavi Run, North Fork Quantico Creek, Orrenda Run, and Taylor's Run (Figure 106). Dissolved oxygen fell below the desired condition of 5.0mg/L October 2008 in Carter's Run, Mawavi Run and Orrenda Run, and September 2009 in Taylor Run (Figure 109). Nitrate has not been above the desired level of 2.0 mg/L at any site

during sampling 2005-2009 (Figure 107). Phosphorus is consistently above the desired range of 0.1 mg/L at all sites almost all of the time (Figure 108). There is no known source within the park, and the Marine Corps Base is required to maintain the headwaters in pristine condition. Potential sources of phosphorus need to be fully investigated.

Water temperature follows expected seasonal trends and stays within the comfort range of most organisms except incidental summer highs in North Fork Quantico Creek (Figure 110).

Becca Fordham Bridging the Watershed stated that they noticed the week of March 29th and April 5th all the streams along South Fork Quantico Creek in the park being more turbid than in years past, with lots of algae and blackfly larvae, but little of anything else (Personal Communication to Jim Pieper). This observation corresponds to the weird ammonia spread in April. Specific conductance and salinity did not spike at the time, though.

There was only sufficient depth (Figure 111) to measure flow (Figure 112) and discharge (Figure 113) in March, June, and August. North Fork Quantico Creek had the greatest range in wetted width. Middle Branch Chopawamsik Creek is the widest stream. Orenda Run, Mawavi Run, Carters Run, Sow Run, and Taylors Run are always less than 8 feet wide and experience less than a 3 foot fluctuation in width on a monthly basis (Figure 114). Carters Run and Mary Bird Branch were dry in September 2009 (Figure 113).

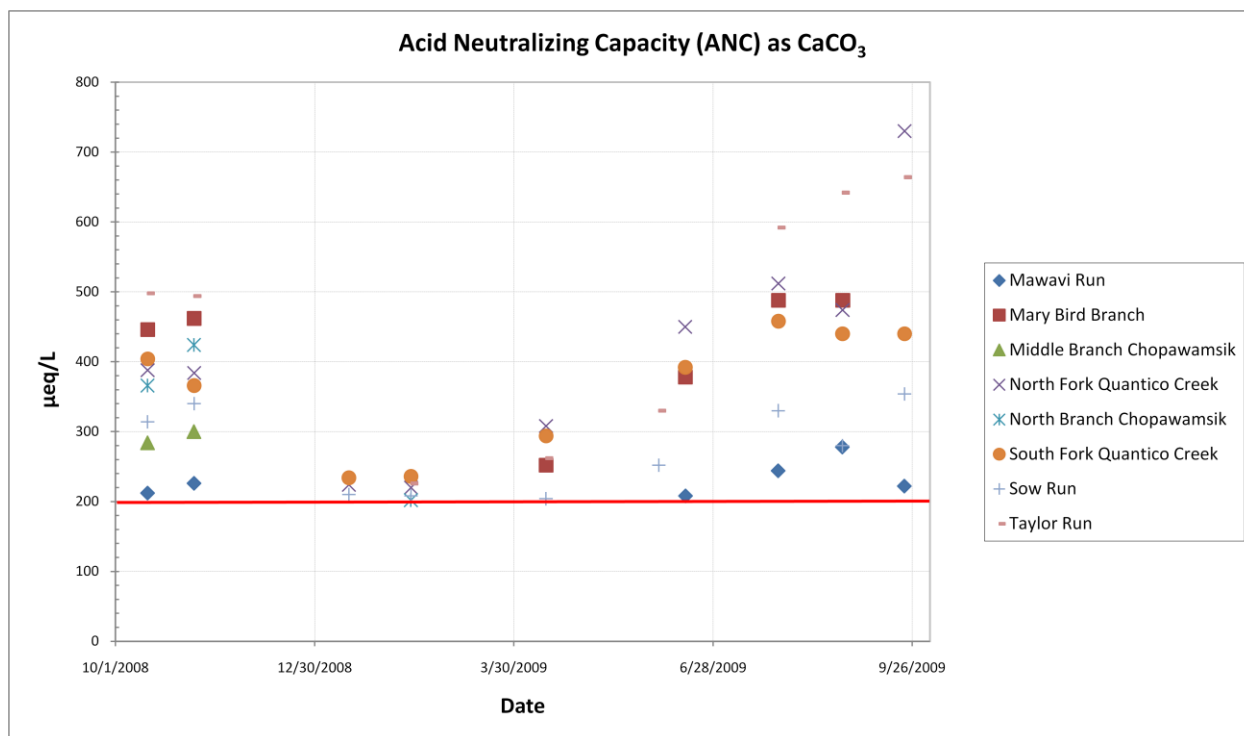


Figure 102: ANC in Prince William Forest Park streams FY 2009. Desired condition is above the 200 µeq/L threshold for non-karst waters shown in red.

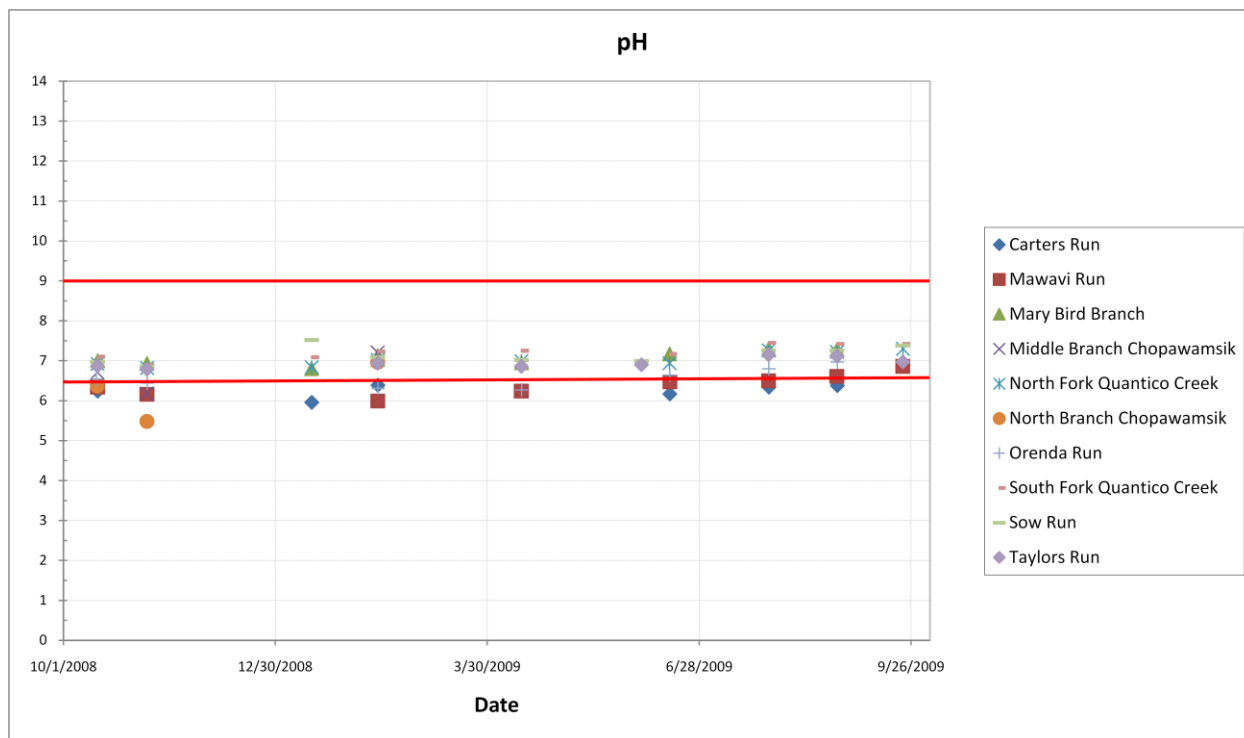


Figure 103: pH in Prince William Forest Park streams FY 2009. Desired condition is between the 6.5 and 9.0 thresholds shown in red.

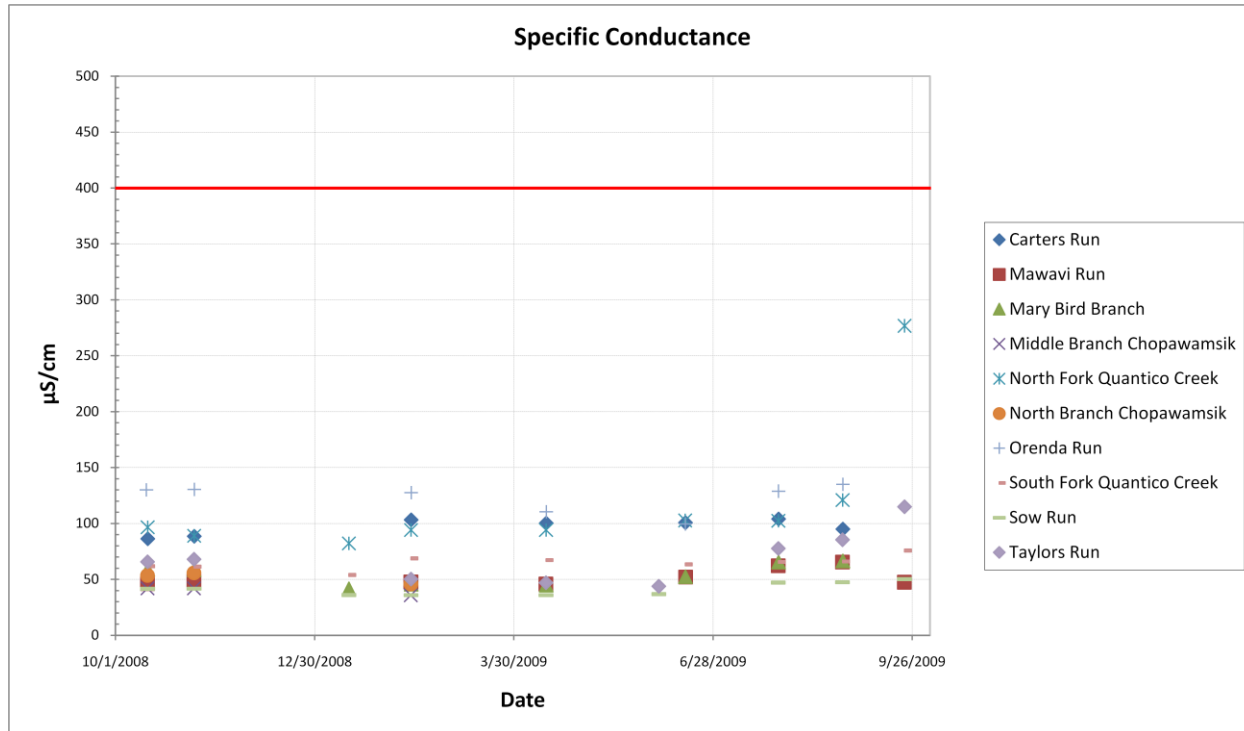


Figure 104: Specific Conductance in Prince William Forest Park streams FY 2009. Desired condition is below the 400 $\mu\text{S}/\text{cm}$ threshold shown in red.

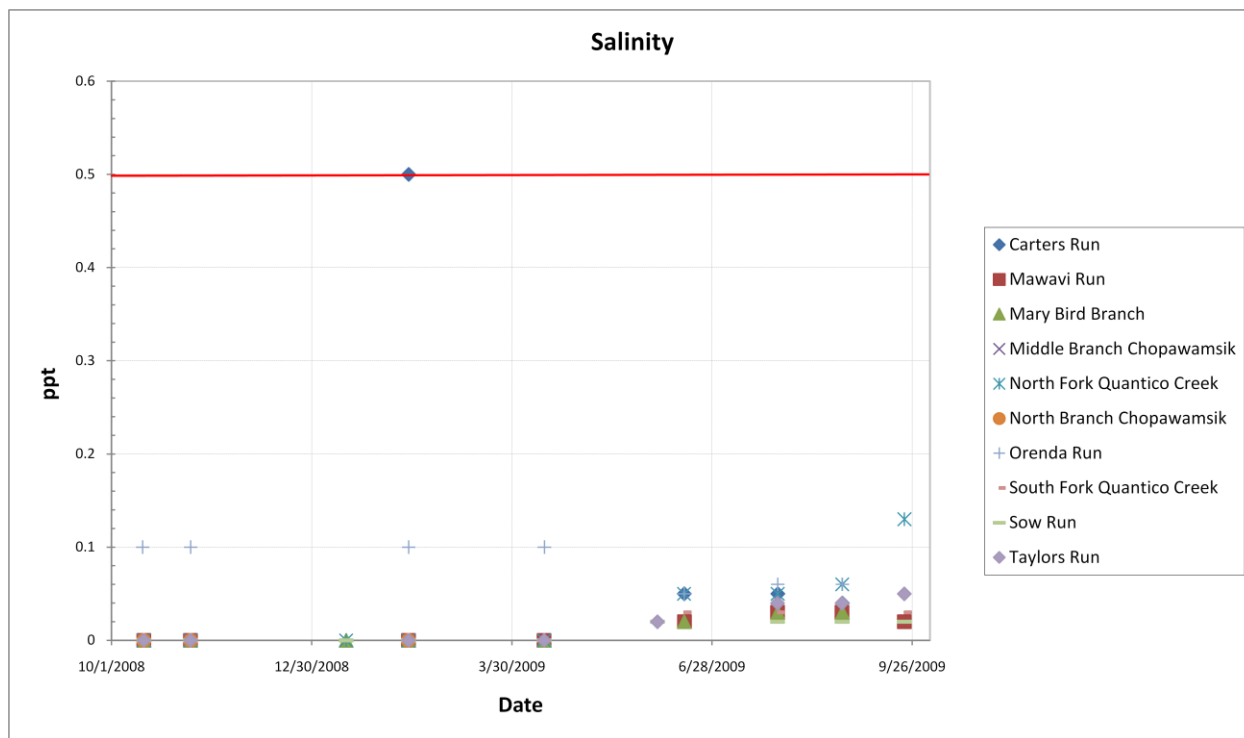


Figure 105: Salinity in Prince William Forest Park Streams. Desired condition is below the 0.5 threshold shown in red.

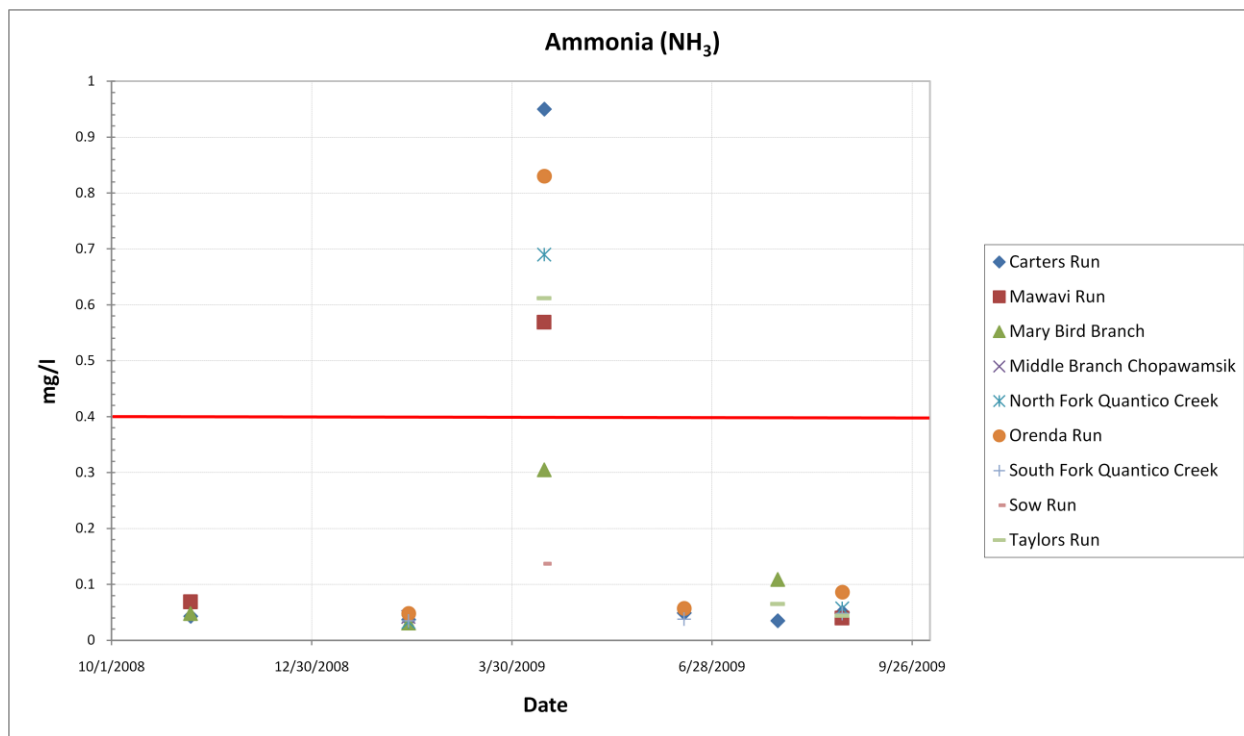


Figure 106: Ammonia in Prince William Forest Park streams FY 2009. Desired condition is below the 0.443 threshold shown in red

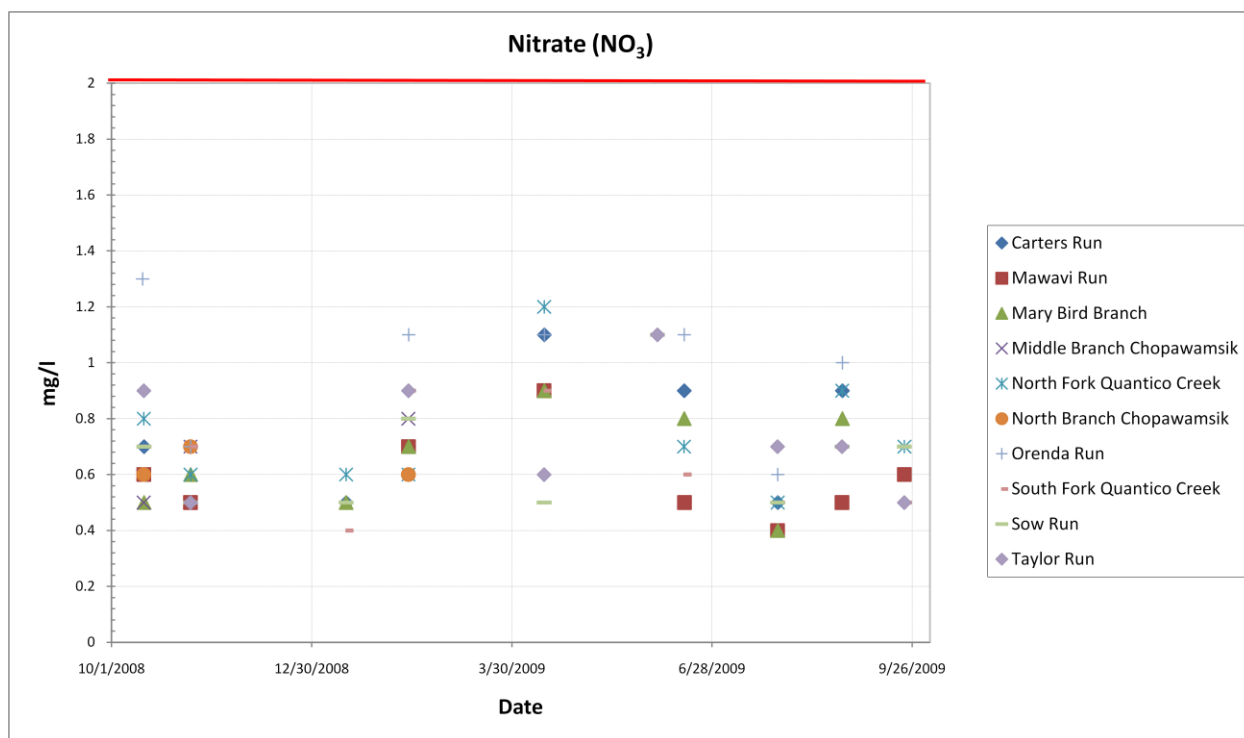


Figure 107: Nitrate in Prince William Forest Park streams FY 2009. Desired condition is below the 2.0 mg/L threshold shown in red.

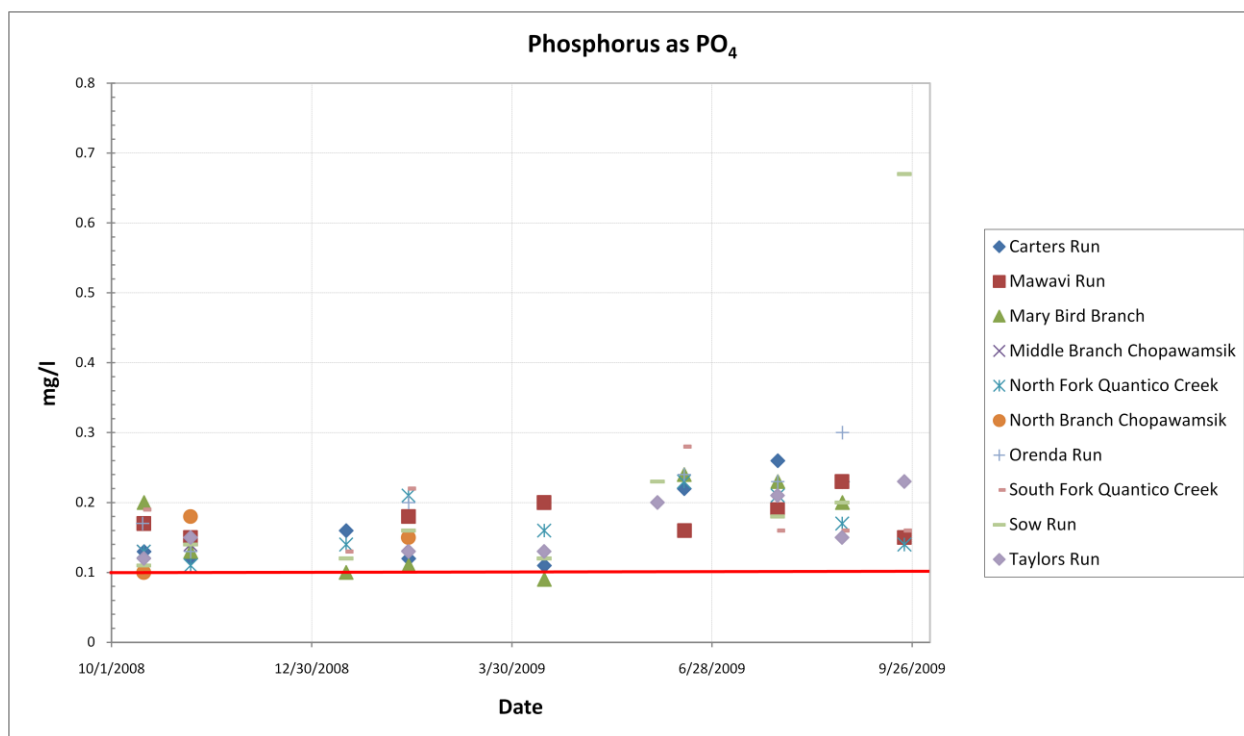


Figure 108: Total Phosphorus in Prince William Forest Park streams FY 2009. Desired condition is below the 0.2 mg/L threshold shown in red.

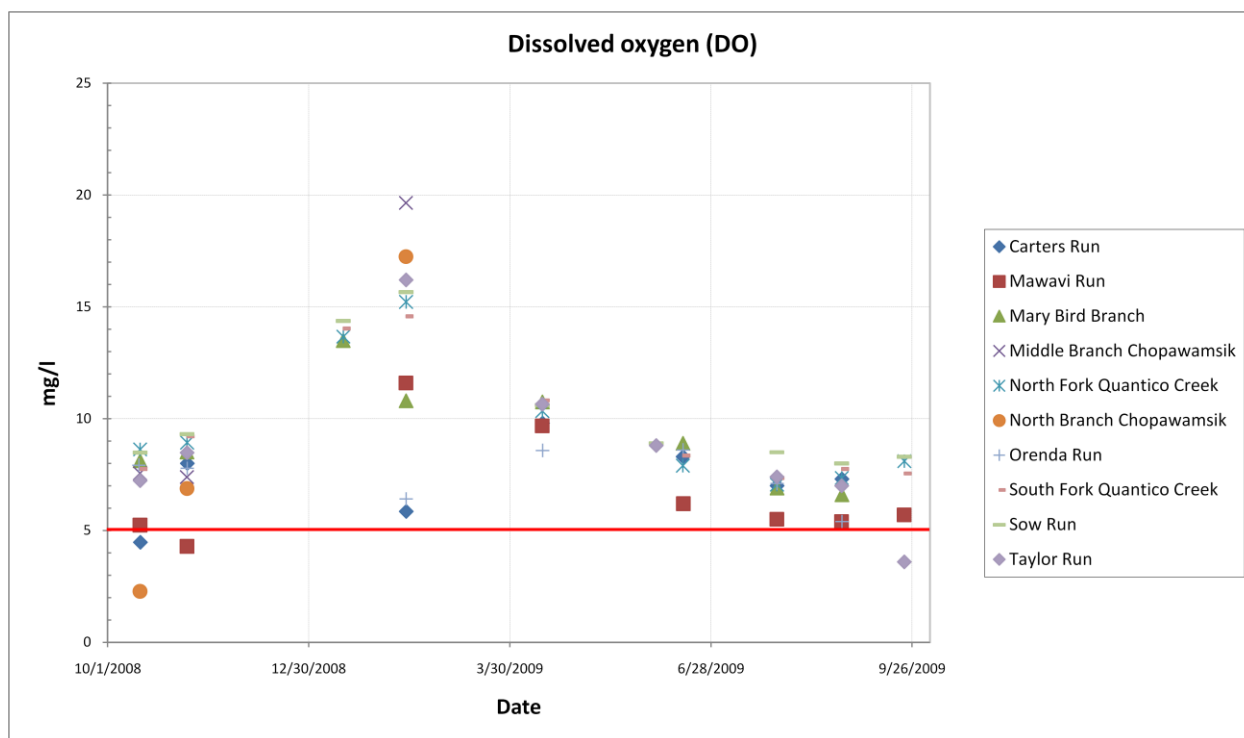


Figure 109: Dissolved Oxygen in Prince William Forest Park streams FY 2009. Desired condition is above the 5.0 mg/L threshold shown in red.

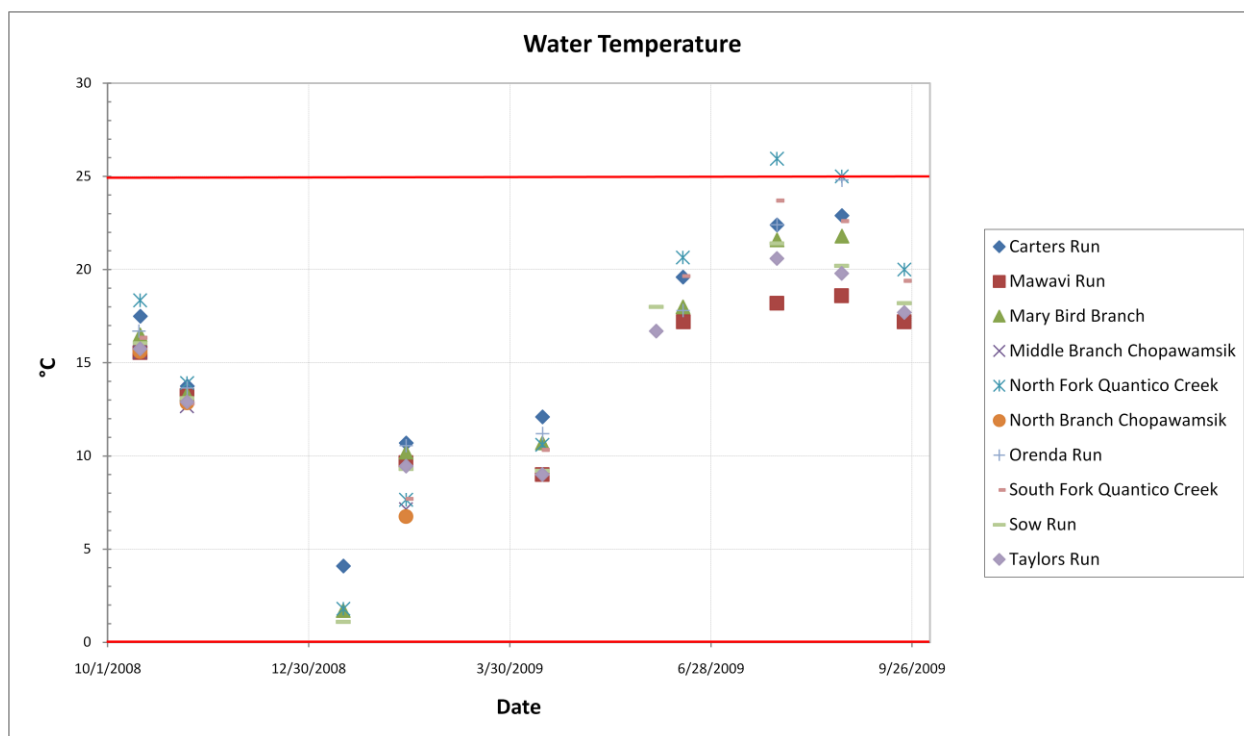


Figure 110: Water temperature in Prince William Forest Park streams, FY 2009. Ideal conditions for aquatic life are between the 0° C and 25° C thresholds shown in red.

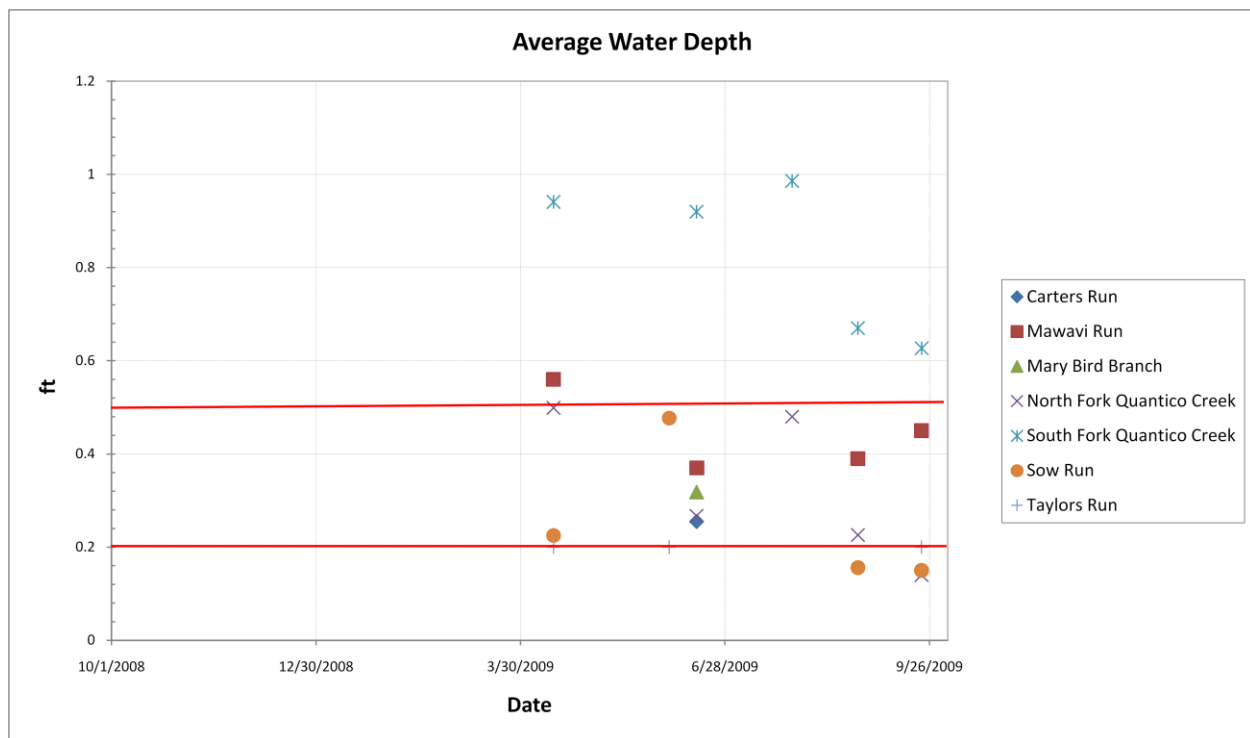


Figure 111: Average water depth in Prince William Forest Park streams, FY 2009. Required condition is above 0.2 foot for discharge measurements and 0.5 foot for data sondes.

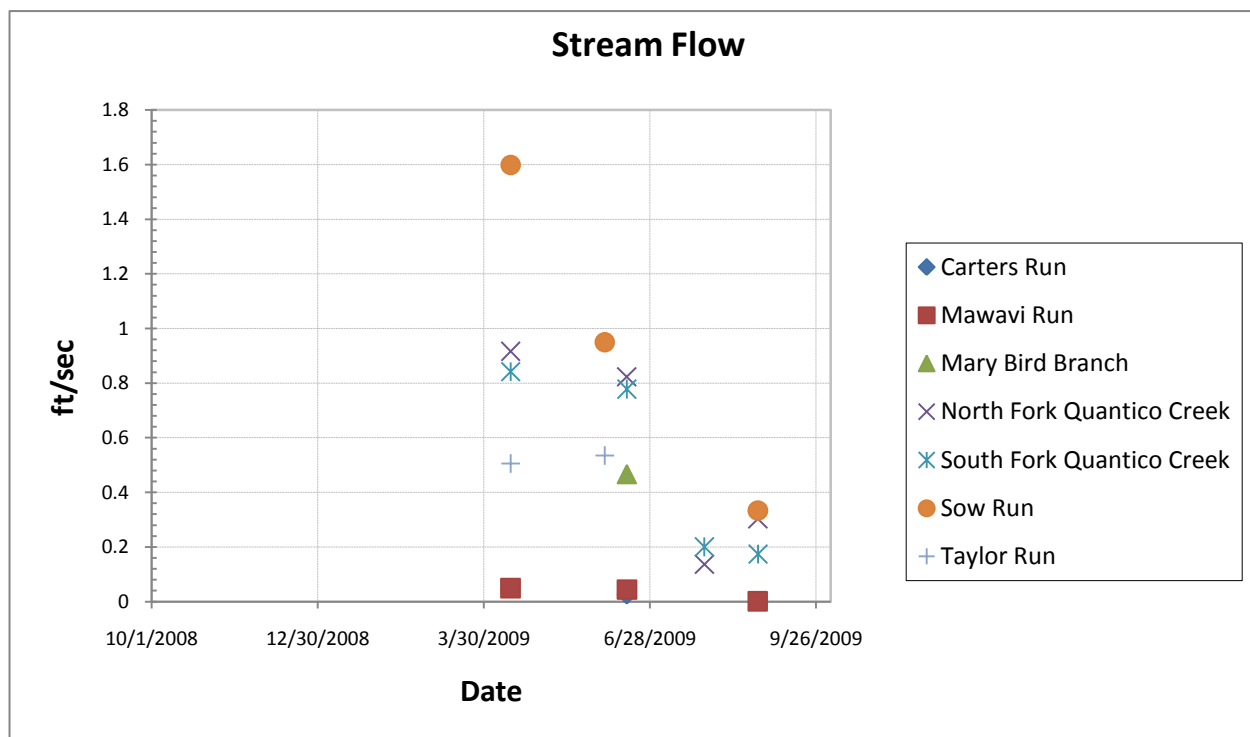


Figure 112: Stream flow in Prince William Forest Park, FY 2009.

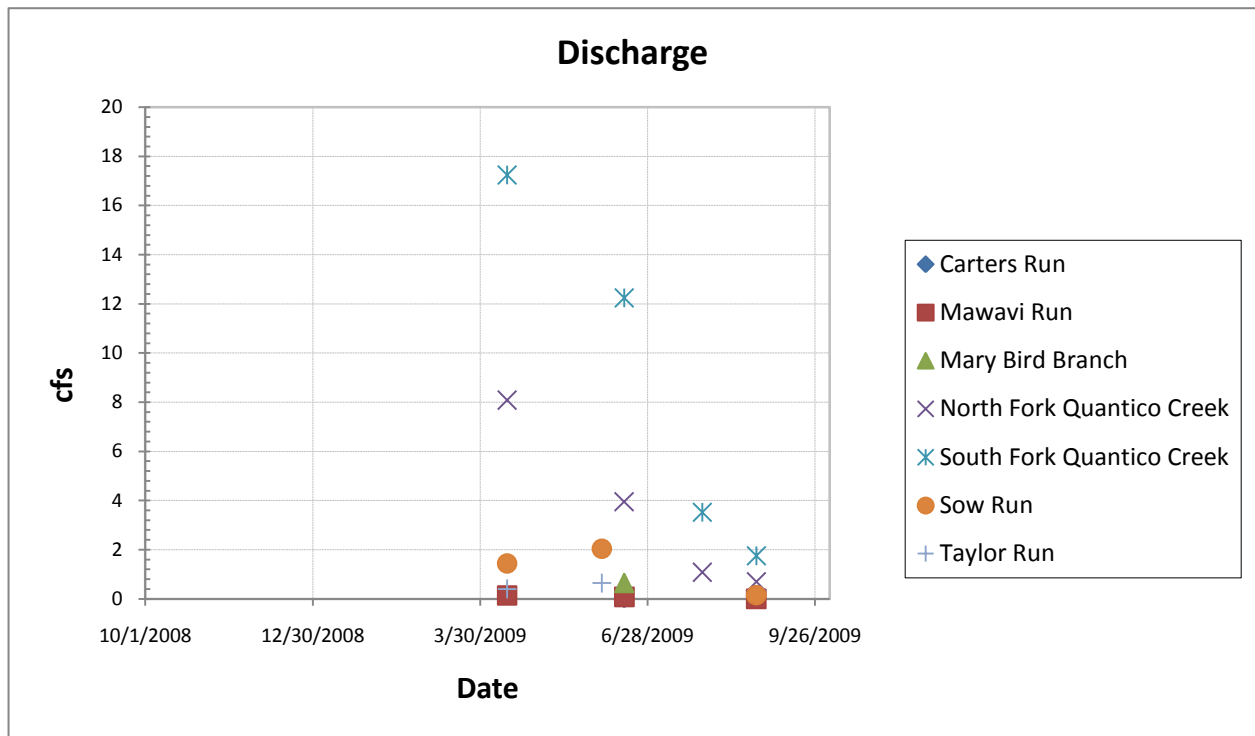


Figure 113: Discharge of Prince William Forest Park streams, FY 2009.

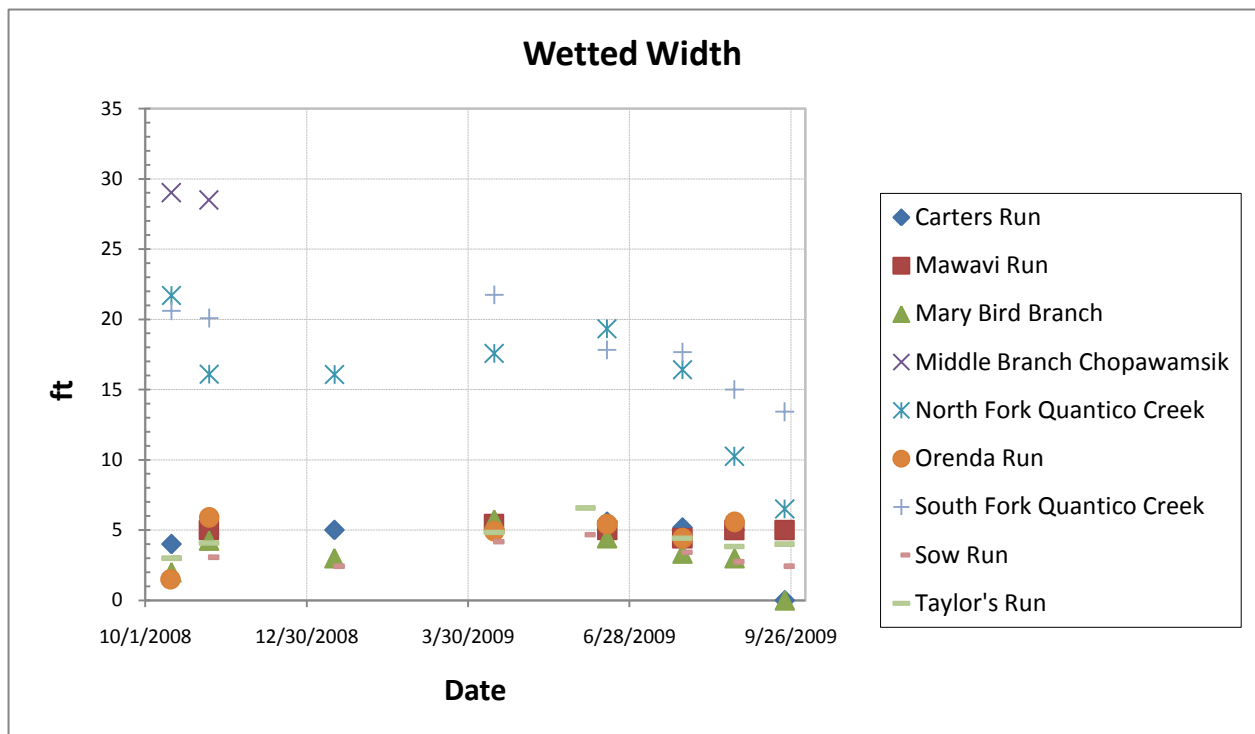


Figure 114: Wetted width of Prince William Forest Park streams, FY 2009.

Rock Creek Park (ROCR)

The park is located in Washington, DC within the Potomac River Watershed and the Piedmont and Coastal Plain physiographic provinces. Rock Creek originates near Laytonsville, in Montgomery County, MD. Approximately 10 miles of its total length of 33 miles are located within the District of Columbia (Figure 115). Rock Creek becomes a fourth-order stream at the confluence of Rock Creek with the North Branch of Rock Creek, north of Rockville, Maryland. It remains a fourth-order stream for the remainder of its length. Except for the narrow extension of parkland into Maryland that is under Montgomery County administration, Rock Creek Park represents a largely isolated natural system surrounded by urban areas, which have significantly impacted the park. These effects include flooding and pollution in park streams, introductions of invasive non-native species into natural areas, extirpations or reductions of sensitive native species, and the artificial inflation of a few native species' populations adversely that affect other native plants and wildlife (Carruthers et al. 2009).

This report discusses data collected October 2008 through September 2009 for Fenwick Branch, Pinehurst Branch, Luzon Branch, Soapstone Valley Stream, Broad Branch, Hazen Creek, Piney Branch, Normanstone Creek, Dumbarton Oaks Stream, Rock Creek, and Palisades Creek. Summary statistics for the time period are shown in Table 10.

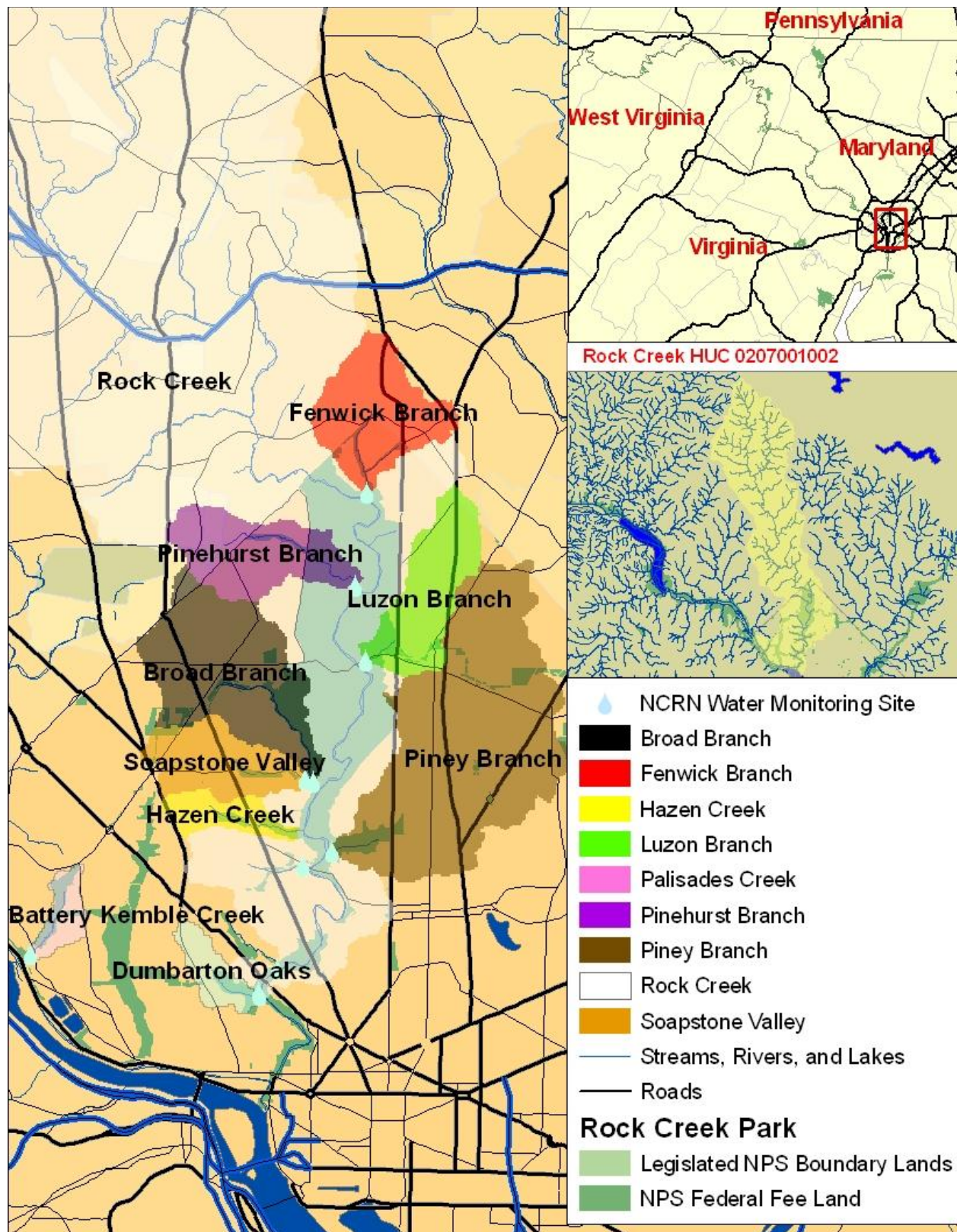


Figure 115: Relationship of the stream monitoring sites to their watersheds and the park boundary

Table 11: Date range, sample size (N), and data range for the vital signs data collected at Rock Creek Park.

Local Name	Units	Period of Record	N	Minimum	Maximum	Mean	Median	Standard Deviation
ANC	µeq/L	10/8/2008 - 9/29/2009	114	912	3112	1823	1824	469
Discharge	cfs	10/8/2008 - 9/29/2009	10	0.02	22.93	2.668	0.45	7.12
DO	mg/l	10/8/2008 - 9/29/2009	114	5.09	17.30	9.77	9.32	2.63
Flow	ft/sec	10/8/2008 - 9/29/2009	10	0.005	0.892	0.240	0.223	0.257
Nitrate	mg/l	10/8/2008 - 9/29/2009	115	0.7	5.1	3.1	3.0	1.1
Ammonia	mg/l	10/8/2008 - 9/29/2009	51	0.032	0.966	0.120	0.063	0.155
pH	None	10/8/2008 - 9/29/2009	114	7.08	8.78	7.82	7.84	0.31
Total Phosphorus	mg/l	10/8/2008 - 9/29/2009	115	0.03	0.99	0.39	0.36	0.17
Salinity	ppt	10/8/2008 - 9/29/2009	114	0.1	0.6	0.34	0.34	0.10
Specific Conductance	µS/cm	10/8/2008 - 9/29/2009	114	292.8	1122.0	685.1	702.8	203.7
Water Depth	ft	10/8/2008 - 9/29/2009	21	0.106	0.829	0.343	0.280	0.204
Water Temperature	°C	10/8/2008 - 9/29/2009	114	1.15	23.94	12.56	13.77	6.54
Wetted Width	ft	10/8/2008 - 9/29/2009	107	3	89	18	14	16

Eleven sites were monitored in the park on a monthly basis for dissolved oxygen, pH, specific conductance, temperature, acid neutralizing capacity, nitrate, ammonia, total phosphorus, width, depth, flow, and discharge. Palisades (Battery Kemble) Creek, Dumbarton Oaks Stream, Normanstone Stream, and Rock Creek at Dumbarton were added in 2008. Rock Creek at Edgewater Stables was replaced with Rock Creek at Dumbarton Oaks as the downstream point on Rock Creek. Rock Creek above Fenwick Branch was dropped in 2009 because we have never been able to wade it for a transect, and the contractor for the macroinvertebrate sampling pointed out that it was not wadeable until well across the park boundary and into Maryland. No data was collected at any site in March 2009, due to adverse winter conditions.

Non-karst streams such as those of Rock Creek park should have a minimum of 200 ueq/L CaCO_3 to buffer against acid inputs such as rain. Streams in Rock Creek park were well-buffered in 2009 (Figure 116). Ideal conditions for aquatic life are pH between 6.5 and 9. In 2009, Rock Creek Park streams all fell within this range (Figure 117). Specific conductance usually exceeds the threshold of 400 µS/cm for all sites (Figure 118). In FY 2009, all rock Creek waters could be defined as fresh except in February when Broad Branch, Soapstone Valley Stream, and Hazen Ctreek had salinities around 0.6. We did not collect data in March, but salinity would most likely also have been elevated, if it is due to the application of road salt as the park suspects (Figure 119). Phosphorus is consistently above the desired range of 0.1 mg/L at all sites (Figure 122). The EPA recommended environmental threshold for stream eutrophication is 0.1 mg/L PO_4 . Rock Creek Park streams exceeded this amount with the

exception of Piney Branch in February. There is no seasonal pattern to nitrate, and all sites are frequently above the desired level of 2.0 mg/L nitrate (Figure 121). The stream threshold for eutrophication due to nitrate is 2.0 mg/L NO_3 . Rock Creek's tributaries exceeded this amount almost all the time in 2009. The exceptions being November 2008 Broad Branch, Fenwick Branch, Pinehurst Branch, Soapstone Valley Stream met the threshold and Dumbarton Oaks and Palisades Creek met the threshold in December. Pinehurst Branch met the threshold 7 of the 11 months it was sampled. The exceptions were February through June. Rock Creek met the threshold half the year, except December – February, April, and August (Figure 121). Rock Creek streams were within acceptable limits of ammonia except for one elevated reading in Dumbarton Oaks in February (Figure 120). DO values were below the desired level of 5mg/L at only Fenwick Branch, Rock Creek, and Pinehurst Branch had low readings in spring and summer 2007, and Soapstone Valley, Normanstone, and Rock Creek at Dumbarton had low readings in late summer 2008. All streams met the threshold for dissolved oxygen in 2009. There is a strong annual trend in DO across all sites to increase late winter early spring and decrease late summer early fall (Figure 123). Water temperature follows expected seasonal trends and is within the comfort range of sensitive species (Figure 124). Most channel widths fluctuate by less than 10 feet a month. Rock Creek fluctuates by 20 feet per month, which makes sense since it is a much larger stream (Figure 125). There was only sufficient depth (Figure 126) to collect flow (Figure 128) and discharge (Figure 127) data in October, April through June and August. The flowmeter had been sent in for repairs in September 2009. Water temperature follows expected seasonal trends and stays within the comfort zone of most aquatic organisms (Figure 124).

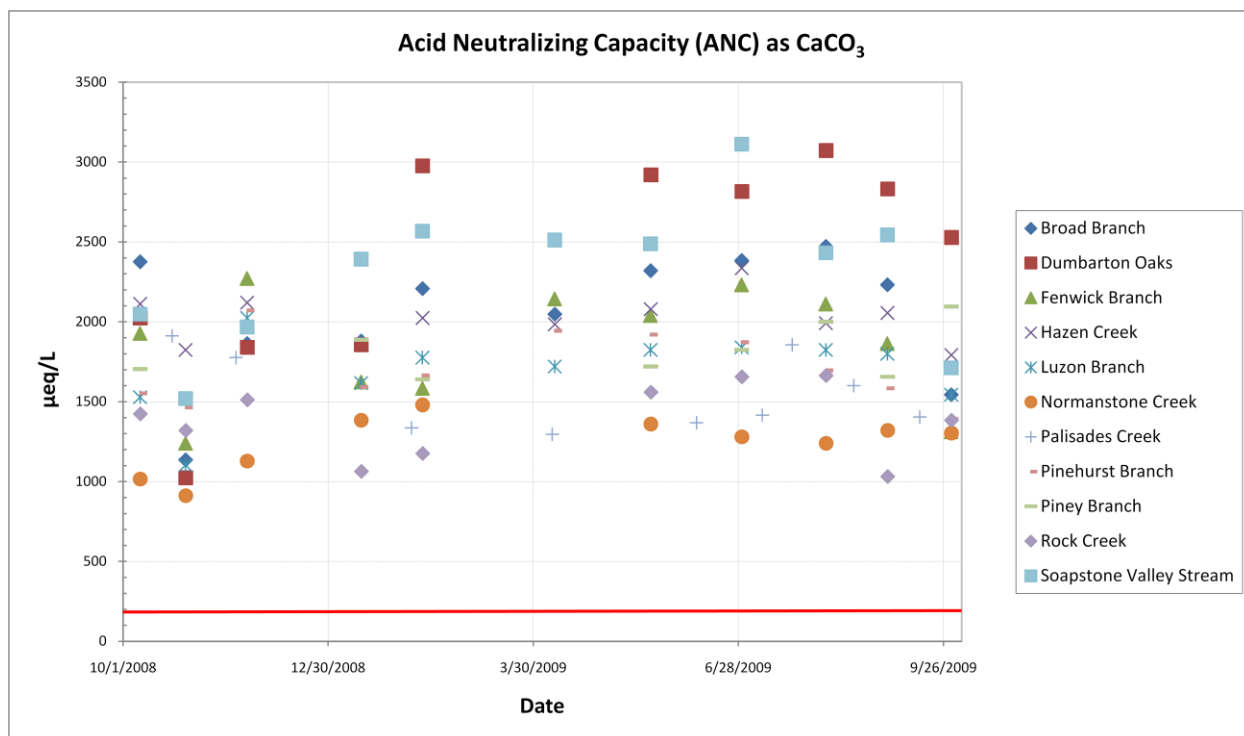


Figure 116: ANC in Rock Creek Park streams in FY 2009. Desired condition is above the 200 µeq/L threshold for non-karst waters shown in red.

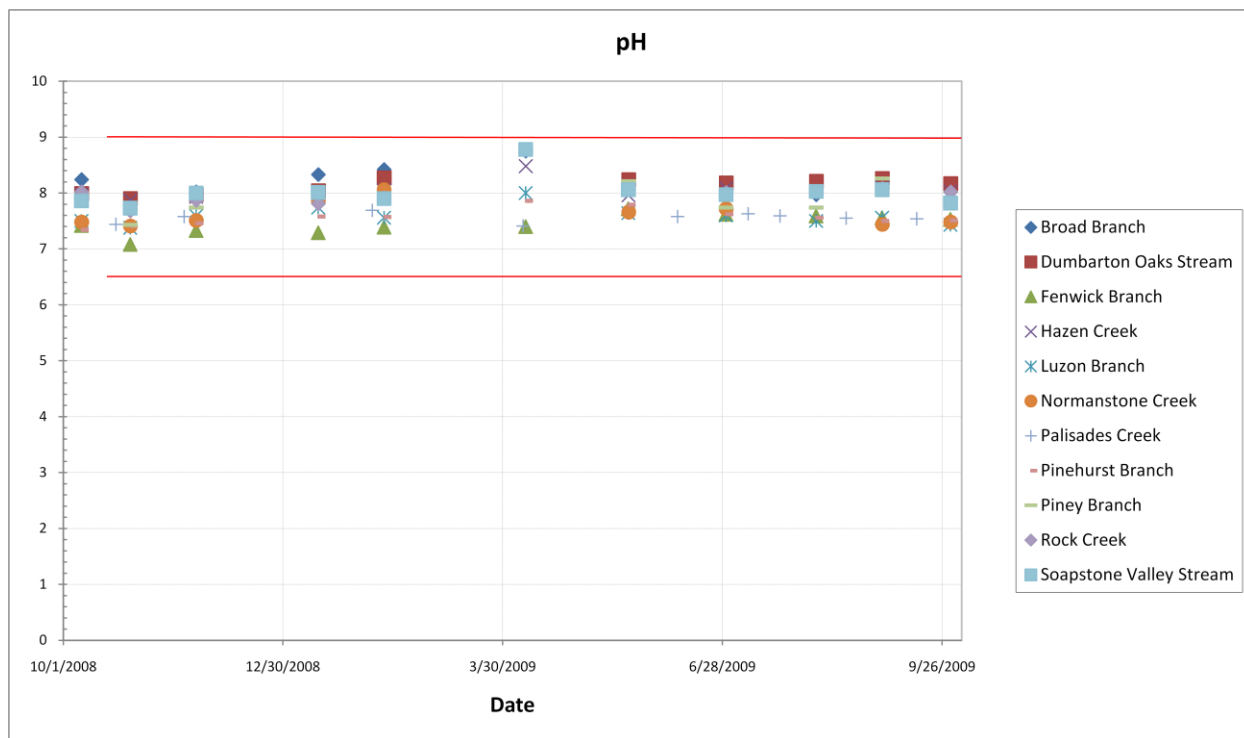


Figure 117: pH in Rock Creek park streams in FY 2009. Desired condition is between the 6.5 and 9.0 thresholds shown in red.

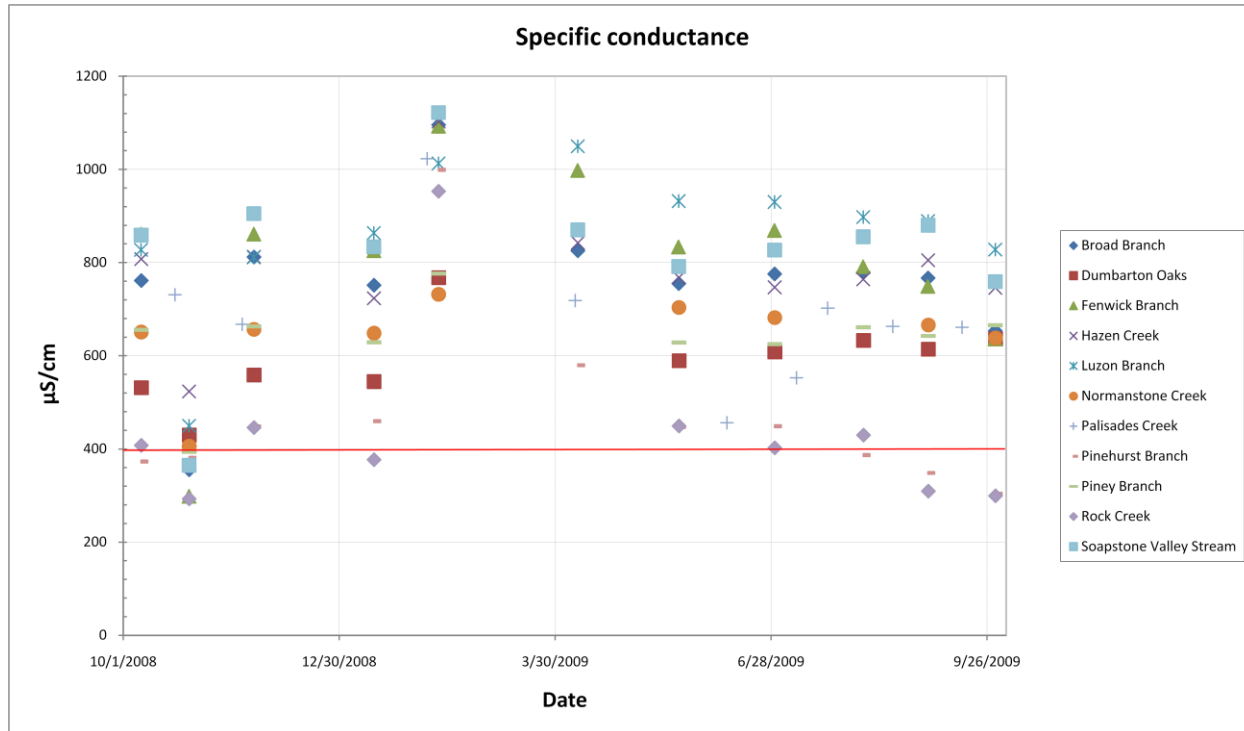


Figure 118: Specific Conductance in Rock Creek park streams, FY 2009. Desired condition is below the 400 $\mu\text{S}/\text{cm}$ threshold shown in red.

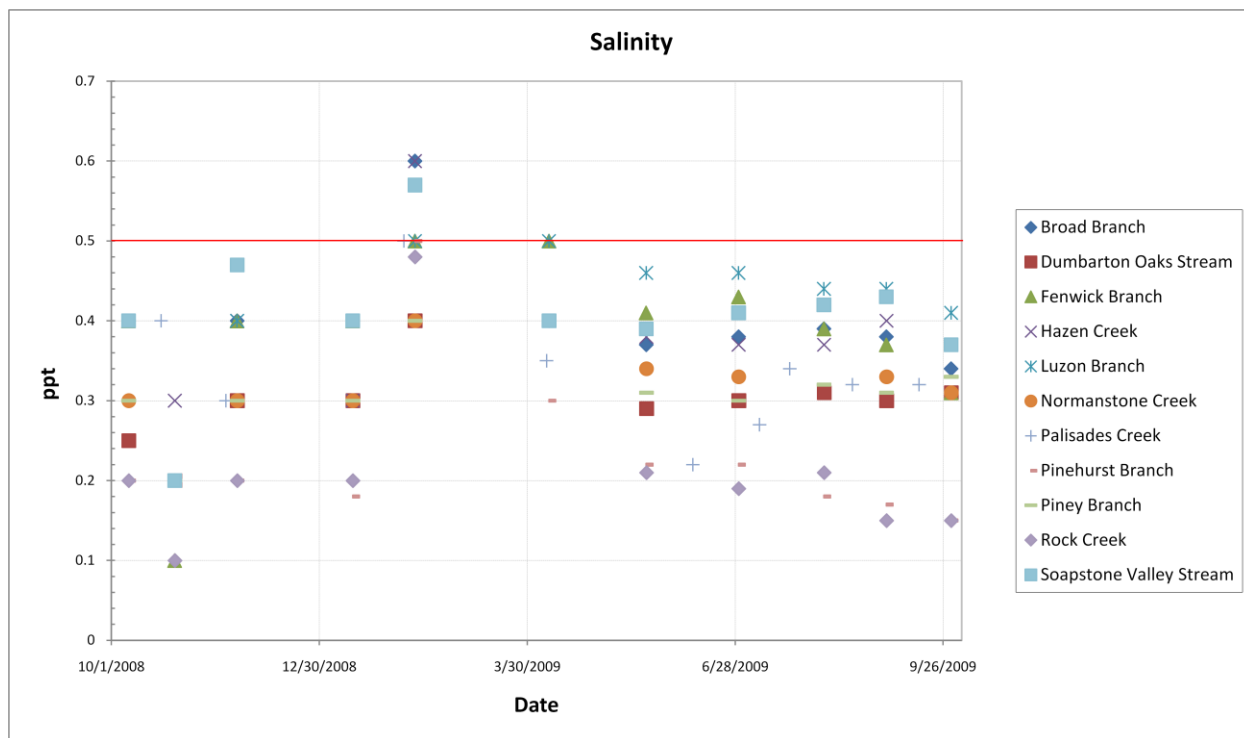


Figure 119: Salinity in Streams of Rock Creek Park FY 2009. Desired condition is below the 0.5 ppt threshold shown in red.

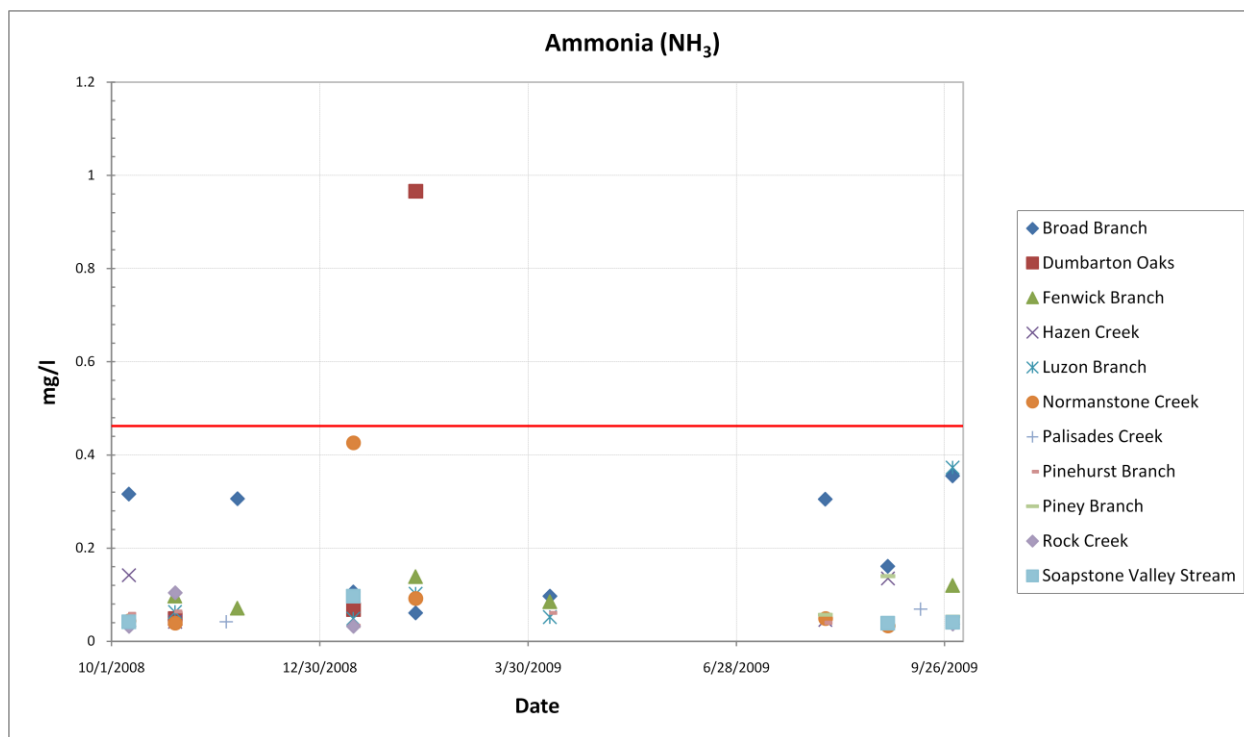


Figure 120: Ammonia in Rock Creek Park streams, FY 2009. Desired condition is below the 0.443 threshold shown in red.

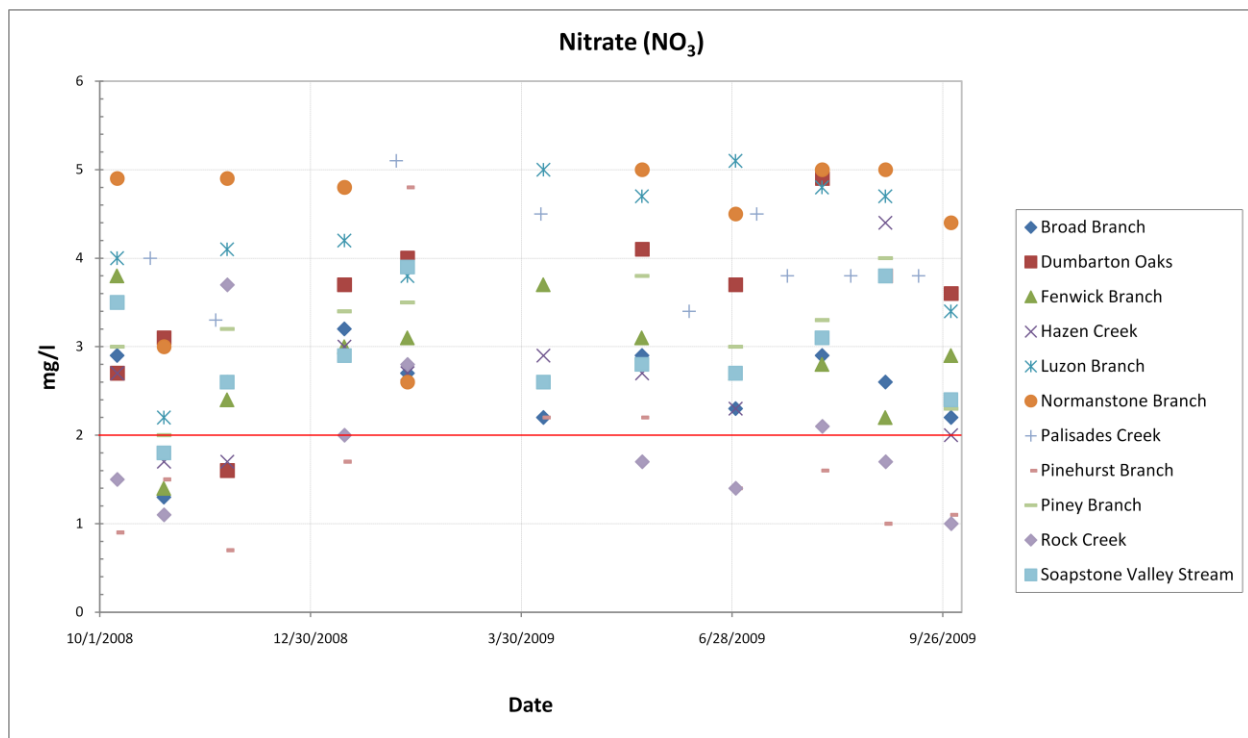


Figure 121: Nitrate in Rock Creek Park streams, FY 2009. Desired condition is below the 2.0 mg/L threshold shown in red.

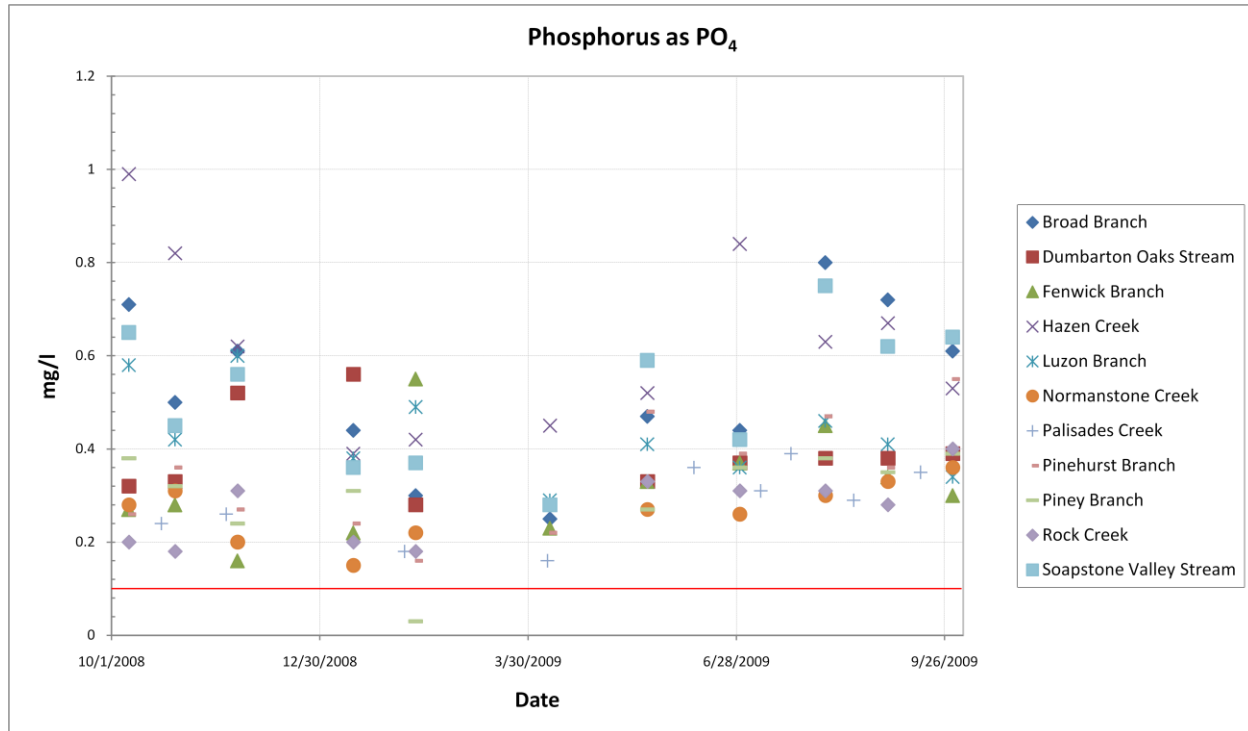


Figure 122: Total Phosphorus in Rock Creek Park streams, FY 2009. Desired condition is below the 0.1 mg/L threshold shown in red.

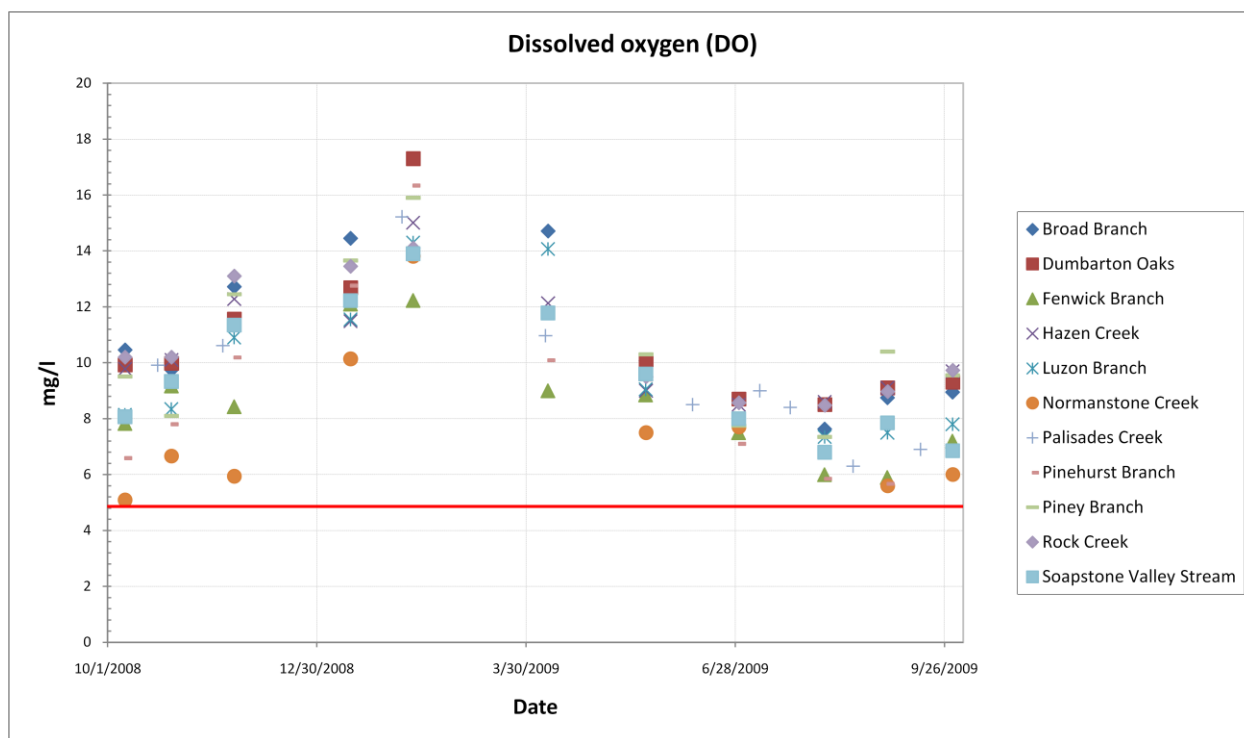


Figure 123: Dissolved Oxygen in Rock Creek Park streams, FY 2009. Desired condition is above the 5.0 mg/L threshold shown in red.

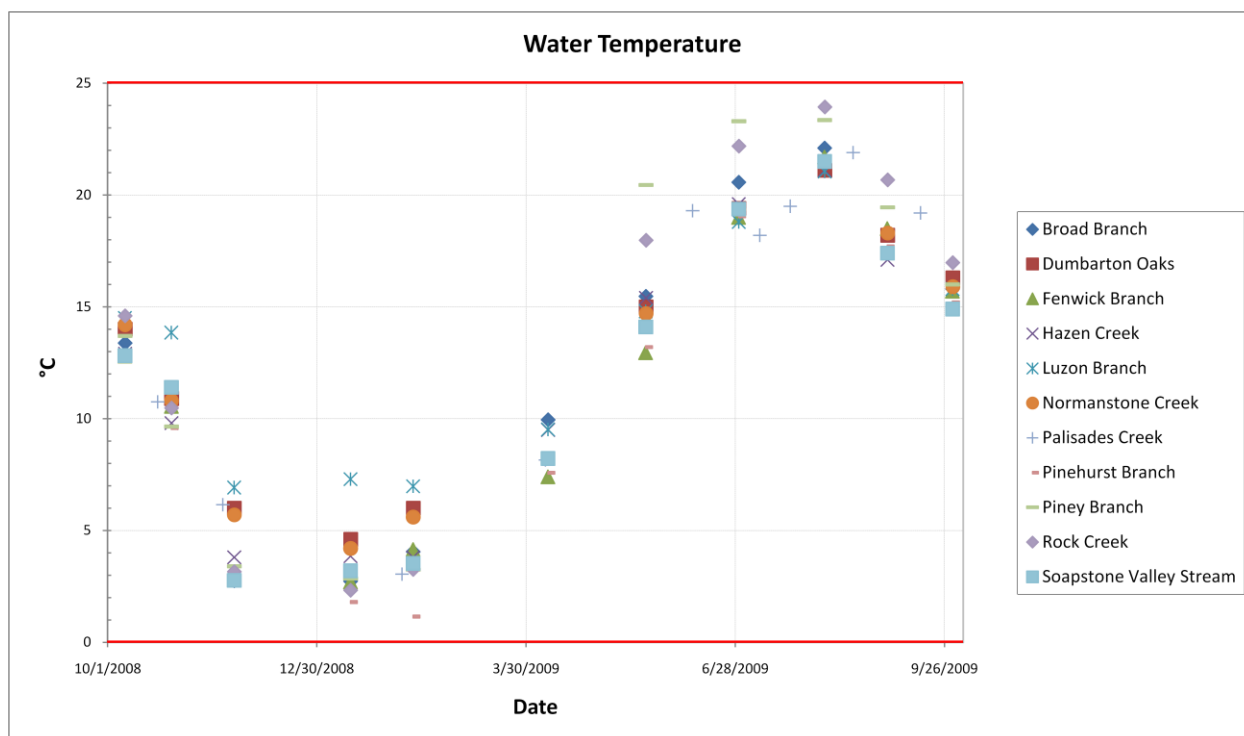


Figure 124: Temperatures of Rock Creek Park Streams, FY 2009. Ideal temperatures for aquatic life are 0 to 25 °C.

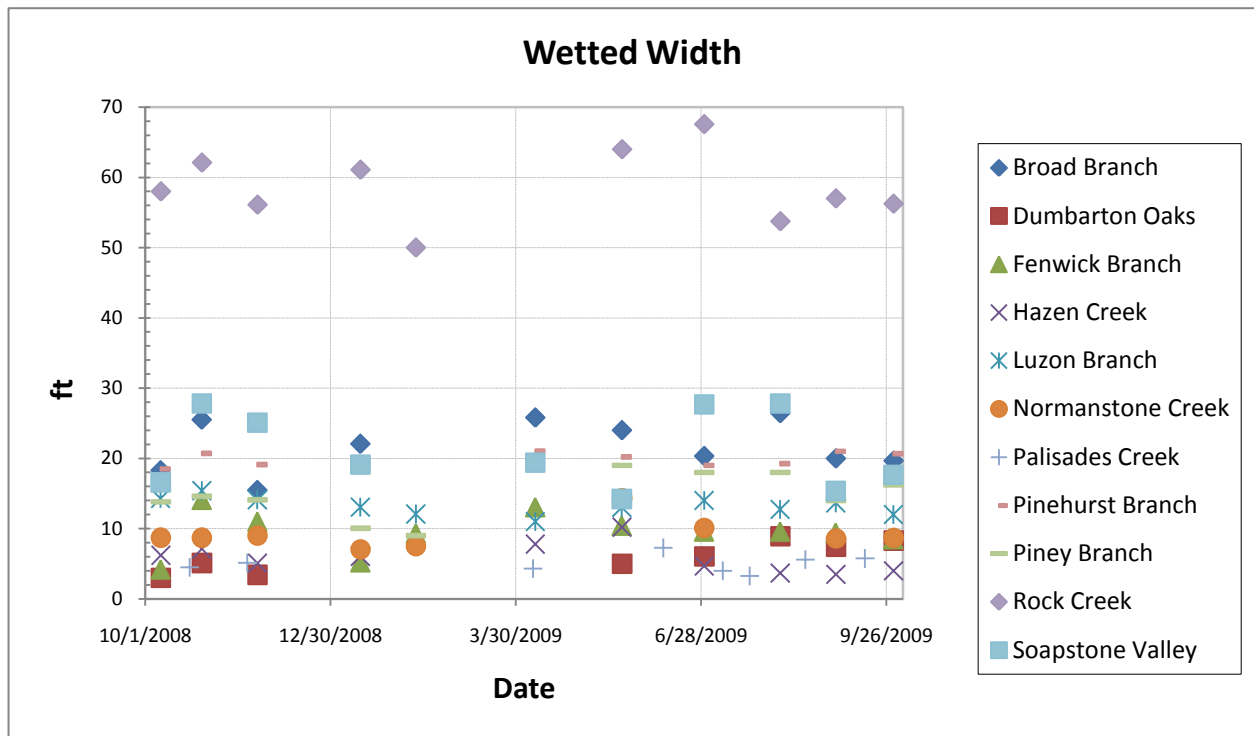


Figure 125: Wetted Width of Rock Creek Park Streams, FY 2009.

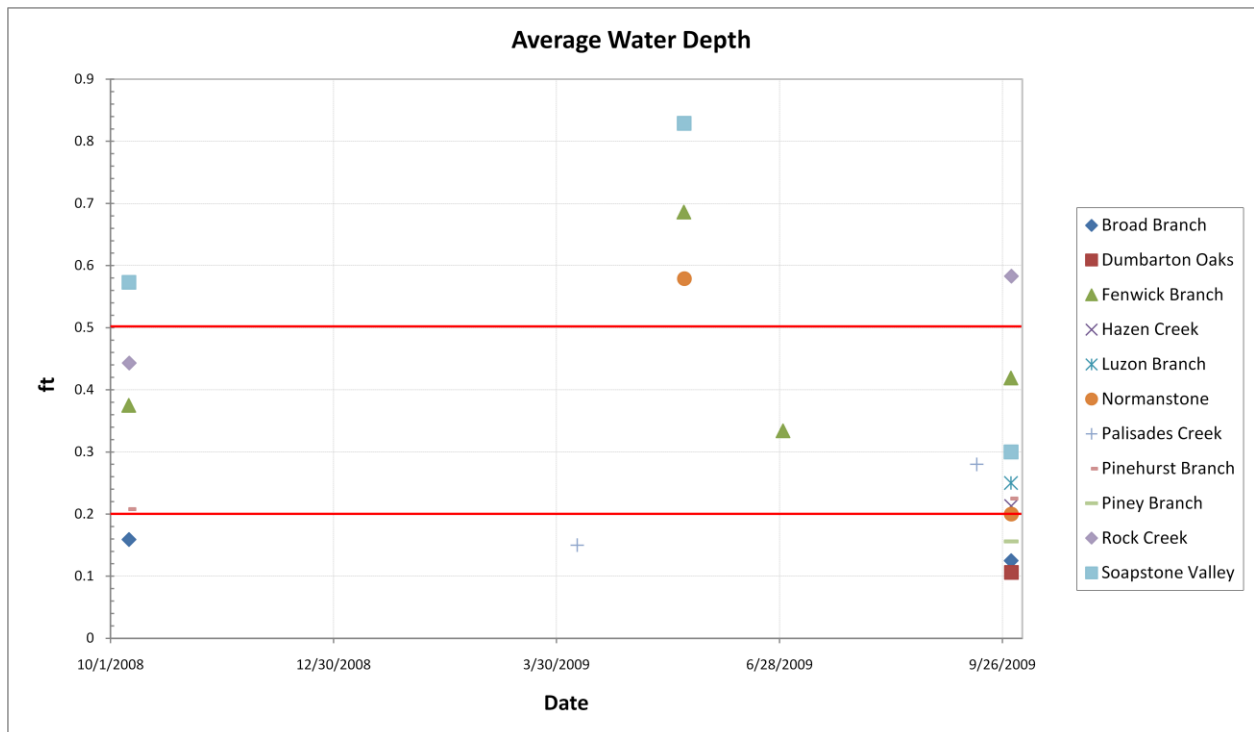


Figure 126: Average depth of Rock Creek Park Streams, FY 2009. Required condition is above 0.2 foot for discharge measurements and 0.5 foot for data sondes.

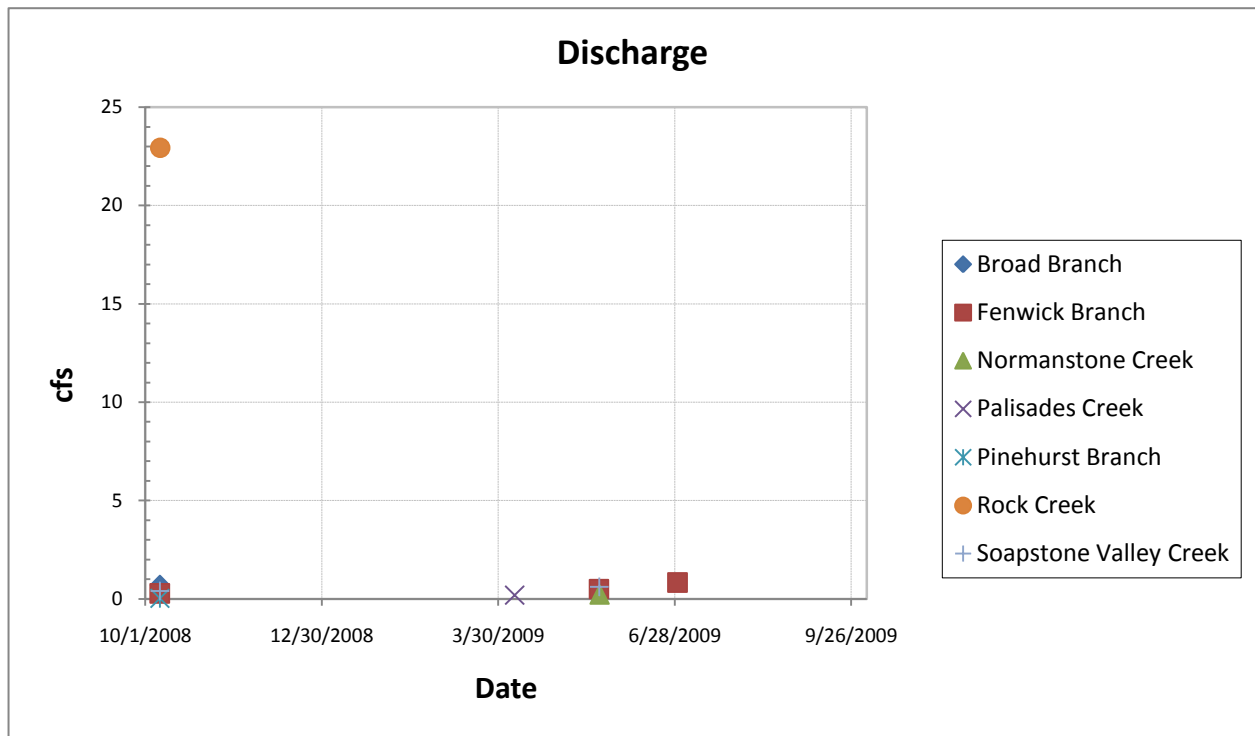


Figure 127: Discharge of Rock Creek Park Streams, FY 2009.

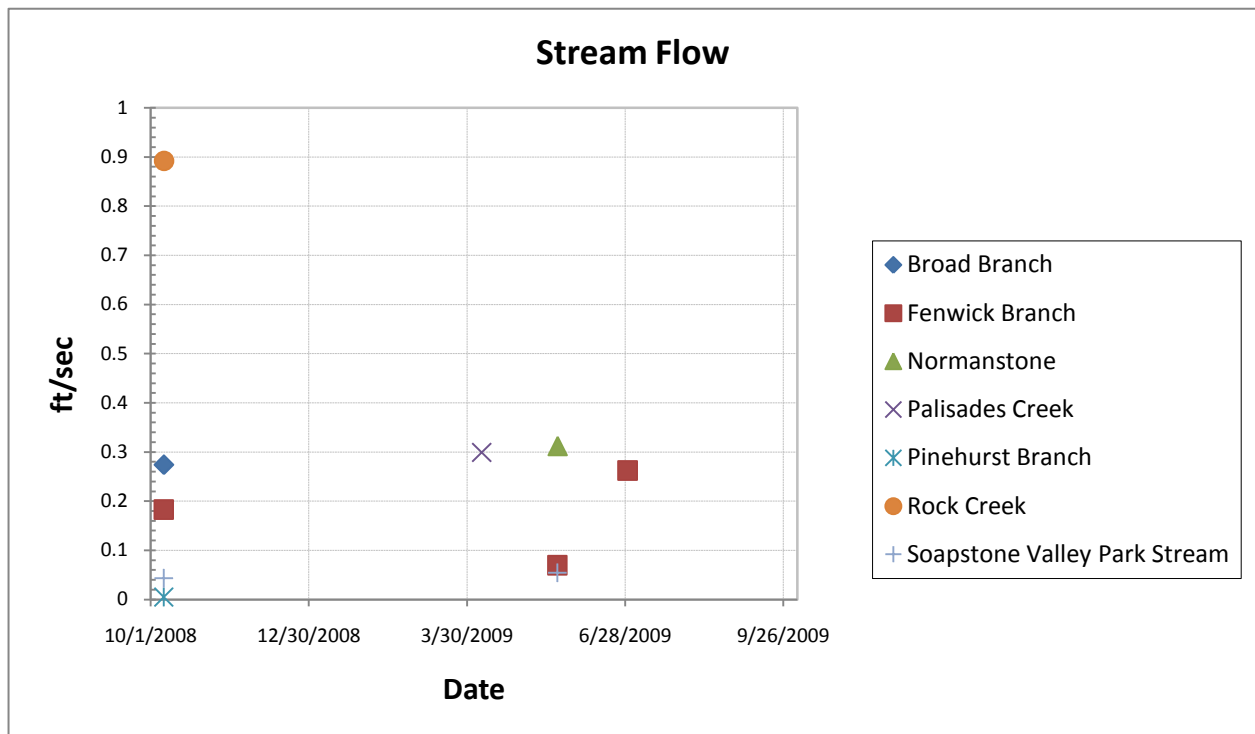


Figure 128: Flow of Rock Creek Park Streams, FY 2009.

Wolf Trap National Park for the Performing Arts (WOTR)

Wolf Trap National Park for the Performing Arts is located in Fairfax County, Virginia within the Potomac River Watershed and the Piedmont physiographic province. Within the boundaries of the park are streams, meadows and wooded areas. The park's three streams, Old Court House Branch, Wolf Trap Creek, and Wolf Trap Run (Figure 129) , and their riparian forest are among the park's most important natural resources. Water quality is a major concern. Stream bank erosion has occurred due to increased development around the park. The erosion may threaten the maintenance yard in the future. This has lead to sediment deposition. Runoff from the Dulles Toll Road may have detrimental effects. Streams are also impacted by fertilizer runoff from the park's management, parking lot runoff, and runoff from salt storage in the maintenance yard.

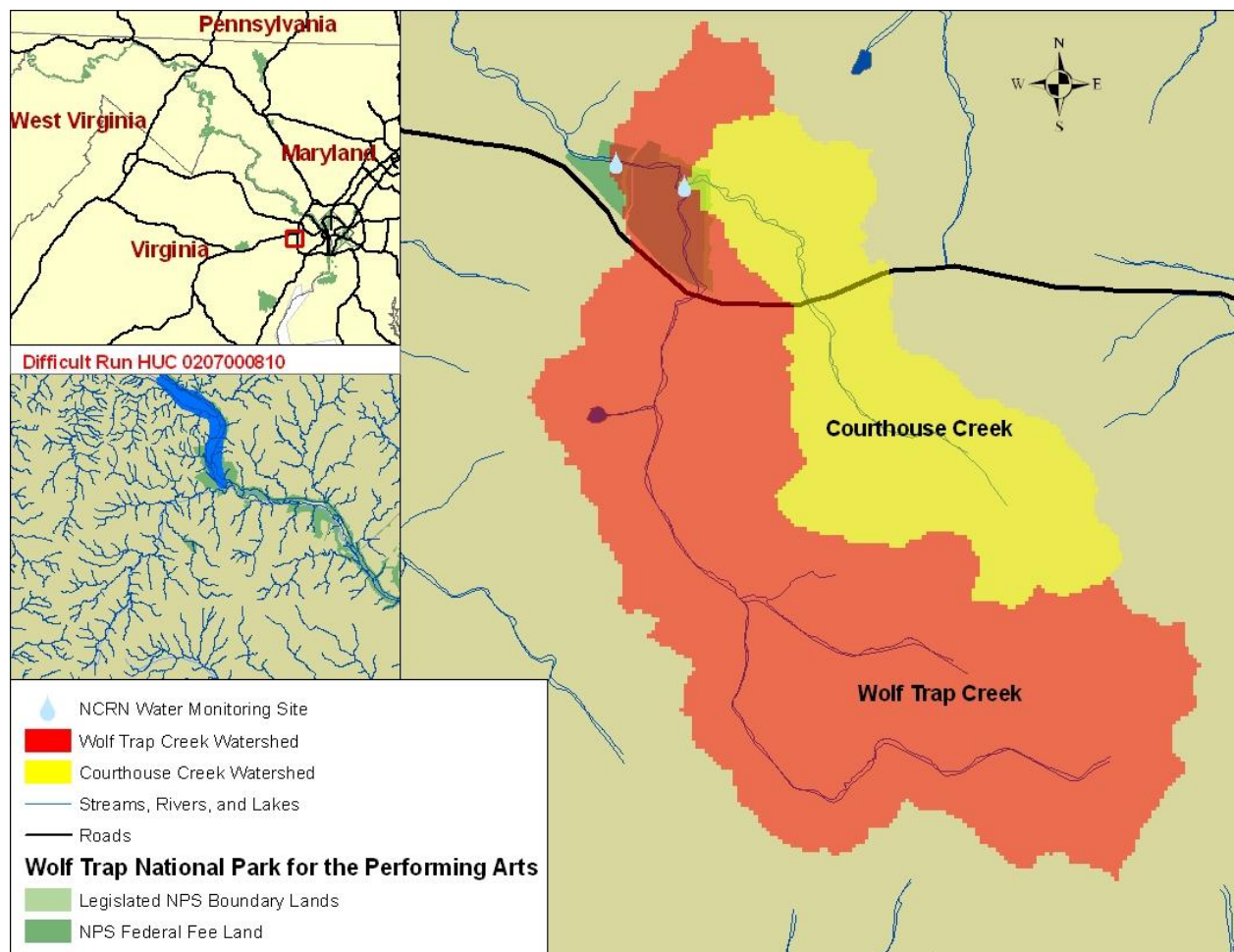


Figure 129: Relationship of the Wolf Trap Creek monitoring site to the watershed and the park boundary.

This report discusses data collected October 2008 through September 2009 for Wolf Trap Creek and Courthouse Creek (Figure 129). Summary statistics for the time period are shown in Table 11.

Table 12: Date range, sample size (N), and data range for the vital signs data collected at Wolf Trap National Park for the Performing Arts.

Local Name	Units	Period of Record	N	Minimum	Maximum	Mean	Median	Standard Deviation
ANC	µeq/L	10/23/2008 - 9/24/2009	19	430	1048	755	736	137
Discharge	cfs	10/23/2008 - 9/24/2009	4	0.1434	2.8100	1.5230	---	1.1230
DO	mg/l	10/23/2008 - 9/24/2009	18	7.40	11.24	9.05	9.14	1.15
Flow	ft/sec	10/23/2008 - 9/24/2009	4	0.5324	1.2870	0.8894	---	0.3770
Nitrate	mg/l	10/23/2008 - 9/24/2009	19	1.3	3.7	2.0	1.8	0.6
Ammonia	mg/l	10/23/2008 - 9/24/2009	8	0.035	0.145	0.067	---	0.035
pH	None	10/23/2008 - 9/24/2009	19	6.82	7.56	7.26	7.31	0.22
Total Phosphorus	mg/l	10/23/2008 - 9/24/2009	18	0.12	0.32	0.19	0.18	0.05
Salinity	ppt	10/23/2008 - 9/24/2009	19	0.08	0.20	0.13	0.12	0.04
Specific conductance	µS/cm	10/23/2008 - 9/24/2009	19	178.9	467.7	282.8	269.0	71.1
Water Depth	ft	10/23/2008 - 9/24/2009	6	0.169	0.362	0.236	---	0.070
Water Temperature	°C	10/23/2008 - 9/24/2009	19	0.15	22.3	15.2	18.2	6.4
Wetted Width	ft	10/23/2008 - 9/24/2009	16	5.50	20.75	12.86	12.96	3.86

Two sites were monitored in the park on a monthly basis for dissolved oxygen, ph, specific conductance, temperature, acid neutralizing capacity, nitrate, ammonia, and total phosphorus. Wolf Trap Creek was frozen during site visits in January and February. Courthouse Creek still had some open flowing channel for sampling in January.

All sites met the acid neutralizing capacity threshold of 200 µeq/L for buffered non-karst waters (Figure 130). All sites were within the range of pH ideal for aquatic life (Figure 131). Only Courthouse Creek exceeded the threshold of 400 uS/cm for specific conductance, once in March. Specific conductance may have a seasonal pattern, increasing in late spring and early fall and decreasing in winter and summer (Figure 132). All streams were well below the salinity threshold for freshwater (Figure 133).

Courthouse Creek exceeded nitrate threshold of 2.0 mg/L in January and April through September 2009. Wolf Trap Creek exceeded the threshold in April and September (Figure 134). Both streams always exceeded threshold for phosphorus (Figure 135). Ammonia was infrequently detected in either stream and never exceeded threshold (Figure 136). During site visits, dissolved oxygen was not below threshold for aquatic life (Figure 137). Water temperature followed expected seasonal trends and stayed within the comfort zone of desired organisms (Figure 138). There was only sufficient depth (Figure 139) for flow (Figure 141) and discharge (Figure 140) measurements in Wolf Trap Creek in October 2008 and May – July 2009.

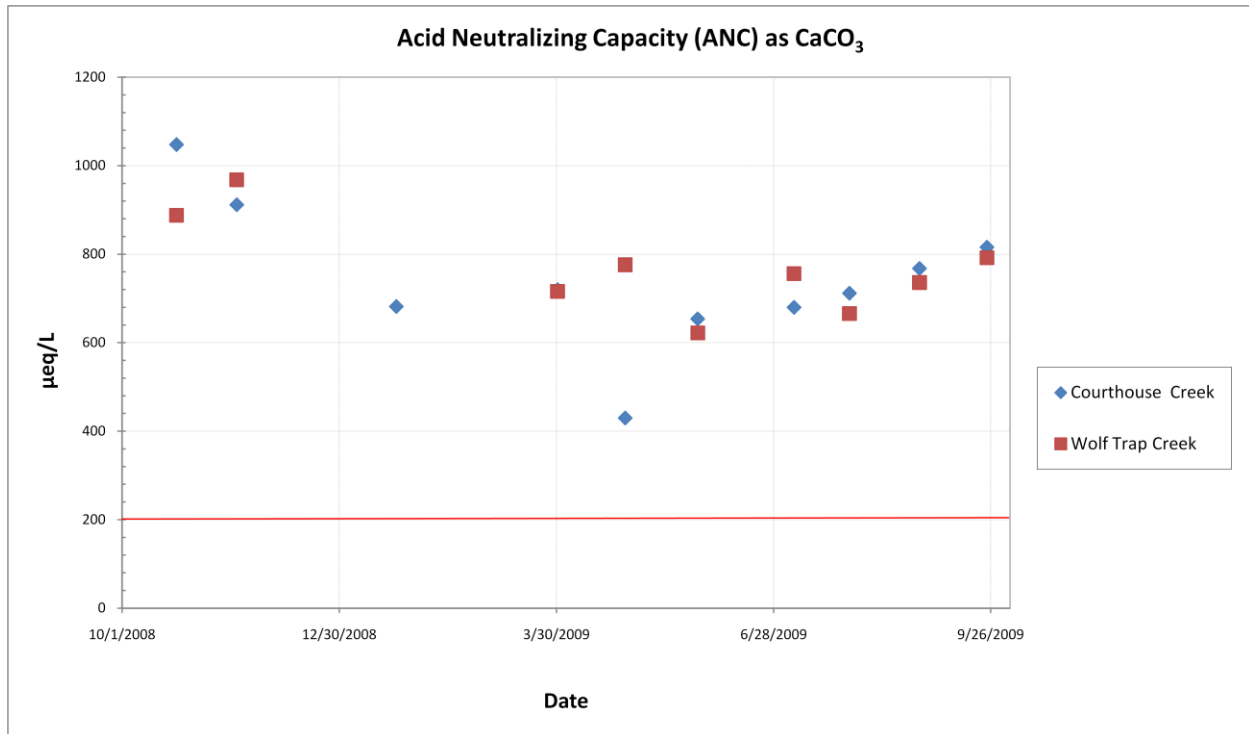


Figure 130: ANC in Wolf Trap Farm Park streams in FY 2009. Desired condition is above the 200 $\mu\text{eq/L}$ threshold for non-karst waters shown in red.

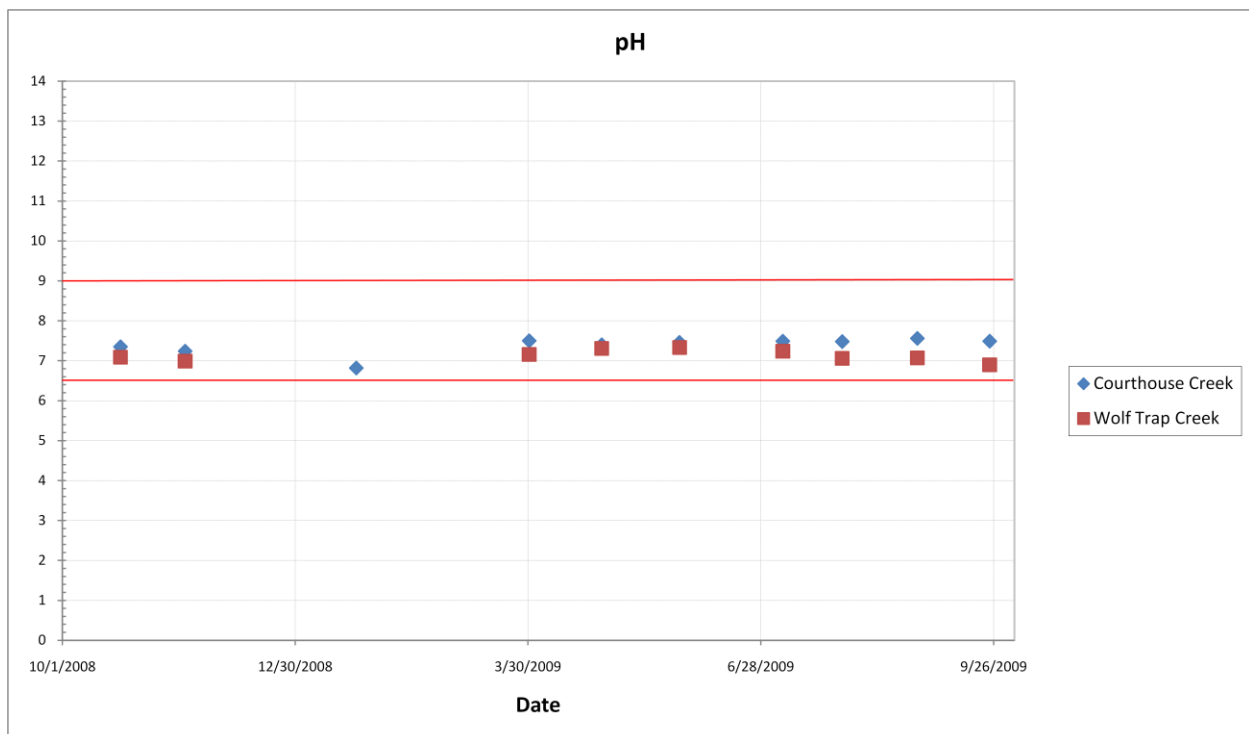


Figure 131: pH in Wolf Trap Farm Park streams in FY 2009. Desired condition is between the 6.5 and 9.0 thresholds shown in red.

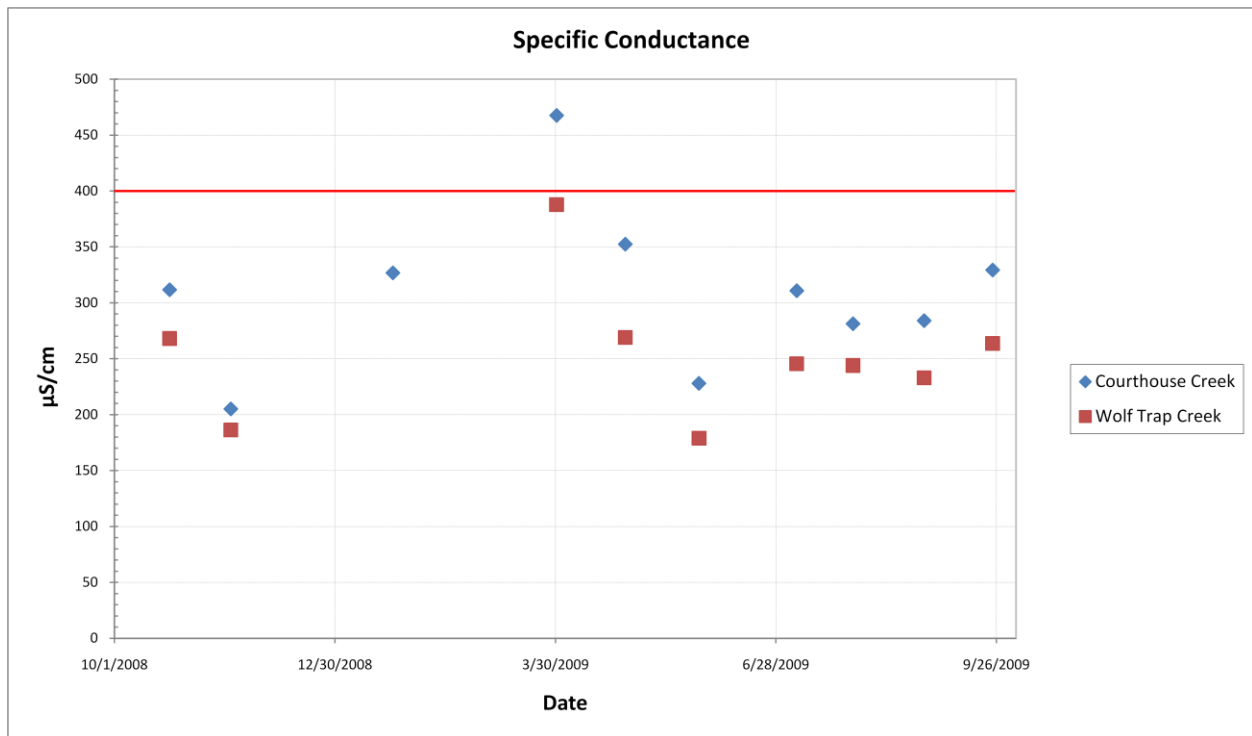


Figure 132: Specific Conductance in Wolf Trap Farm Park streams, FY 2009. Desired condition is below the 400 µS/cm threshold shown in red.

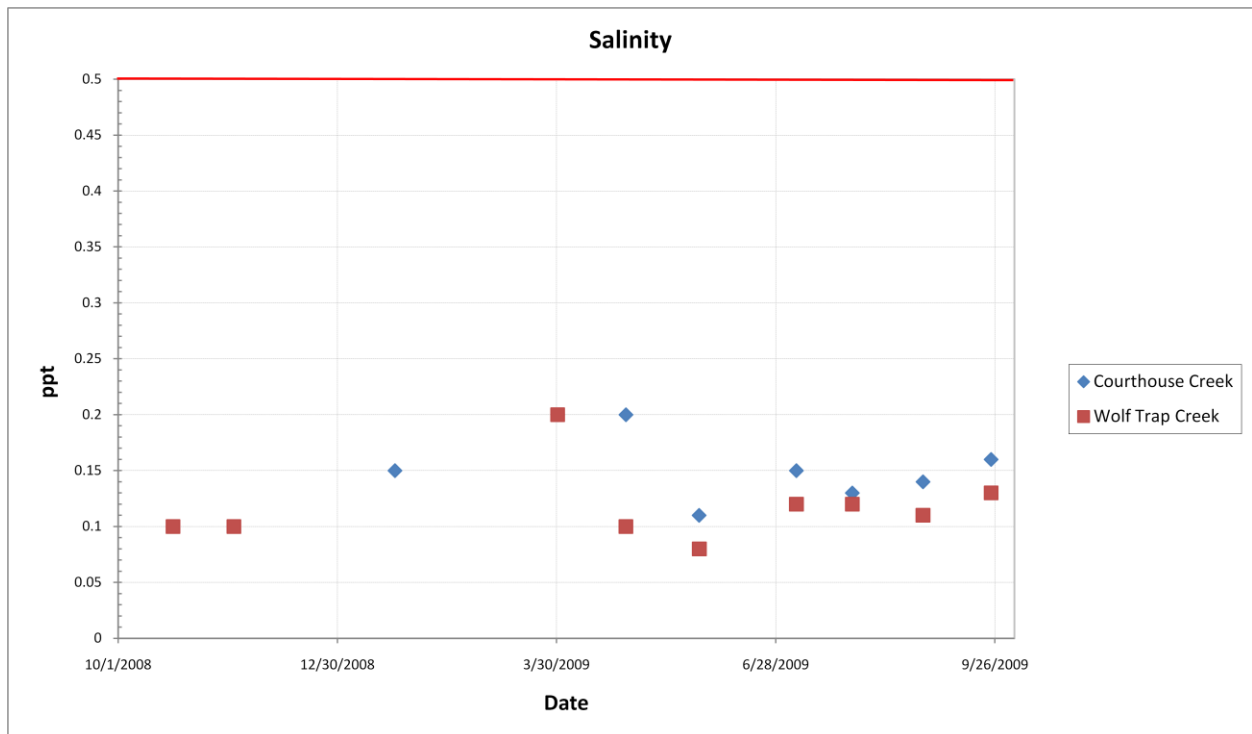


Figure 133: Salinity in Wolf Trap Farm Park streams FY 2009. Desired condition is below the 0.5 ppt threshold shown in red.

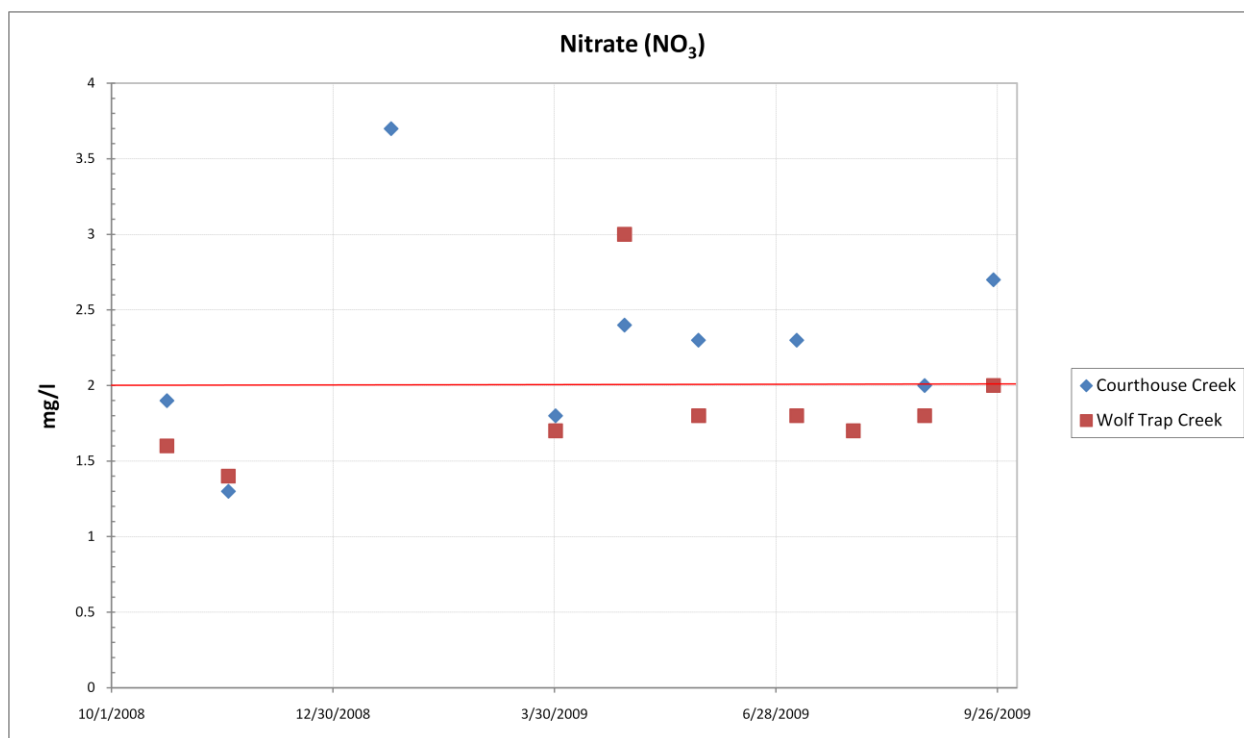


Figure 134: Nitrate in Wolf Trap Farm Park streams, FY 2009. Desired condition is below the 2.0 mg/L threshold shown in red.

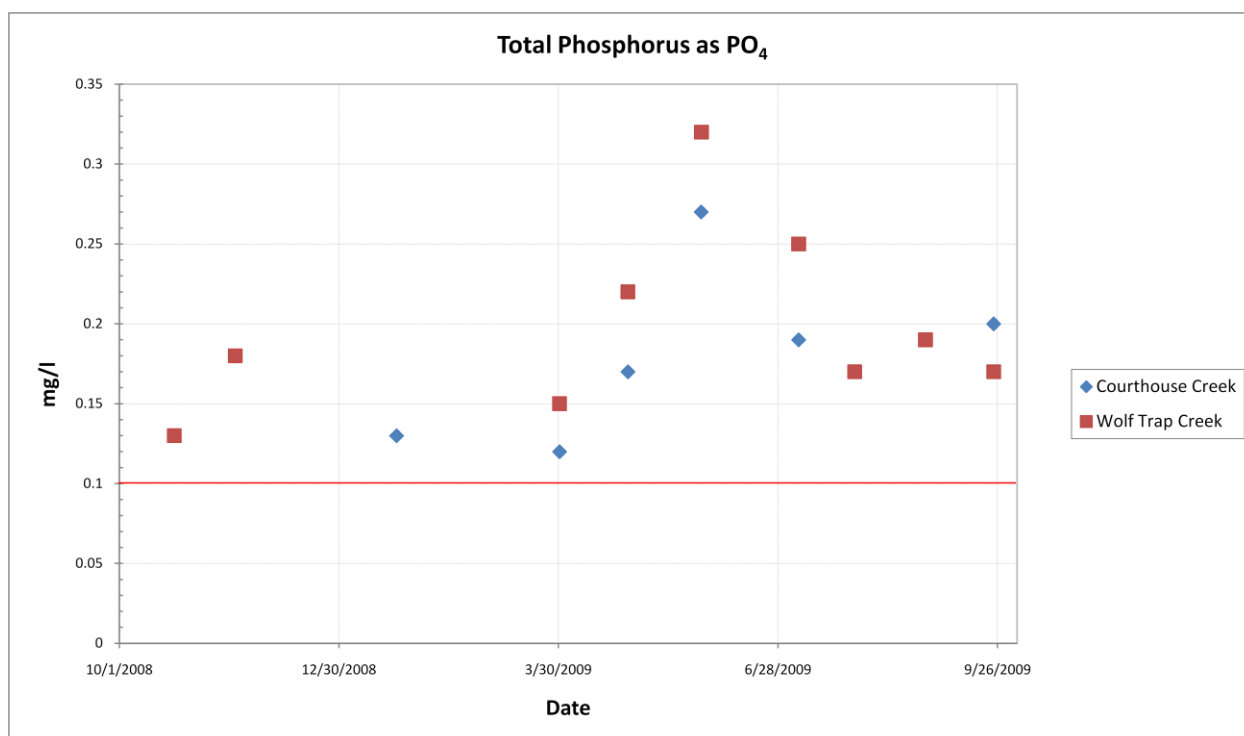


Figure 135: Total Phosphorus in Wolf Trap Farm Park streams, FY 2009. Desired condition is below the 0.1 mg/L threshold shown in red.

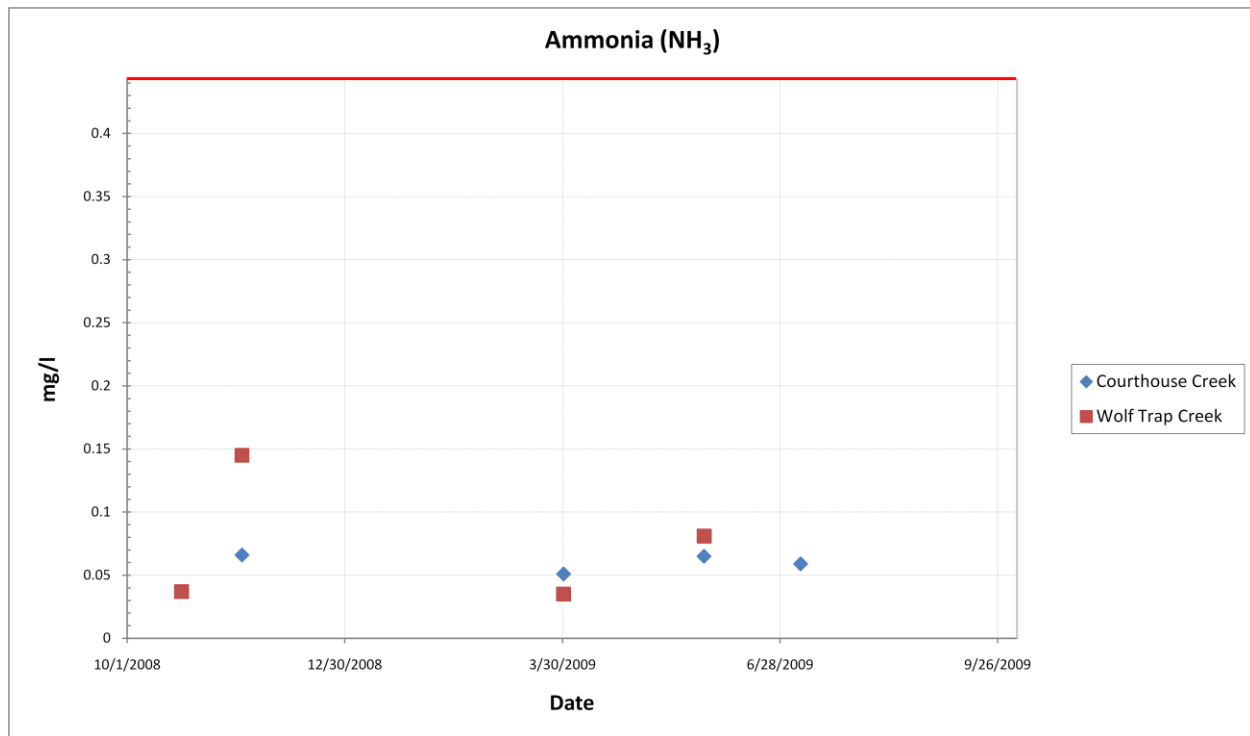


Figure 136: Ammonia in Wolf Trap Farm Park streams, FY 2009. Desired condition is below the 0.443 threshold shown in red.

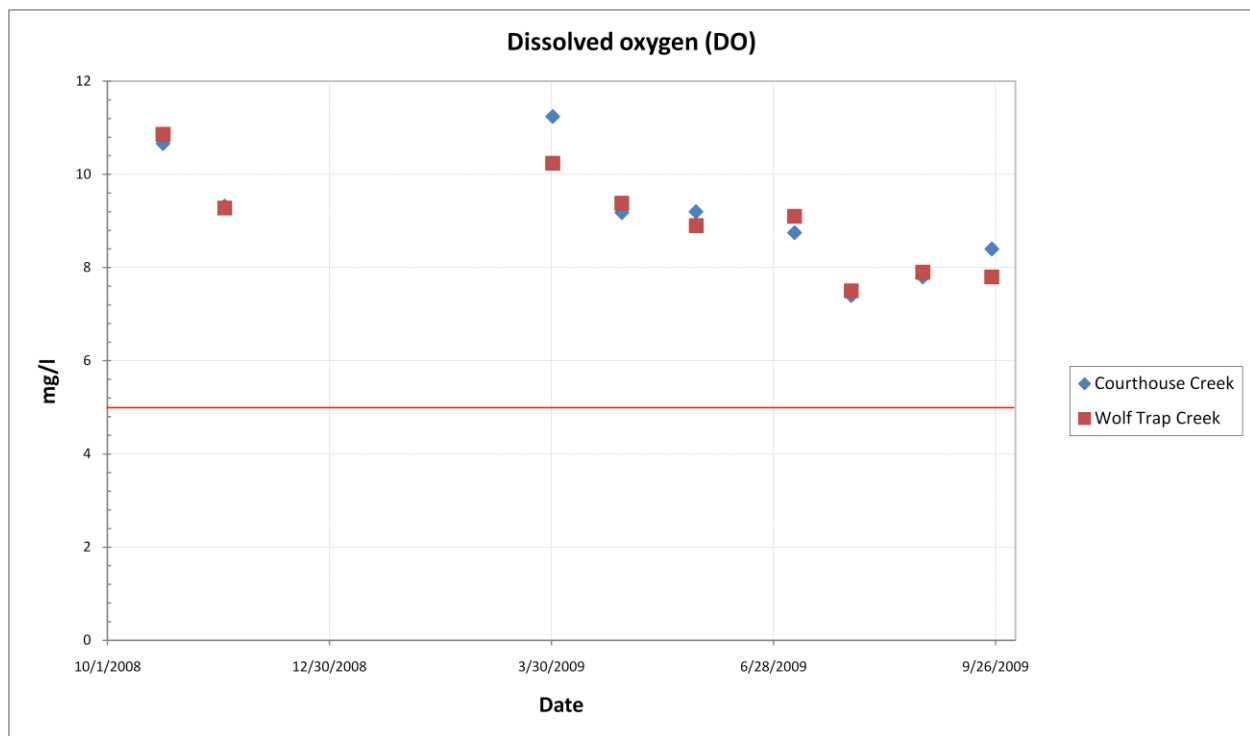


Figure 137: Dissolved Oxygen in Wolf Trap Farm Park streams, FY 2009. Desired condition is above the 5.0 mg/L threshold shown in red.

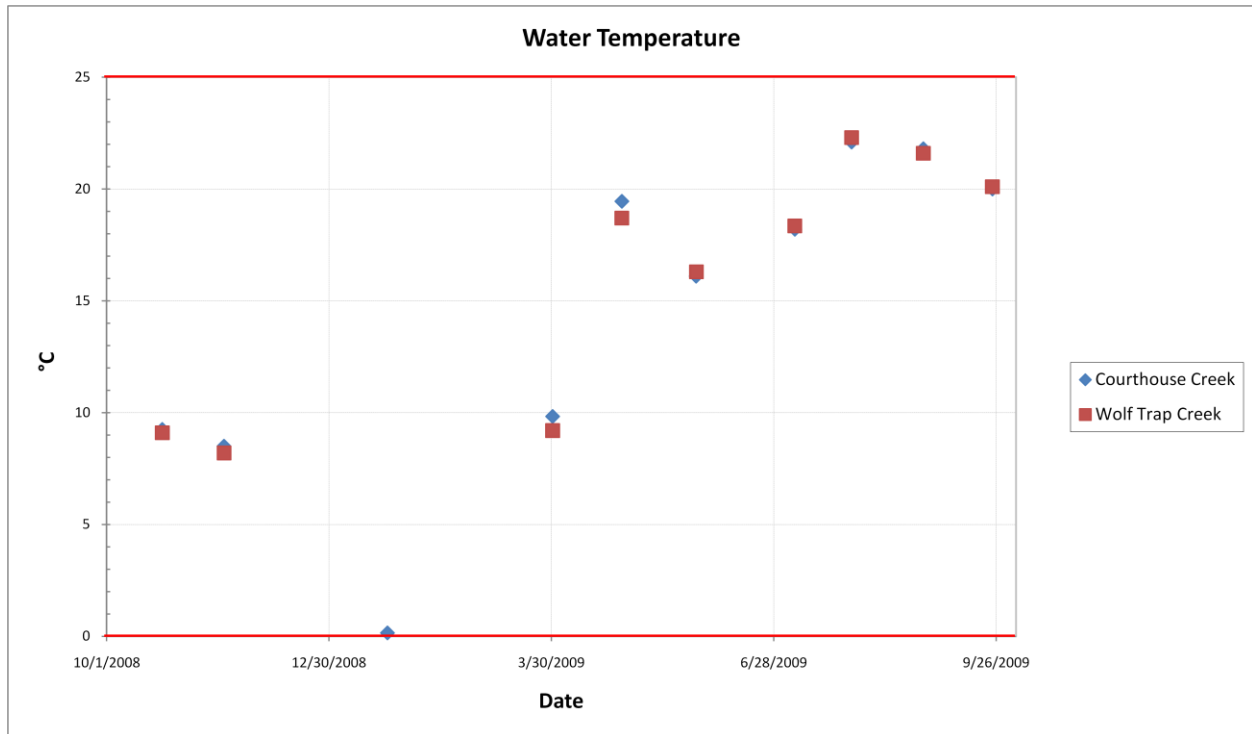


Figure 138: Temperature in Wolf Trap Farm Park streams, FY 2009. Desired condition is between the 0°C and 25°C thresholds shown in red.

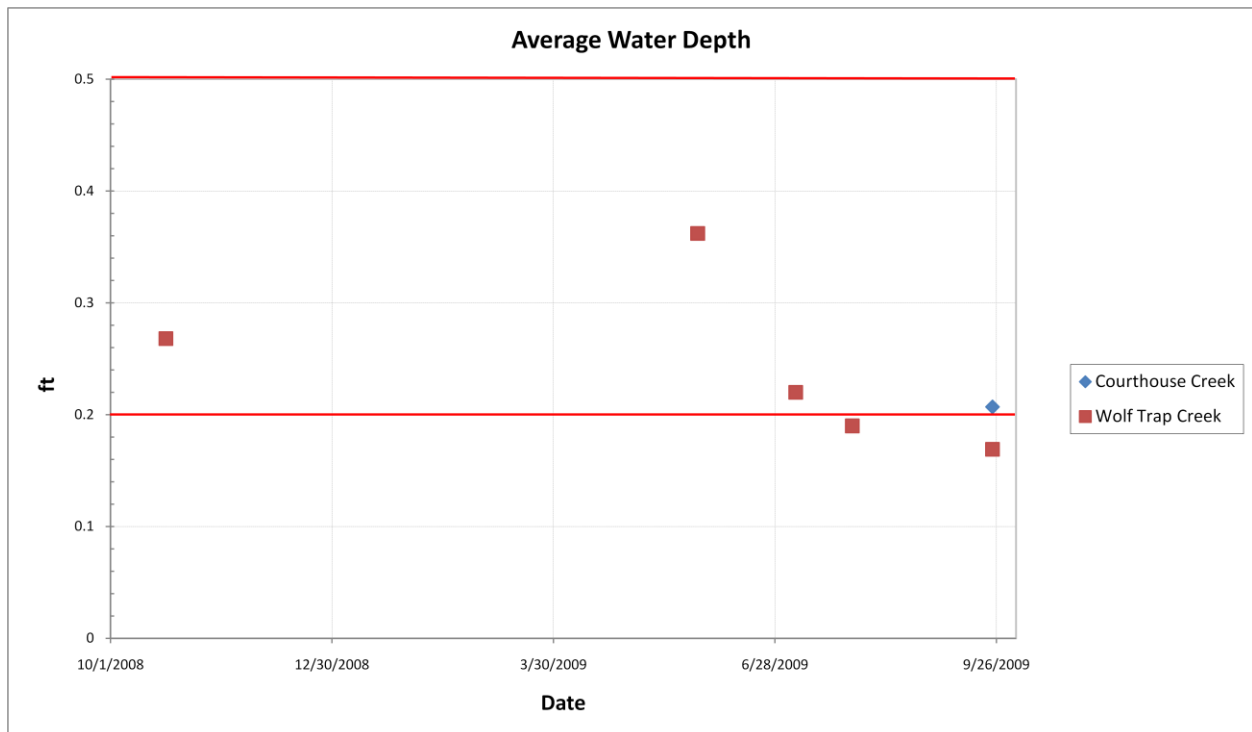


Figure 139: Average depth of Wolf Trap Farm Park streams. Required condition is above 0.2 foot for discharge measurements and 0.5 foot for data sondes.

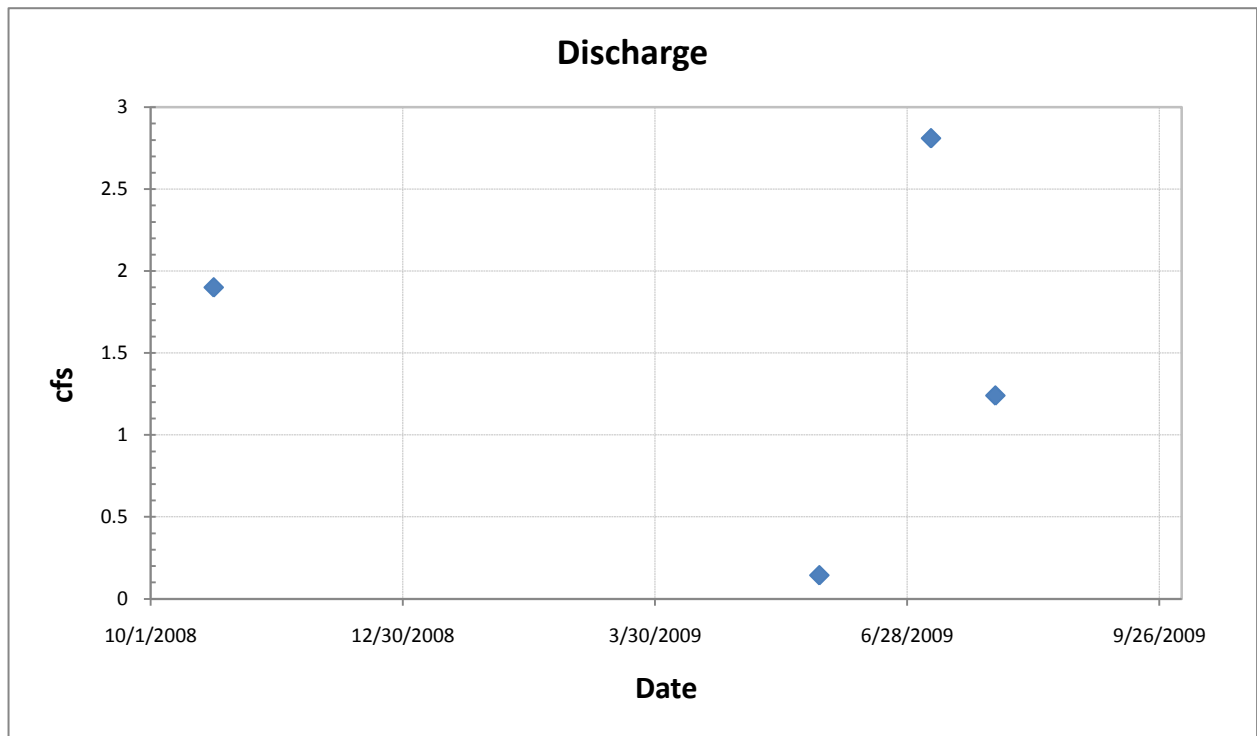


Figure 140: Discharge of Wolf Trap Creek, FY 2009.

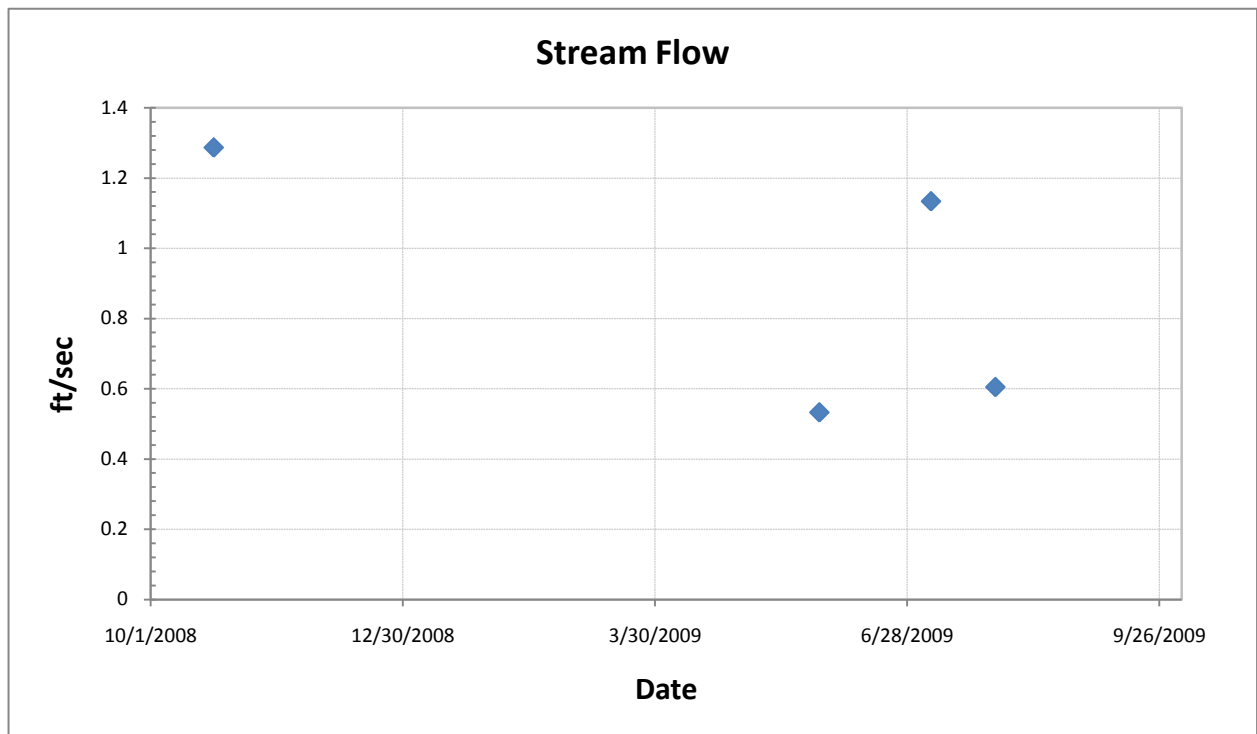


Figure 141: Flow of Wolf Trap Creek, FY 2009.

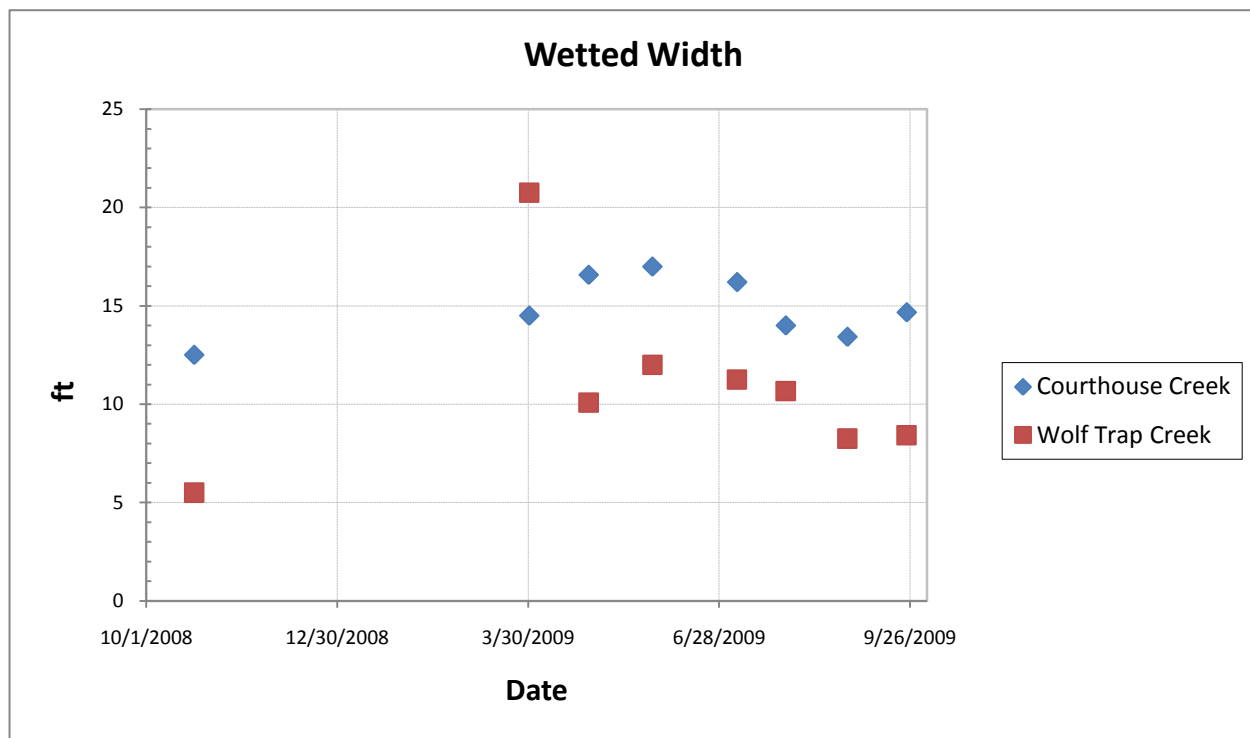


Figure 142: Wetted Width of Wolf Trap Farm Park streams, FY 2009.

Literature Cited

- Allan, J. D. 1995. *Stream Ecology: Structure and Function of Running Waters*. Chapman and Hall, New York.
- Allan, J. D. and M. M. Castillo. 2007. *Stream Ecology: Structure and Function of Running Waters*. Springer, Dordrecht, The Netherlands.
- Benbow, M. and R. W. Merritt. 2005. Road Salt - WQ-831. *in* J. H. Lehr and J. Keeley, editors. *Water Encyclopedia*. Wiley, New York, NY.
- Blomquist, J. D., G. T. Fisher, J. M. Denis, W. H. Werkheiser, and J. W. Brakebill. 1996. Water-quality assessment of the Potomac River Basin: Basin description and analysis of available nutrient data, 1970-90. U.S. Geological Survey, Reston, VA.
- Burke, T. A., J.S.Litt, and M.A.Fox. 1999. Linking Public Health and the Health of the Chesapeake Bay. *Environmental Research Section A* **82**:143-149.
- Carruthers, T., S. Carter, L. N. Florkowski, J. Runde, and B. Dennison. 2009. Rock Creek Park Natural Resource Condition ASsessment. NPS/NCRN/NRR-2009/109, Natioanl Park Service, Fort Collins, CO.
- Eaton, A. D., L. S. Clesceri, E. W. Rice, and A. E. Greenberg, editors. 2005. *Standard Methods for the Examination of Water and Wastewater*. 21st / Centennial edition. American Public Health Association, American Water Works Association, Water Environment Federation, Washington, DC.
- EPA. 2000. *Ambient Water Quality Criteria Recommendations: Information Supporting the Development of State and Tribal Nutrient Criteria for Rivers and Streams in Nutrient Ecoregion IX*. EPA 822-B-00-019, US Environmental Protection Agency, Washington, DC.
- Fenneman, N. M. 1938. *Physiography of Eastern United States*. 1st edition. McGraw-Hill, New York and London.
- Gore, J. A. 1996. Chapter 3: Discharge Measurements and Streamflow Analysis. Pages 53-74 *in* R. Hauer and G. A. Lamberti, editors. *Methods in Stream Ecology*. Academic Press, New York.
- Gregory, K. J. and D. E. Walling. 1973. *Drainage basin form and process*. Edward and Arnold, London, UK.
- Hem, J. D., ed. . Government Printing Office. Available from the Distribution Branch, Text Products Section, USGS, Alexandria, VA, 263 pp. . 1989. *Study and interpretation of the chemical characteristics of natural water*. 2253, U.S. Geological Survey.
- Hilderbrand, R. H., R. L. Raesly, and D. M. Boward. 2005. *Sampling Results for Inventory and Monitoring Protocols for Water Resources of National Capital Region Parks*, Final Report. National Park Service, Washington, DC.
- Hugh Engineers Inc. and R.E. Wright Associates Inc. 1981. *Hydro-geology Study of Catoctin Mountain Park, Maryland*. National Park Service Contract CX 2000-0-0-0032, Catoctin Mountain Park, Thurmont, MD.
- Jackson, R. B. and E. G. Jobbágy. 2005. From icy roads to salty streams. *Proceedings of the National Academy of Sciences of the United States of America* **102**:14487.
- Kaushal, S. S., P. M. Groffman, G. E. Likens, K. T. Belt, W. P. Stack, V. R. Kelly, L. E. Band, and G. T. Fisher. 2005. Increased salinization of fresh water in the northeastern United States. *Proceedings of the National Academy of Sciences of the United States of America* **102**:13517.

- Kazyak, P., S. Stranko, D. Boward, J. Kilian, C. Millard, A. Becker, R. Gauza, A. Schenk, A. Roseberry-Lincoln, and M. O'Connor. 2007. Maryland Biological Stream Survey Sampling Manual: Field Protocols. CBWP-MANTA-EA-07-01, Maryland Department of Natural Resources, CHESAPEAKE BAY AND WATERSHED PROGRAMS, MONITORING AND NON-TIDAL ASSESSMENT, Annapolis, MD.
- Leopold, L. B., M. G. Wolman, and J. P. Miller. 1964. *Fluvial Processes in Geomorphology*. Freeman, San Francisco, CA. .
- MacDonald, L. H., A. W. Smart, and R. C. Wissmar. 1991. Monitoring guidelines to evaluate effects of forestry activities on streams in the Pacific Northwest and Alaska. EPA 910/9-91-001.
- Maryland Department of Natural Resources. 2003. Lower Monocacy River watershed characterization. Annapolis, MD.
- Means, J. 1995. *Maryland's Catoctin Mountain Parks*. The McDonald & Woodward Publishing Company, Blacksburg, VA.
- Monocacy Scenic River Local Advisory Board. 1990. The Monocacy River scenic river study and management plan. Frederick, MD.
- Morgan II, R. P. and S. F. Cushman. 2005. Urbanization effects on stream fish assemblages in Maryland, USA. *J. of the North American Benthological Society*:643-655.
- Motivans, K. 1995. Vegetation and aquatic survey of the Bush Creek tract with emphasis on rare, threatened, and endangered species of plants and freshwater mussels. Monocacy National Battlefield, Maryland Natural Heritage Program, Maryland Dept. of Natural Resources, Annapolis, Md.
- National Park Service. 1995. Water Resources Division and Servicewide Inventory and Monitoring Program Baseline Water Quality Data Inventory and Analysis: Antietam National Battlefield. . Water Resources Division Technical Report NPS/NRWRD/NRTR-95/71, National Park Service, Fort Collins, CO.
- National Park Service. 1996. Water Resources Division and Servicewide Inventory and Monitoring Program Baseline Water Quality Data Inventory and Analysis: Chesapeake and Ohio Canal National Historical Park. Water Resources Division Technical Report NPS/NRWRD/NRTR-96/87, National Park Service, Fort Collins, CO.
- National Park Service. 1997. Water Resources Division and Servicewide Inventory and Monitoring Program Baseline Water Quality Data Inventory and Analysis: Manassas National Battlefield Park. Water Resources Division Technical Report NPS/NRWRD/NRTR-97/99, National Park Service, Fort Collins, CO.
- National Park Service, W. R. D. 2002. Draft Recommendations for Core Water Quality Monitoring Parameters and Other Key Elements of the NPS Vital Signs Program Water Quality Monitoring Component, Freshwater Workgroup Subcommittee, June 14, 2002. National Park Service, Water Resources Division, Fort Collins, Colorado.
- Norris, M. E., J. M. Pieper, and A. Cattani. 2008. National Capital Region Network Inventory & Monitoring Program Water Chemistry Monitoring Protocol., National Park Service, Washington, District of Columbia.
- Norris, M. E. and G. Sanders. 2009. National Capital Region Network biological stream survey protocol: Physical habitat, fish, and aquatic macroinvertebrate vital signs. NPS/NCRN/NRR—2009/116, Fort Collins, Colorado.

- Radtke, D. B., J. V. Davis, and F. D. Wilde. 1998. Specific electrical conductance. Page 22 p. *in* F. D. Wilde and D. B. Radtke, editors. National Field Manual for the Collection of Water-Quality Data: Field Measurements. U.S. Geological Survey Reston, VA.
- Southworth, S. and D. Denenny. 2005. Geologic Map of the National Parks in the National Capital Region, Washington, D.C., Virginia, Maryland, and West Virginia. 2005-1331, USGS, Reston, VA.
- Statzner, B., J. A. Gore, and V. H. Resh. 1988. Hydraulic stream ecology: Observed patterns and potential applications. *Journal of the North American Benthological Society* **7**:307-360.
- Stednick, J. D. and D. M. Gilbert. 1998. Water quality inventory protocol: riverine environments. NPS/NRWRD/NRTR-98/177, National Park Service, Servicewide Inventory and Monitoring Program, Fort Collins, CO.
- Thornbury, W. D. 1968. Principles of Geomorphology. Wiley, New York,.
- Trombley, T. J. and L. D. Zynjuk. 1985. Hydrogeology and water quality of the Catoctin Mountain National Park Area, Frederick County, Maryland. 85-4241, Towson, MD.
- Turk, J. T. and N. E. Spahr. 1989. Chemistry of Rocky Mountain Lakes. IN: Acidic Precipitation **1**.
- U.S. Geological Survey. 1980. Surfacewater. Page 130 p. *in* U. S. G. Survey, editor. National handbook of recommended methods for water-data acquisition. U.S. Geological Survey.
- Vannote, R. L. and G. W. Minshall. 1982. Fluvial processes and local lithology controlling abundance, structure, and composition of mussel beds. *Proceedings of the National Academy of Sciences* **79**:4103-4107.
- Vannote, R. L., W. G. Minshall, K. W. Cummins, J. R. Sedell, and C. E. Cushing. 1980. The river continuum concept. *Can. J. Fish. Aquat. Sci.* **37**:130.
- White, W. B. 1998. Geomorphology and Hydrology of Karst Terrains. Oxford University Press, New York.
- Wilde, F. D. and D. B. Radtke, editors. 1998. National field manual for the collection of water-quality data—Field measurements: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A6. Reston, VA, U.S. Geological Survey.
- William & Mary. 2000. The Geology of Virginia. The College of William and Mary, Williamsburg, Virginia.
- Woods, A. J., J. M. Omernik, and D. D. Brown. 1999. LEVEL III AND IV ECOREGIONS OF DELAWARE, MARYLAND, PENNSYLVANIA, VIRGINIA, AND WEST VIRGINIA. Page Size: 62 p.

The U.S. Department of the Interior (DOI) is the nation's principal conservation agency, charged with the mission "*to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian tribes and our commitments to island communities.*" More specifically, Interior protects America's treasures for future generations, provides access to our nation's natural and cultural heritage, offers recreation opportunities, honors its trust responsibilities to American Indians and Alaska Natives and its responsibilities to island communities, conducts scientific research, provides wise stewardship of energy and mineral resources, fosters sound use of land and water resources, and conserves and protects fish and wildlife. The work that we do affects the lives of millions of people; from the family taking a vacation in one of our national parks to the children studying in one of our Indian schools.

NPS 800/105739, September 2010

National Park Service
U.S. Department of the Interior



Natural Resource Program Center
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

www.nature.nps.gov

EXPERIENCE YOUR AMERICA ^T