D.C. Water Resource Research Center

Annual Technical Report

FY 2000

Introduction

Introduction

This report summarizes the activities of the D.C. Water Resources Research Center (WRRC) for the period of March 1, 2000 through February 28, 2001. Principal investigators for FY 2000 research projects include two (2) University investigators and two (2) investigators within the university consortium. The DC WRRC continues to move toward the establishment of a credible program base. WRRC has been removed from probationary status and is now fully operational.

The Anacostia River is still a priority in the District of Columbia. The major environmental problems include non point source run-off, storm water problems, toxic contamination of sediments, and loss of natural habitat for fish. Aligning with this issue, WRRC provided funding for a UDC principal investigator for the study of Toxic Conditions in the Lower Anacostia. Further, funds were supplied for another University principal investigator to conduct an Anacostia Urban River Issues Study. A third study, Nitrogen and Phosphorus in DC Waterways, conducted by an investigator in the university consortium, also received funding. WRRC continues to pursue relationships/partnerships with stakeholders on this issue.

In support of environmental research, WRRC awards seed grants to researchers within the University consortium. For FY 2000, an investigator from the George Washington University was awarded funds for the development of a proposal, Series Approximation in Analysis of Risk. This research examines a basic problem in quantitative risk assessment which is to provide an accurate estimate and a measure of confidence in that estimate for the general risk model. The basic idea of this research is to use a very accurate approximation to the distribution of the risk function; thereby, eliminating the need for performing Monte Carlo simulation on the computer.

WRRC continues to disseminate the results of its research to its stakeholders to include the residents of the District of Columbia, administrators, faculty, students, and staff of the University of the District of Columbia (UDC), and public and private agencies via newsletters, brochures, fact sheets, and information documents. Additionally, a web page was recently developed that can be accessed through UDCs web site. The WRRC web page will benefit those who may seek information and/or assistance from the D.C. Water Resources Research Center.

Research Program

Introduction

The Anacostia River water quality continues to be the most pressing issue in the District of Columbia. The Anacostia Watershed still suffers from chronic problems of NPS pollution from urban run-off, combined sewer overflows and sediments made toxic by past dumping and industrial activity. The River has incited the involvement of the U.S. Environmental Protection Agency, resulting in financial and technical assistance for study of the Anacostia River Watershed.

As the major body of water of the District of Columbia, the Anacostia River is a distinctly unhealthy body of water, especially as compared to the Potomac estuary that the Anacostia joins. In addition to a consumption advisory on fish, the bottom life of the Anacostia is highly depauperate (Cummins e.a. 1991). The clams, mussels and submerged aquatic vegetation found in the nearby Potomac are missing in the Anacostia (Phelps 1985). Most problems of the bottom life in the Anacostia have been attributed to contaminants in the sediment (ICPRB 1991, 1992). However, evidence suggests problems may also come from toxic water conditions (anoxia & toxic ammonia) developing in the Anacostia basin in late summer.

In recent years there has been an ever increasing demand for urban river restoration projects. This demand has been sparked by the amount of pollution that these rivers have endured over the years. Environmental degradation and other adverse effects emanating from pollution have indeed paved the way for some segments of the population to call for and initiate meaningful policies designed to restore these dying rivers. Heavily polluted river basins such as the Anacostia River basin have not been accorded the attention they deserve. There are those who question the efficacy of existing policies vis-a-vis river restoration projects, as well as those who claim that the failure to clear the Anacostia River rests on an issue of environmental equity. Whatever the reasons for this sad state of the Anacostia River, the paramount issue that confronts us is how we can implement the restoration of this precious resource to a healthy state and sustain and monitor this restoration. River pollution is a by-product of pollution from industrial and agricultural sources, as a result of the effects of urbanization. These problems are not only creating environmental degradation but are constantly being cited as serious health problems afflicting the local population.

Basic Information

Title:	Program Management
Project Number:	00-01
Start Date:	3/1/2000
End Date:	2/28/2001
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	Program Management
Lead Institute:	D.C. Water Resource Research Center
Principal Investigators:	Gloria Wyche-Moore

Publication

The FY 2000 program provides a significant increase in both scope and diversity of projects from last year, as the University seeks to rebuild the Water Resources Research Center (WRRC). The Center, placed on probationary status since FY 1999, has now been released from probation and is fully operational. The Interim Director continues to work to re-establish the network of relationships that make an Institute viable. Further, the Interim Director is working with University administrators to provide greater non-cash support for the Center. The relationship building strategies appear to be successful and will increasingly allow us to more easily attract internal investigators, as well as those from other universities in the District of Columbia.

The core of program development is active participation in the DC community concerned with water resources and local environmental issues. In general, WRRC must establish and maintain relationships with six (6) groups of persons and organizations. These groups are:

1) UDC faculty and academic departments;

2) UDC administration;

3) Federal science and technology agencies;

4) local environmental organizations;

5) DC and other local water and environmental agencies; and

6) the local community

Understanding and organizing the expertise in the entire DC university community will be the main thrust in the next fiscal year. Using the base program funding, the WRRC will continue to develop relationships and seek to identify the priority water resource and watershed environmental issues which need to be addressed, identify credible investigators and project teams for a coherent and high quality program.

Three (3) specific goals that WRRC will work toward include the following:

<u>GOAL ONE</u>: Establishment of an Advisory Committee

As a research evaluation committee has been established, WRRC will now focus on the formation of an Advisory Committee. This committee will be instrumental, as its valuable input will help direct the research efforts of the WRRC. Committee members will be sought from organizations such as the Anacostia Garden Club, DC Environmental Health Administration, Environmental Protection Agency, Northeast Region Aquaculture Center, and D.C. Area universities.

GOAL TWO: Reestablishment of Relations with other District of Columbia Universities

This goal is being addressed, as we currently have two consortium investigators conducting studies in WRRC. However, WRRC will continue to pursue relationships with other DC Area institutes to strengthen its research base in the DC community. The formation of relationships with other DC Area institutions will enhance our Seed Grant initiative, thus providing opportunities to fund proposals leading to environmental research projects that may greatly benefit the citizens of the District of Columbia, as well as other citizens across our country.

GOAL THREE: Greater Outreach to Stakeholders & Committee Input

Greater outreach to stakeholders, as well as input from District of Columbia Universities and an advisory committee will efficiently provide better judgment on where to invest effort and will enhance credibility for a more balanced and relevant future program. Increased partnerships with other universities will provide the Center with a broader capability to respond to the major water resource issues of the District of Columbia.

PROGRAM PRIORITIES

The most pressing water resources priorities in the District of Columbia are the restoration of the Anacostia River, strong minority training, public education, and outreach. WRRC will work to develop partnerships, identify researchers, and to extend information and education to the community.

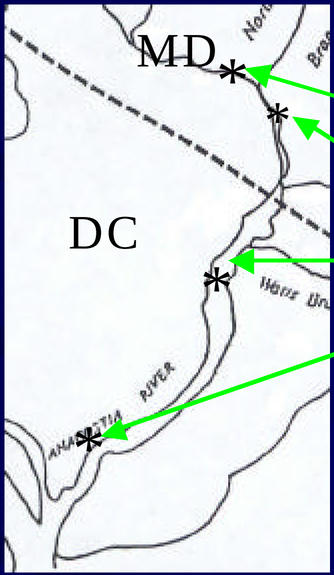
Basic Information

Title:	Toxic Conditions in the Lower Anacostia
Project Number:	00-12
Start Date:	3/1/2000
End Date:	2/28/2001
Research Category:	Water Quality
Focus Category:	Toxic Substances, None, None
Descriptors:	ammonia, anoxia, toxics, urban, biomonitoring, molluscs
Lead Institute:	D.C. Water Resource Research Center
Principal Investigators:	Harriette L. Phelps

Publication

PCB Congenors and Chlordane in Anacostia Estuary Sediments and Asiatic Clams (<u>Corbicula fluminea</u>): Possible Effects of Recent Dredging

- The Anacostia River is a ten mile long freshwater estuary in DC formed by the Northeast and Northwest Branches rivers at Bladensburg, MD
  - Enters the Potomac River estuary at Haines Point.
  - 1964 fishing advisory due to PCBs and chlordane.
- note: PCB and chlordane uses have been banned nationwide for several years.



Sampling Sites:
Northwest Branch
Bladensburg (upper)
Kingman Island (mid)
Navy Yard/Pumphouse (lower estuary)

Surface sediments were collected from the Anacostia in 5/99 for a contaminant bioavailability study with Corbicula clams.

- Surface sediment samples were collected at Bladensburg, MD (upper estuary),

- Kingman Island (mid-estuary),

William Idoniboye

- Navy Yard (lower-estuary), all with a 6” Ekman dredge.

- Potomac Asiatic clams were placed on trays of Anacostia sediment in the nearby Potomac.

Clams did not accumulate sediment contaminants

Sediments and clams were analyzed for 26 PCB congenors, 20 pesticides, 18 PAHs and 5 metals by Severn-Trent Laboratories, Sparks, MD. One set was spiked for pollutant recovery control.

PCB’s by GC (SW 8082)

Chlorinated Pesticides by GC (SW 8082)

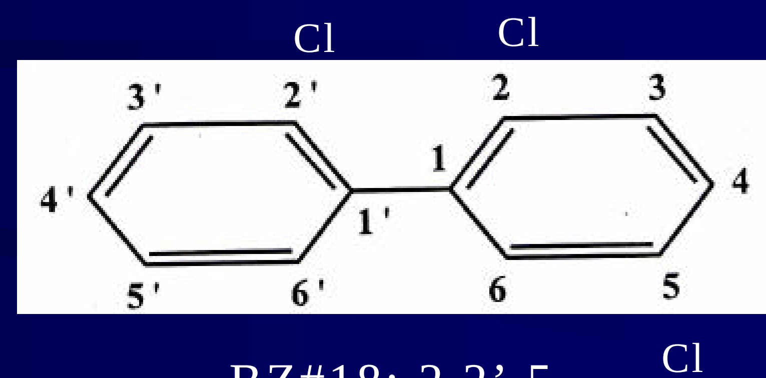
PAH’s by HPLC (SW 8310)

Total Cu, ZN, Fe, Cd and Cr by ICP (SW 6000, 7000)

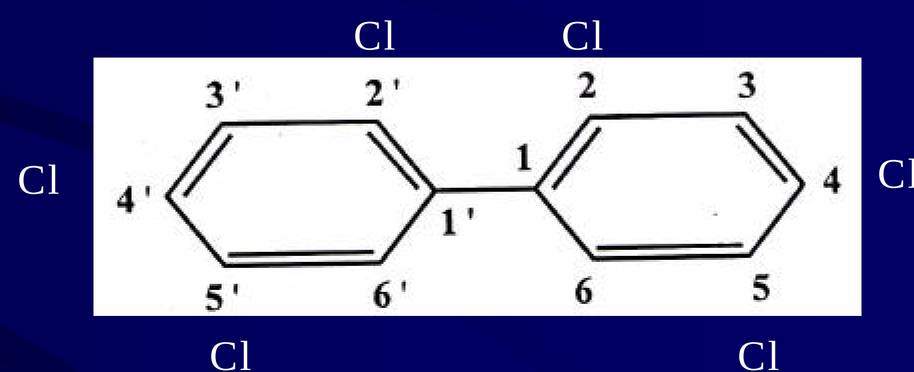
Total Organic Carbon by oxidation (SW 9060)

PCB congenors are numbered (BZ#) by the IUPAC convention

- PCB congenor BZ# indicates positions and increasing numbers of chlorine atoms.
- No Aroclor PCB congenor mixtures, typical of electrical equipment, were found…possibly had been degraded.
- Asiatic clams are noted for good PCB bioaccumulation.



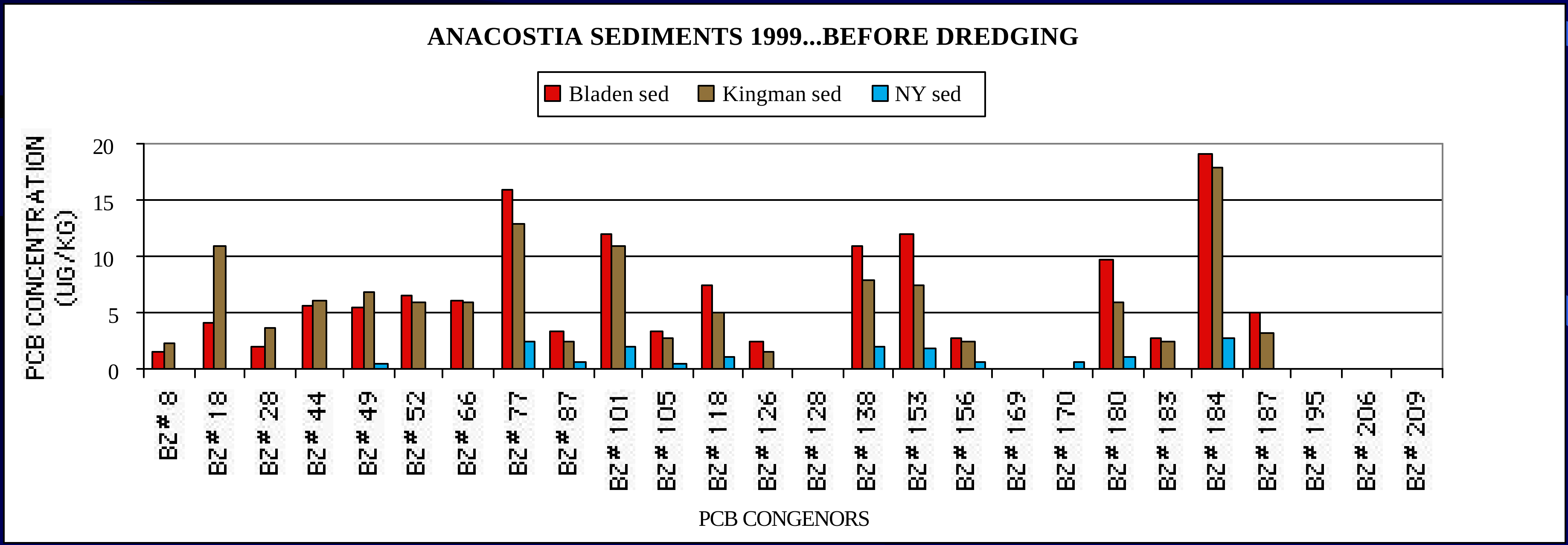
BZ#18: 2,2’,5



BZ# 153: 2,2’,4,4’,5,5’

Before dredging - PCB congenors in Anacostia sediments.

- Note: **Similar** PCB congenor profiles among up-estuary (Bladensburg) and mid-estuary (Kingman Island) sediments
- Note: **Much lower** (1/8) total PCBs in low-estuary (Navy Yard) sediment
- ... possibly due to natural capping by Potomac sediment.



Anacostia Estuary dredging 12/99 - 4/00

- Dredge cutter head in upper Anacostia …note sediment disturbance.
- 179,400 cubic yards dredged from mid and upper channel and pumped to Kingman Island

- Anacostia estuary channel (L) and Kingman Island marsh construction (R - note higher turbidity).

- Dredge connector pump in Anacostia channel...

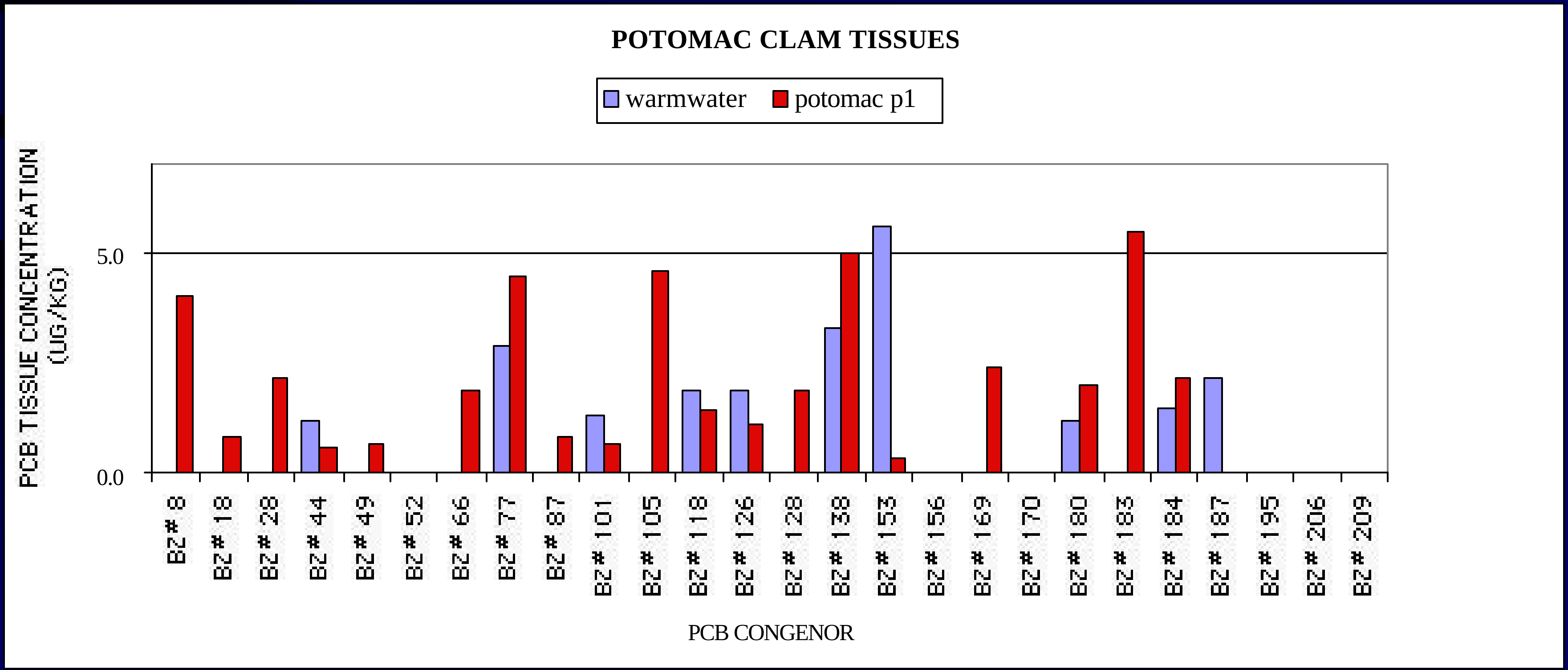
After dredging - Asiatic clams placed in cages in the tidal Anacostia for a contaminant bioaccumulation study.

- Corbicula collected from the Potomac.
- Clams put in cages in the Anacostia estuary for 11 weeks, 8 /00 - 10/00
- Cages put at two locations: upper head of tide (Bladensburg) and near the mouth (Pumphouse).
- Clams depurated (24 hr) and tissues analyzed, 30 - 40 clams per sample.

Castle, Perkins and Greenidge

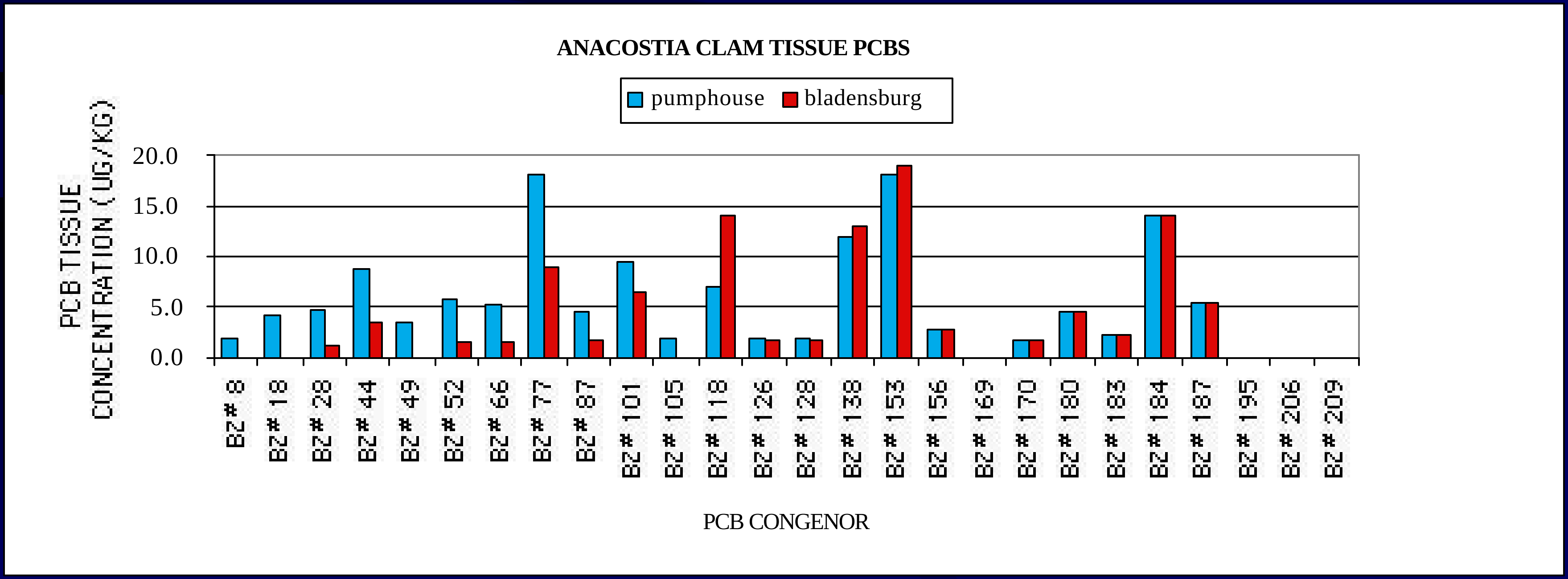
PCBs in Control Asiatic Clams from the Potomac River

- 2 locations: Warmwater State Park at Fort Foote in the Potomac Estuary below Great Falls (red) and the Potomac River above Great Falls (blue)
- Note: Low total PCB levels
- Different congenor profiles suggest different PCB sources in the Potomac River and Estuary portions



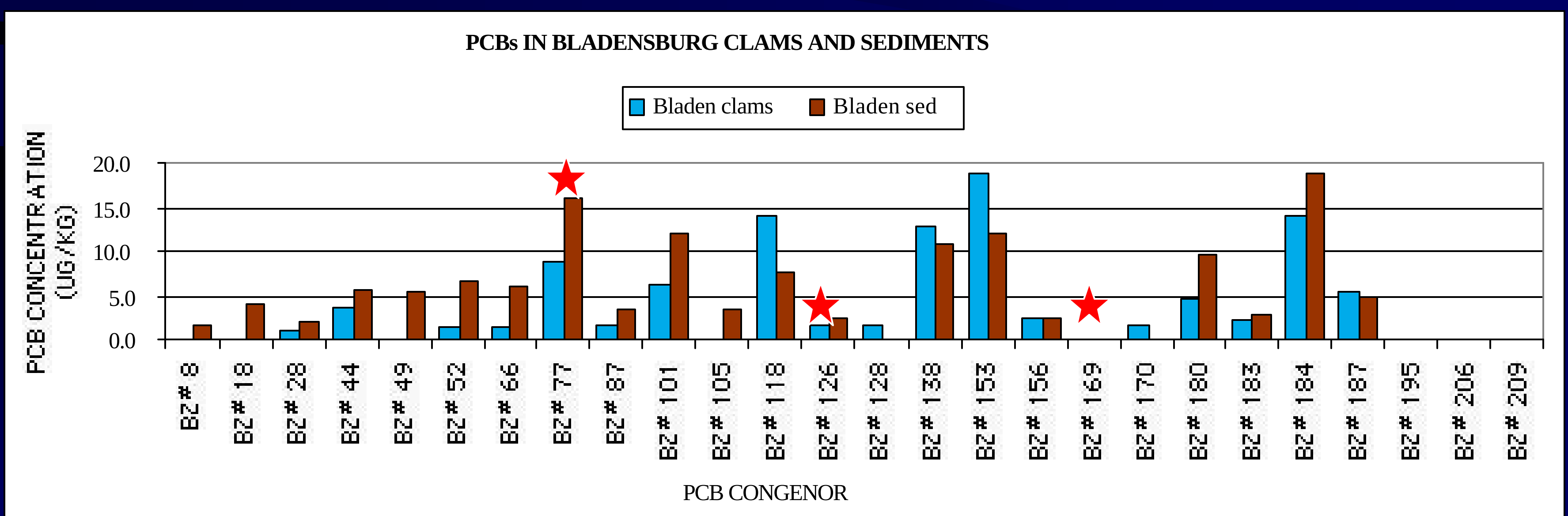
After Dredging - PCBs in caged Anacostia Estuary Clams

- Clams placed in the lower estuary (Pumphouse) and upper estuary near head of tide (Bladensburg, MD)
- Similar PCB congenor levels above BZ# 126 at **both** locations. These tend to be sediment-bound.
- Increased lower MW congenors in the lower estuary.



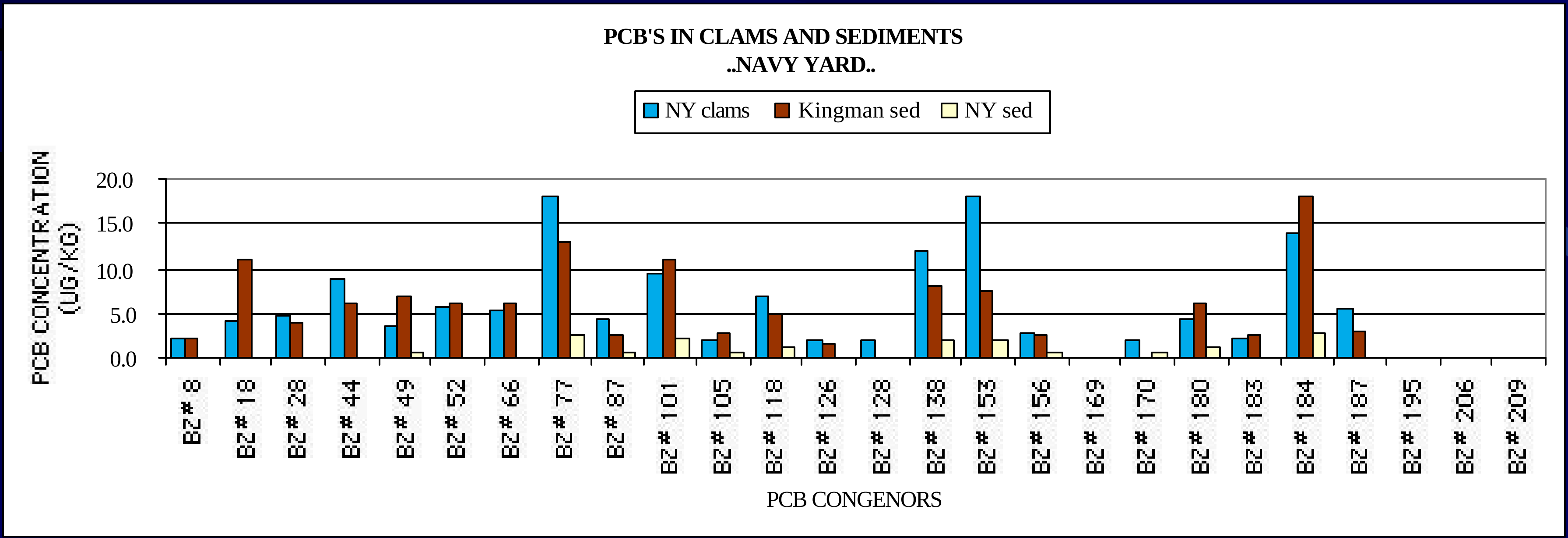
Upper-estuary PCB congenors between clams and sediments

- **Similar** PCB congenor profiles between upper-estuary (Bladensburg) sediments and clams
- Fewer low MW PCB congenors in clams.
- Relatively low total concentration of toxic co-planar PCB's, #77, #126 and #169 (★).



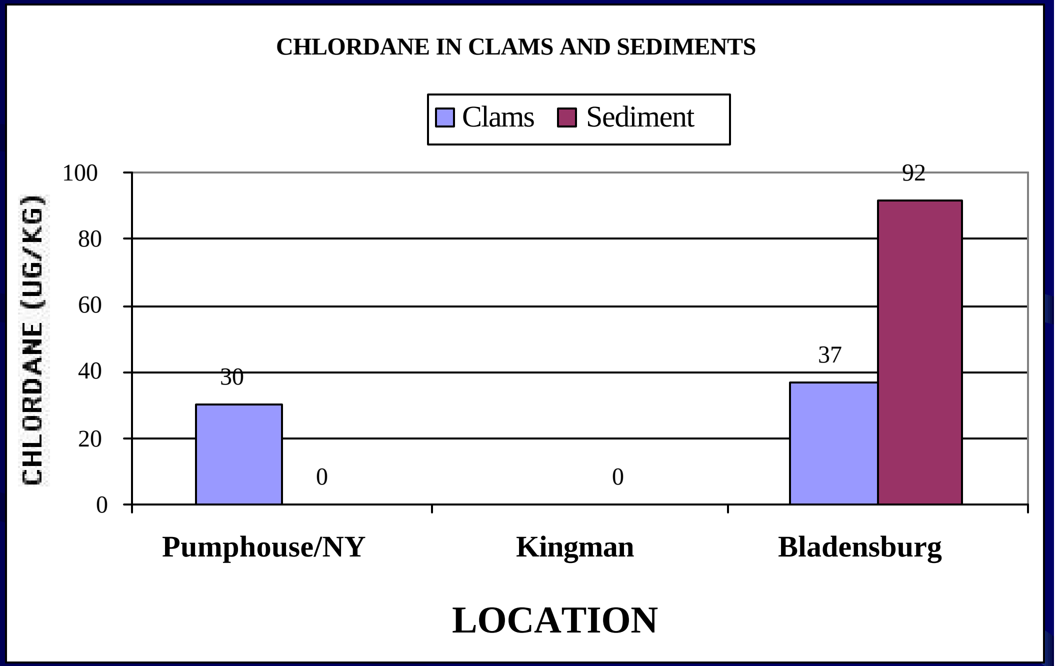
After dredging - PCB congenors among low-estuary clams and low- and mid- estuary sediments

- Note: **Different** PCB profiles among low-estuary (Pumphouse) clams and low-estuary (Navy Yard) sediments.
- Note: **Similar** PCB profiles among low-estuary clams and mid-estuary (Kingman Island) sediments.
- …suggesting low-estuary clam exposure to mid-estuary sediment PCBs.



Chlordane levels in Anacostia sediments and clams - before and after dredging

- Before dredging in 2000, only upper estuary Anacostia surface sediments at Bladensburg showed chlordane... however Bladensburg had had recent local dredging.
- After dredging, Anacostia clams accumulated similar high chlordane at both upper and lower estuary sites.
- ….suggesting bioavailable chlordane was now throughout Anacostia estuary waters.



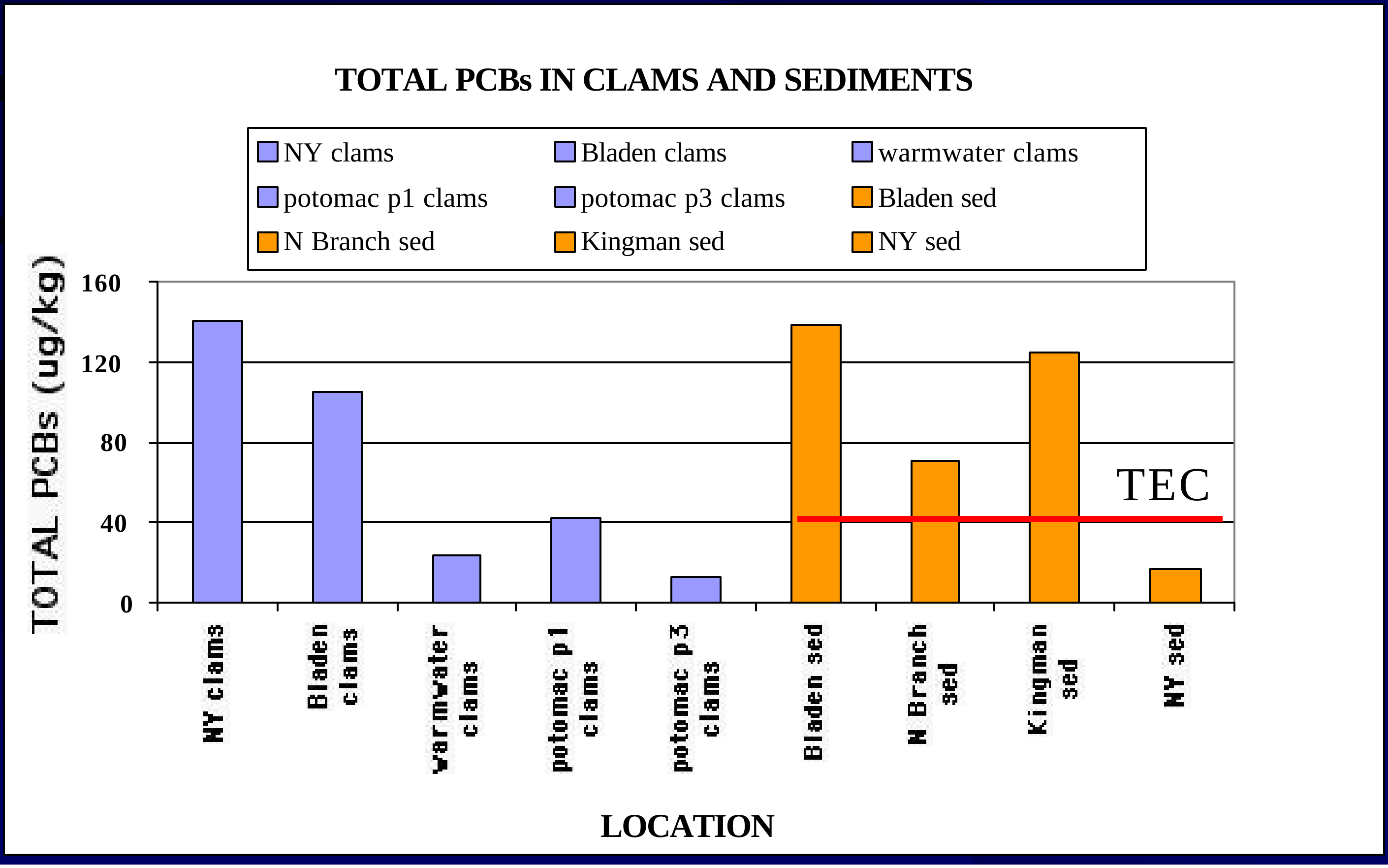
(other pesticides not found in 1999 Anacostia surface sediments but in clams following dredging were: DDT, DDD, DDE, heptachlor, β,δ,γ-BHC, endrin, endosulfan I and endosulfan sulfate).

Toxicity of total PCBs (TPCB) in Clams and Sediments

----All clam tissue TPCB was below the NAS/NAE maximum (290 ug/kg, dw).

----Sediment TPCB in mid and upper estuary was between Threshold Effects Concentration (TEC) (40 ug/kg) and Moderate Effects Concentration (MEC) (400 ug/kg).

----This range has a low incidence (7%) of adverse bioassay effects.



In Conclusion:

- 1. Asiatic clam tissues reflect water not sediment contaminants.
- 2. TPCB in lower Anacostia estuary surface sediments was 1/8 of mid and upper estuary TPCB before dredging...suggesting natural capping by Potomac sediment.
- 3. PCB congenors above BZ#126 were the same in Asiatic clams at both ends of the Anacostia estuary after dredging... suggesting a widespread water source of sediment-bound PCBs.
- 4. Only upper-estuary Anacostia surface sediments had chlordane before dredging. After dredging, upper and lower estuary Asiatic clams had high chlordane levels….suggesting widespread chlordane bioavailability.
- It is suggested the dredging operation 12/99-4/00 mobilized higher MW PCBs and chlordane from buried Anacostia sediments and these were bioaccumulated by Asiatic clams placed in the Anacostia.

Grateful Acknowlegements are made to:

UDC Undergraduate Students:

William Idoniboye

Thomas Perkins

Earl Greenidge

UDC Faculty advisor:

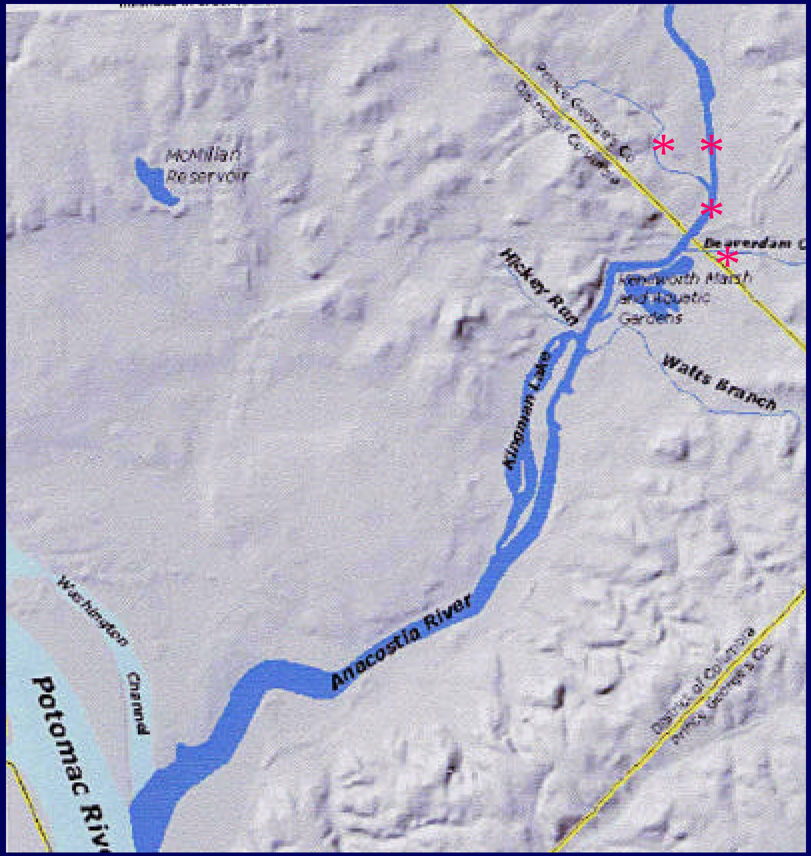
Dr. Harriette Phelps

Funding:

USGS/DC Water Resources Research Center

Future Study: Sourcing Bioavailable Anacostia Pollutants

- Place Asiatic clams in cages at suspected riverine sources of PCBs and chlordane to the Anacostia.
- Leave cages for 10 weeks, May - October.
- Analyze clams as before for EPA Priority Pollutants.



Basic Information

Title:	Anacostia Urban River Issues Study
Project Number:	00-13
Start Date:	3/1/2000
End Date:	2/28/2001
Research Category:	Social Sciences
Focus Category:	None, None, None
Descriptors:	Exploration of community’s pollution concerns and restoration initiatives
Lead Institute:	D.C. Water Resource Research Center
Principal Investigators:	Sheila F. Harmon-Martin, Julius A. Ndumbe

Publication

ANACOSTIA URBAN RIVER ISSUES STUDY

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<u>Water Resources Research Center</u>

ABSTRACT

This research is an exploratory study of issues of the Anacostia River. The Anacostia River is a tidal river and one of the tributaries of the Chesapeake Bay, which is one of the largest estuaries in the world. Years of urbanization and development have contributed to the ecological degradation and transformation of the Anacostia River watershed. In recent years, there has been an increasing demand for urban river restoration projects. Federal, state and local officials, the private sector, community activists and advocacy groups have conducted studies and implemented initiatives designed to restore the Anacostia River as a viable community resource.

This study explores the various public and private sector initiatives designed to promote public awareness and involvement in restoration activities. It also discusses the initiative to redevelopment the Anacostia waterfront. The purpose of the research is to ascertain the level of knowledge and attitudes of residents in the southeastern and northeastern quadrants of Washington, DC toward issues of the Anacostia River, especially pollution concerns and redevelopment initiatives. A telephone survey of five hundred (500), randomly selected, residents of the study area was conducted during a seven-week period. Study findings reveal 1) Respondents were very knowledgeable about the overall state of the Anacostia, including the sources of pollution. 2) They overwhelming support a partnership between the District of Columbia, Maryland, the federal government and private sector in efforts to clean up and improve the Anacostia River. 3) Over half of the respondents (51%) were not aware of restoration activities and 82% have not attended a meeting/conference focusing on issues of the Anacostia River. 4)

Although over a majority of the respondents indicated that they were not aware of Mayor Anthony A. Williams' Anacostia waterfront initiative, they also felt that it would be beneficial to their community. 5) Lastly, a majority of respondents included the Anacostia River as an important community issue along with education, crime, children and housing. Although there are many public awareness activities focusing on the Anacostia River, this study indicates that there is an "impact gap", especially among the residents in Washington, DC communities near the River. There is a need for a concerted, focused effort that targets this study area. Education outreach initiatives designed to inform and convince them of their vested interest will go a long way in insuring their commitment to the protection of the River and participation in activities designed to accomplish this goal.

INTRODUCTION

The Anacostia River watershed, once herald as a thriving natural and commercial resource, reflects an ecosystem that has suffered from years of environmental neglect and urbanization. American Rivers, a nonprofit conservation organization, dedicated to protecting and restoring the nation's rivers, report that rapid and poorly planned urban and suburban growth are perhaps the greatest current threat to the nation's rivers. The Anacostia River watershed, encompassing 176 square miles within Montgomery and Prince George's Counties, Maryland and the District of Columbia, with a population of more than 800,000 residents, is one of the most densely populated watersheds within the Chesapeake Bay drainage basin. Decades of urbanization have resulted in the pollution of the Anacostia River Watershed from a variety of sources. Storm and agricultural runoffs, combined sewer overflow (CSO), sediment, heavy metals and other toxins have created such a dangerous level of pollution in the Anacostia River, that American Rivers categorized it as an endangered river for two (2) consecutive years, 1993 and 1994. In 1995, it made the threatened rivers list. Today, the Anacostia River remains one of the three toxic "hotspots" flowing in the Chesapeake Bay. (American Rivers Web Link, www.americanrivers.org)

Rapid urbanization and uncontrolled development have led to growing regional concern about the state and health of the Anacostia River watershed. The ongoing loss of forest and wetland habitat, excessive surface runoff, industrial waste, sewer overflow and illegal dumping contributes to its continuing degradation. This concern has mobilized various stakeholders to coalesce and address the pollution problems of the river. Federal, state and local officials, community activists, the private sector and advocacy groups have proposed and implemented numerous initiatives designed to restore the Anacostia River as a viable resource of the community and the DC metropolitan region.

This study explores the various public and private sector initiatives designed to promote public awareness and involvement in the Anacostia River restoration activities. It also discusses the initiative to redevelopment the Anacostia waterfront. The purpose of the research is to ascertain the level of knowledge and attitudes of residents in the southeastern and northeastern quadrants of Washington, DC toward issues of the Anacostia River, especially pollution concerns and redevelopment initiatives. The research also addresses factors that have contributed to the river's pollution problem. A telephone survey of five hundred (500), randomly selected, residents of the study area was conducted during a seven-week period.

BACKGROUND

The waters of the Anacostia River began in the northern most areas of Montgomery and Prince George's Counties, flows through Washington, DC into the Potomac River and eventually to the Chesapeake Bay. The northwest and northeast branches are free flowing streams that join to form the tidal Anacostia River near the historic port of Bladensburg, Maryland. The tidal river flows 8.4 miles to its confluence with the Potomac River near the southern tip of the District of Columbia. Along the course of the river, numerous small streams contribute directly to the tidal river, although many are streams enclosed in storm sewer systems. (Anacostia Ecosystem Initiative, EPA,1997)

Four hundred (400) years of urbanization and development have contributed to the enormous ecological and hydrological transformations that the region has undergone. The Anacostia watershed of the early 17th century was occupied by the Nanchotank Indians, a semi-agricultural tribes, who inhabited the land area of the Anacostia and Potomac Rivers, which is now Washington, DC. At its virgin stage, the Anacostia River was crystal clear, a habitat to a variety of fisheries and surrounded by lush forests with abundant wildlife. (Anacostia Watershed Network, 1999.)

The establishment of settlements by the Europeans was the beginning of the alteration of the ecosystem of the Anacostia watershed. During the eighteenth and nineteenth centuries, tobacco, corn and cotton farming dominated large portions of the watershed. Severe erosion resulted and sediment accumulated in the Anacostia River, eventually making it impossible for ships to navigate up the river to the once thriving port of Bladensburg. Since the late nineteenth century, urbanization and the associated changes in land use have drastically altered the natural ecosystem of the Anacostia River. Today more than 800,000 people live in the Anacostia watershed, an average population density of 4,570 people per square mile. It is the most densely populated urban stream system in the United States. (Anacostia Watershed Network, 1999)

In 1990 a study commissioned by the House Committee on Public Works and Transportation on the problems of the Anacostia River was completed. Conducted by the United States Army Corps of Engineers, it determined that the causes of ecological degradation of the Anacostia River were problems associated with lack of environmental controls during extensive urbanization and past activities of the Corps of Engineers. (Water Quality of the Anacostia River, 1991). Specifically, the study noted that storm runoff and annual sewage spillage into the Anacostia River, breached its water quality. The debris and gases from surfaces of roads, commercial and residential buildings, parking lots, and sidewalks contributed to storm run-offs that had flowed into the river. These run-offs contained traces of metals such as mercury, copper, lead, zinc, and petroleum hydrocarbons. According to the study, the activities of the Corps of Engineers also negatively impacted the condition of the Anacostia River. The Corps had been involved with the River for 115 years in a variety of activities such as flood control, channelization, navigation implementation, debris removal, and aquatic-vegetation control. Between 1902 and 1960, Corps activities destroyed approximately 2,600 areas of wetland, 99,000 linear feet of aquatic habitat, and 700 acres of bottom land hardwood forest in the Anacostia Watershed. (Water Quality of the Anacostia River, 1991)

Other contributing factors to the degradation of the Anacostia Watershed have also been identified. Sedimentation, resulting from upstream agricultural cultivation, erosion of the river’s banks and bed, and soil erosion from construction and poor land use, is a serious threat to water quality of the Anacostia River. (Graber and Graber, 1992) Combined sewer overflows (CSO) have also been cited as a major source of organic pollution to the Anacostia. A combined sewers system is designed so that one set of pipes transport sewage to a treatment plant while another set of pipes carry storm water runoff to the river. During a storm, the system may exceed its capacity and the overflow, including sewage and storm runoff, spill into

58 emergency outlets that take the mixture directly to the Anacostia and Potomac Rivers. Some of the overflow receives cursory treatment immediately before being dumped, but not nearly enough to render it clean. It is estimated that about 6% of the annual pollutant load of the Anacostia are a result of COS. However, a major concern is that the combined system that serves about one-third of the District Columbia, 12,955 acres in older, core neighborhoods and including the White House and Capitol Hill, was largely built in the 19th century and the potential for increased pollutants is a eminent danger. (Anacostia Watershed Network, 1997) Recently, however, the Water and Sewer Authority of the District of Columbia announced a draft plan to build three concrete-lined tunnels beneath the city to store overflow of sewage and storm water until it could be treated at the Blue Plains plant. The proposed system will cost one billion ($1,000,000,000) dollars. (Washington Post, June 25, 2001) and would began to address the problem.

Confronted with the deteriorating conditions of the ecosystem of the Anacostia Watershed, numerous studies as well as public and private initiatives have been undertaken to address its problems. For the purpose of this study, a cursory examination of the studies and initiatives will be address.

Public Sector Initiatives

The initial, comprehensive effort of the District of Columbia, Montgomery and Prince George's counties and the State of Maryland to address the increasing problems of Anacostia River watershed occurred in 1987 with the signing of the Anacostia Watershed Agreement. The agreement was designed to formalize a cooperative, intergovernmental partnership to clean up and restore the Anacostia

River and its tributaries. The Anacostia Watershed Restoration Committee (AWRC) was established to coordinate the various entities in the restoration efforts and to develop an action plan for restoring the Anacostia River by the year 2000. The members of the AWRC includes the signatory jurisdictions, U.S. Army Corps of Engineers, Environmental Protection Agency Region III as well as the National Park Service and Department of Agricultural, the two largest land owners in the watershed. The Metropolitan Council of Government provides the administrative and technical support for the AWRC. The Interstate Commission on the Potomac River (ICPRB) assists in the areas of living resources and citizen outreach and education. (Anacostia Watershed Restoration Committee, http://www.epa.gov).

In 1991, the AWRC developed and formally adopted the Six-Point Plan for the Restoration of the Anacostia Watershed. The goals are: 1) Dramatically reduce the pollutant loads in the tidal estuary to measurable improve water-quality conditions by the turn of the century; 2) Restore and protect the ecological integrity of degraded urban Anacostia streams to enhance aquatic diversity and encourage a quality urban fishery; 3) Restore the spawning range of anadromous fish to historical limits; 4) increase the natural filtering capacity of the watershed by sharply increasing the acreage and quality of tidal and non-tidal wetlands; 5) Expand the forest cover throughout the watershed and create a contiguous corridor of forest along the margins of its streams and rivers; and 6) Make the public aware of its role in the Anacostia cleanup and increase citizen participation in restoration activities. (Hoch, Restoring the Anacostia River; Six-Point Action Plan, Metropolitan Council of Government, 1991)

Numerous studies indicate that progress has been made in achieving some of the goals of the Six-Point Plan for the Restoration of the Anacostia Watershed. Successful restoration efforts include 1) the creation of wetlands at the Kingman Lake and Kenilworth Gardens; 2) multifaceted restoration of Sligo Creek that include storm water management, riparian reforestation, restoration of the stream channel and reintroduction of native fish species; 3) reforestation of acres in the River basin; 4) hiring of urban foresters dedicated specifically to the project; and 5) numerous activities to raise public awareness such ecosystem school programs, educational newsletters, adopt-a-stream programs, save our stream programs and community clean the river campaigns. In 1996, AWRC established the Anacostia Watershed Citizens Advisory Committee (AWCAC), a citizen-based committee, in an effort to strengthen its ties to the residents of the watershed. AWCAC 's primary role is to serve as an advising body to the AWRC on its restoration and protection efforts. Its membership is comprised of an appointed nine-member Board, and general membership of interested citizens. Three appointments each are made by the Mayor of the District of Columbia, the County Executive of Montgomery County, and the County Executive of Prince George's County. These representatives are responsible for disseminating and collecting information to their representative communities about restoration efforts. (Anacostia Watershed Restoration Committee, Fact Sheet, 1999)

Recently, the Anacostia Watershed Society successfully settled its five-year legal suit against the US Navy. Filed in 1996, AWS alleged violations of the Clean Water Act and the Resource Conservation and Recovery Act for dangerous levels of toxins, PCB's and heavy metals found in the soils and storm drains of the Navy Yard and Southeast Federal Center. The Washington Navy Yard occupies approximately 64 acres in southeast Washington and is adjacent to neighborhoods comprised of public housing, numerous churches, schools and St. Elizabeth's Hospital. Environment justice concerns expressed by the community at a public meeting were one of the contributing factors of the lawsuit. As a result of the lawsuit, the Navy has spent $17million to completely update the storm water infrastructure. Additionally, to insure that further contamination of the storm water does not occur, contaminated sediments were removed, and all pipes were cleaned, videoed, repaired and sealed. The Navy was also required to obtain a new national pollutant discharge elimination system permit (NPDES) from the Environmental Protection Agency. (Voice of the River, Anacostia Watershed Society Newsletter, 2001; EPA Environmental News, 1997)

According to the EPA, Hazard Site Cleanup Division, progress has been difficult in effectively addressing the problems of toxic contamination in river sediment and the watershed. To address the problem of toxic sediments in the tidal Anacostia River, the Anacostia Watershed Toxic Alliance (AWTA) was formed in March 1999. AWTA is a public-private partnership of approximately 25 participating members including federal regulatory and resource agencies, state and local environmental agencies, industry, academia and the public. Its objective is to investigate toxic substances that present an unacceptable risk to human health and the environment and develop and implement a comprehensive contaminated sediment management strategy. (EPA, Hazard Site Cleanup Division, 1999)

AWTA has been successful in developing a watershed -based approach to address the problem of contaminated sediments. Actions to cleanup several properties along the Anacostia River have been initiated. Some of these sites include: Camp Simms, Barney Circle, St. Elizabeth's Hospital, Washington Gas & Light, Southeast Federal Center, and Bolling Air Force Base. EPA is currently participating in cleanup activities at these sites and an investigation of the sediments in the Anacostia watershed. (EPA, Hazard Site Cleanup Division, 1999)

Both the government of the District of Columbia and the U.S. Environmental Protection Agency have published extensive reports that addresses the critical issue of the problem of toxic contamination in the sentiment and watershed of the Anacostia River. (The Anacostia River Toxic Management Action Plan, DC Environmental Regulation Administration, 1996; An Environmental Characterization of the District of Columbia, EPA, 1997) Both studies provide a comprehensive examination of the polluted conditions of the waterways of the Nation's Capital and the sources of the pollution. Additionally, they point out the importance of involving residents in the Anacostia watershed in the restoration efforts through public awareness and involvement. Recommendations for addressing the problems of the Anacostia River include a need "to better communicate the idea of environmental risk to those persons whose activity patterns and lifestyles may result in potentially higher risks." (The Anacostia River Toxic Management Action Plan, DC Environmental Regulation Administration, 1996; An Environmental Characterization of the District of Columbia, EPA, 1997)

The Interstate Commission on the Potomac River Basin (ICPRB) and the Metropolitan Washington Council of Governments (MWCOG), two groups that have been driving forces in promoting public outreach programs, cites as a major goal to "make the public aware of their role in the Anacostia cleanup, and increase their participation in restoration activities." (Alliance for the Chesapeake Bay *fact-sheet*, May 1994) Building on their successful model of grass-roots involvement in the rehabilitation efforts of the Chesapeake Bay, they have developed a volunteer program designed to implement small-scale restoration projects. These activities have included volunteers from both the public and private sectors.

Private Sector Initiatives

The numerous studies and initiatives focusing on the Anacostia River watershed by the political jurisdictions and agencies of the federal government have been supplemented by activities of the private sector and community groups. Numerous advocacy groups and grass roots citizen have joined efforts to promote public awareness of the conditions of the Anacostia watershed. Their activities have ranged from promoting public awareness and cleanup campaigns to the development of comprehensive revitalization plans of the Anacostia River waterfront. Some of these groups include:

The Anacostia Watershed Society (AWS), a non-profit environmental organization established in 1989, has as its goal the restoration and protection the Anacostia River and its watershed. Through its volunteer restoration activities, residents of the Anacostia watershed are provided an opportunity to become involved in determining their destiny and that of the river. Since its inception, AWS has brought together 17,000 volunteers who have planted 10,567 trees, removed 314 tons of debris, and 7,202 tires from the Anacostia River watershed. The organization has educated over 9,800 people using slides to explain the history of and present threats to the river. AWS has also developed projects to inform people about activities they can undertake to have a positive impact on the life of the river. (Anacostia Watershed Society Website, 2001)

The Metropolitan Council of Governments sponsors Anacostia Watershed Network (AWN). Its main objective is to inform and update the public on restoration efforts of the Anacostia River. AWN provides comprehensive information on land use patterns physical and biological characteristics of the Anacostia. In 1998, it published "The Anacostia Watershed Restoration and Condition Report 1990-1997" which was a comprehensive report of restoration activities. (Anacostia Watershed Network http://www.anacostia.net/citizens.htm.)

The Summit Fund, a private funding agency, established in 1993 "supports organizations working to bring about tangible and measurable improvements in the quality of life within the Washington, DC community." One of its two priority funding areas is to promote protection and restoration of the Anacostia River. The Summit has recently awarded eighteen (18) grants supporting Anacostia River activities in the following areas: 1) promoting environmental education and public awareness; 2) public advocacy; 3) fostering collaboration among diverse groups; and 4) public goal setting and monitoring progress. (www.summitfund.org , 2000)

The Anacostia River Business Coalition (ARBC) established in 1997 is comprised of businesses from throughout the metropolitan Washington region that are concerned about the health of the Anacostia River. Its main objective is to educate citizens and businesses on the prevention of chemical pollution. ARBC members have sponsored pollution prevention workshops; participated in annual Earth Day Environmental fairs; sponsored poster campaigns to increase public awareness about the connection between everyday activities and pollution in the river; and participated with agencies of the DC government in the annual Anacostia River PRIDE (Partnership to Raise Awareness About Illegal Dumping and Enforcement) Day Cleanup. (Anacostia River Business Coalition Website, 1999; http://www.potomacriver.org/arbc.htm)

The Earth Conservation Corps (ECC) is another organization that has been actively involved in restoration efforts of the Anacostia River. Working with disadvantaged young men and women, ECC has restored riparian habitats damaged by overuse, degradation and pollution. The program participants obtain life and job skills that enable them to acquire employment opportunities in the conservation field. Additionally, the Eagle Corps, an ECC AmeriCorps National Service program, provides volunteers who have planted gardens and trees, repaired stream banks, provided fish passage around small dams and repaired fences along local tributaries of the Anacostia River. Corps members have also conducted environmental and drug use education events in the community. (Earth Conservation Corps Website, 1999; www.earthconcorps.org) The ECC in partnership with the Anacostia Watershed Society provides financial support for Damon Whitehead to serve as the full-time Anacostia riverkeeper. The Anacostia Riverkeeper, a member of the International Water Keeper Alliance, is an environmental "neighborhood watch" program. The riverkeeper is responsible for the protection of the river through daily vigilance. (Anacostia Riverkeeper Website, 1999; www.anacostiariverkeeper, org)

The Anacostia Community Partnership (ACP) consists of representatives from the Anacostia Watershed Society, Anacostia Garden Club, the Wilderness Society, River Terrace Civic Association, DC Consumer Utility Board and community residents. ACP works to improve the quality of life of residents in the Anacostia community and addresses issues of the Anacostia River. (Www.ward8net.org)

Bridge to Friendship is a community-based sustainable development partnership for environmental restoration and improvement of the Navy Yard and the greater southeastern Washington, DC community on both sides of the Anacostia River. Participating organizations include: federal agencies such as General services Administration, Departments of Labor, Housing and Urban Development, EPA, Interior, US Navy, and USDA Forest Service; DC Department of Housing and Community Development, community groups such as Alice Hamilton Occupational Health Center, Covenant House Washington, Friendship House Association. (www.earthvision.net/bridges/Bground.html; 1999)

The Student Conservation Association, Inc. (SCA) is an organization that provides national and community conservation service opportunities, outdoor education and career training for youth. (www.sca-inc.org, 2000) Presently, as a result of a grant award from the Summit Fund, SCA under the auspices of its education initiative, reaches out to four (4) District high schools and allied community groups to promote conservation and protection of the Anacostia River. It has involved hundreds of students in planting trees, clean-up campaigns and conservation service projects such as repair of brick walls in parks, boat dock repairs and trail restoration. As part of SCA's summer 2001 activities, fifteen-hundred (1500) children from kindergarten to six (6) grade will be provided weekly orientations about the Anacostia River in an effort to promote awareness of the value of the River to future generations. (Interview, Reginald Hagood, SCA, 6/2000).

The public and private groups, grass roots organizations and initiatives discussed in this review do not represent an exhaustive discussion of those involved in restoration activities of the Anacostia River watershed. However, it does indicate that collaborative and cooperative strategies are leading to gradual and effective progress.

As the ecosystem of the Anacostia River watershed begins to improve, economic development initiatives for the Anacostia waterfront are being promulgated. On March 22,2000, the Anacostia Waterfront Initiative Memorandum of Understanding (MOU) was signed by DC Mayor Anthony A. Williams, and representatives of a dozen federal agencies, creating a partnership to develop a comprehensive plan for development of the Anacostia Waterfront. (DC Office of Planning, Anacostia Waterfront Initiative, March 2000) The agreement calls for a design that is a mixture of commercial, residential, recreational and open spaces. The initiative will coordinate waterfront development and conservation, develop enhanced park areas and provide greater access to the waterfront from neighborhoods. Since ninety (90) percent of the Anacostia Waterfront is publicly owned by the District of Columbia, National Park Service and Department of

Defense, these entities will be the primary partners working in conjunction with the DC Office of Planning and General Services Administration. So far, $150 million dollars has been dedicated for the revitalization of the waterfront. (Anacostia Waterfront Initiative, DC Office of Planning, March 2000) Three major activities of the Initiative that seem to be designed to insure citizen awareness and participation in the planning process are: 1) community workshops addressing river-wide opportunities; 2) dialogue with the Southeast community to create a broad vision for the Waterfront and 3) an Anacostia Waterfront Summit that wraps up all of the activities of the Initiative. (Anacostia Waterfront Initiative, DC Office of Planning, March 2000) In an effort to support the major activities of the Initiative, the DC Office of Planning is the recipient of a $225,000 grant from the Summit Fund, which will be utilized to support public participation in the Anacostia Riverfront Initiative. (www.summitfund.org, 2000)

Additionally, in a continual show of his commitment to restoration of the Anacostia River watershed, Mayor Williams and World Bank President James D. Wolfensohn joined hundreds of volunteers from the World Bank, the DC government and local community and advocacy groups on June 21, 2001 in a clean-up campaign of Kingman and Heritage Islands located in the Anacostia River. Both of these islands are part of the larger Anacostia waterfront initiative. (Office of the Mayor, June 21, 2001)

Numerous studies have led to efforts to restore the ecosystem of the Anacostia River watershed. Partnerships between the political jurisdictions, federal agencies, private sector and advocacy groups have been encouraging and led to measurable results. All entities involved in restoring the Anacostia River purport to promote community awareness of protecting the River. The River flows through the heart of the nation's capital, separating 1/3 of the city's residents living in wards 6,7, and 8 from the western portion of the city. It is the supposition of this study that these residents in the northeastern and southeastern quadrants of Washington are not knowledgeable of issues relating to the Anacostia River, including pollution and recent initiatives to redevelop the Anacostia waterfront. Additionally, it is assumed that they are not involved in restoration activities.

METHODOLOGY

The methodology utilized in this study was a telephone survey and content analysis. A telephone survey was conducted of five hundred (500) randomly selected residents in selected census tracts (precincts- 78,79, 80, 87, 91, 92, 100,101, 119, 127, 131, 132, 133, 139 & 140) in the southeastern and northeastern quadrants of Washington, DC. These census tracts were selected because of their close proximity to the area of the Anacostia River that flows through the city. The census tracts are located in Wards 6,7 and 8. A telephone bank was set up at the University of the District of Columbia and five (5) student operators administered the survey during a seven (7) week period (September 11-October 27, 2000). The survey was administered to 500 residents in the Anacostia area of southeastern and northeastern Washington, DC. Telephone surveys were selected as the data gathering instrument because they are cost effective, involves low risk to the interviewers and have the potential for a greater response rate. The survey questionnaire included questions that ranged from demographic data to knowledge and perceptions of the river.

Content analysis is also utilized in this study. It is a "detailed and systematic examination of the content of a particular body of materials for the purpose of identifying patterns, themes or biases" (Leedy &Ormrod, 2001). Content analysis places in context the problem being studied. Information about the Anacostia River was obtained from government publications, studies conducted by advocacy groups, Internet web sites and personal interviews. Government reports as well as studies conducted by advocacy groups failed to address perception and attitudinal issues of citizens about the Anacostia River.

SURVEY ANALYSIS AND RESULTS

As noted, 500 randomly selected residents in the southeastern and northeastern quadrants of Washington, DC, who live in close proximity of the Anacostia River were survey to ascertain their level of knowledge and attitudes toward the River. Of the 500 residents contacted, 221 residents or 44.2% responded to all questions completing the interview. Table 1 provides a demographic profile of the respondents.

Table I. Demographic Profile of Respondents

Gender	Male 4 3%	Female 57%		
Race	African Americans 72%	Whites 19%	Hispanics 8%	Asian & Native Americans 1%
Education	High School 54%	Technical Education 12%	College 23%	Graduate School 11%
Employment Status	Employed 61%	Unemployed 10%	Retired 22%	Student 7%

Of the telephone respondents, 57% were females while 43 % were males. Racially, the survey results indicated that 72% of the respondents were African-American, 19% Whites, 8% Hispanics and 1% represented Native and/or Asian Americans. The data on race reveal a profile that closely resembles the demographic profile population of the city. Table I further illustrates the demographic variables of educational attainment and employment status. An educational profile of the respondents indicate that 54% have attained a high school education, 23% were college graduates, 11% have completed graduate studies and 12% received a technical education. The data suggests that the respondents are an educationally informed group who has the ability to participate in a decision making process on issues affecting them. Lastly, 61% of the respondent are employed, 10% were unemployed, while retirees and students represented 22% and 7%, respectively. By implication, this data suggest that these respondents are or have been in the labor force which could be assume to be a contributing factor enhancing one's awareness and/or involvement in community issues.

The respondents were asked approximately fifteen (15) questions (including follow-up questions depending on their response to an initial question) to ascertain their knowledge and perception about the Anacostia River. Several questions were also designed to determine whether they had participated in any community meeting or clean-up activities focusing on the River. In an effort to ascertain how the respondents viewed the Anacostia River, they were asked to rate it on a scale of good to poor. Twelve (12%) percent of the respondents rated the River as good, followed by a rating of 28% and 56% reflecting opinions of fair and poor, respectively. Four (4%) percent of respondents expressed no opinions about the River.

The following tables address respondents' knowledge and perception about the sources of pollution of the Anacostia River; clean-up efforts of the Anacostia; and proposed redevelopment activities. Residents were asked to agree or disagree to the following statements related to the Anacostia River as reflected in Table II.

Table II. Survey Responses to General Anacostia River Issues

	Agree	Disagree	No Opinion/ Did Not Know
The Anacostia River is polluted.	89%	7%	4%
The fish in the Anacostia River is contaminated.	60%	25%	15%
The government of the District of Columbia has neglected to clean up the Anacostia River.	70%	24%	6%
The Federal government has neglected to clean up the Anacostia River.	84%	10%	6%
Mayor Anthony Williams' plan to develop the Anacostia Waterfront will benefit the residents living near the River.	68%	24%	9%
Efforts to clean up and improve the Anacostia River should be the major priority of government officials.	79%	14%	7%

An examination of the survey responses reveal that 89% of the residents indicated that the Anacostia River was polluted and 60% felt that the fish in the River was contaminated. A majority of the residents viewed the federal government and the district government as equally responsible for neglecting to clean up the Anacostia

River, with response rates of 84% and 70% respectively. Seventy-nine (79%) percent of the residents stated that clean up and improvement of the Anacostia River should be the major priority of government officials. Lastly, sixty-eight (68%) percent of respondents indicated that Mayor Anthony Williams' plan to develop the Anacostia waterfront would benefit residents living near the River. A primary observation gleamed from the responses in Table II is that residents view the Anacostia River as polluted and the federal and district governments as primarily responsible for its neglect, thus, these entities should make its clean-up a major priority.

The survey also sought to ascertain the respondents' knowledge about the sources of pollution in the Anacostia River. They were asked to respond to three (3) contributing sources that were responsible for polluting the River. They were: 1) waste materials dumped into the River by government and/or businesses (22%); 2) trash dumped into the River by residents from the District of Columbia and Maryland (33%); and industrial pollution from farms on the eastern shores of Maryland, especially chicken farms (4%). Thirty-three (33%) percent of the respondents stated that a combination of all three sources were responsible for polluting the Anacostia. Lastly, eight (8%) percent of those surveyed indicated a lack of knowledge about the causes of pollution.

Table III Responsible for Anacostia River Clean-up Efforts

District of Columbia Government	6%
Federal Government	23%
DC and Federal Governments	19%

Partnership of DC, Maryland and federal governments; and private sector	52%

In Table I seventy-nine (79%) percent of the respondents indicated that efforts to clean up and improve the Anacostia River should be the major priority of government officials. Table III attempts too specifically identify who are these government officials that should exercise this responsibility. Fifty-two (52%) percent of survey participants stated that clean-up efforts of the Anacostia River should be the responsibility of a public-private partnership comprised of the DC, Maryland and federal governments as well as the private sector. Only six (6%) percent felt that DC government should bear the sole responsibility for the clean up of the Anacostia.

In an effort to ascertain how residents obtained information about issues concerning the Anacostia River, they were asked whether they had attended a meeting/conference or participated in clean up activities. Eighty-two (82%) percent of respondents have never participated in a meeting/conference discussing the Anacostia River while eighteen (18%) percent indicated that they have. The same respondents' results applied to participation in clean up activities. Residents were further questioned about Mayor Williams' proposal to redevelop the Anacostia waterfront. When asked whether they were aware of Mayor Williams' proposal to develop the Anacostia waterfront, forty-nine (49%) of respondents had an affirmative response while 51% stated that they had no prior knowledge. Those responding affirmatively indicated that they had obtained their information from television (31%), newspaper (22%), neighborhood meeting (18%), and radio (15%) and at a city council hearing (13%). Interestingly, although 82% of respondents have never participated in activities associated with the Anacostia River, 49% were aware of the Mayor's waterfront proposal from various sources of information. Additionally, despite the fact that 51% indicated that they were not aware of the waterfront initiative, 68% of the respondents felt that it would benefit residents living near the River and by implication, themselves.

Lastly, residents were asked to rank several identified issues that they felt were more important to the community than cleaning and improving the Anacostia River. The identified issues were education, crime, housing, and concerns about children.

Table IV. Priority Issues of the Community

Education	12%
Crime	20%
Children	5%
Housing/Homelessness	3%
Anacostia River	10%
All of the Above	50%

Fifty one (51%) percent of the respondents indicated that all of the issues (education, crime, children and housing/homelessness) including the Anacostia River should be priority issues for the community while ten (10%) percent viewed the River as the most important community issue.

CONCLUSION

Restoring the Anacostia Watershed to a semblance of its original beauty, after decades of neglect, is a major undertaking. Since 1987 numerous studies have led to coordinated efforts to restore the ecosystem of the Anacostia River watershed. Partnerships between the political jurisdictions, federal agencies, private sector and advocacy groups have been encouraging and led to gradual, yet measurable results. To date, the levels of state and federal funds to the Anacostia restoration project reflect the attitude that saving this urban river is an important investment in our future. However, despite the fact that all entities involved in restoring the Anacostia purports to promote community awareness of the impact and necessitate of protecting the River, over half of the residents in this study who live in its close proximity, lacked awareness and/or have not participated in restoration activities. Interestingly, however, these respondents were very knowledgeable about the overall state of the Anacostia, including its sources of pollution. They overwhelmingly support a partnership between the District of Columbia, Maryland, the federal government and private sector in efforts to clean up and improve the Anacostia River. A majority of residents included the Anacostia River as an important community issue along with education, crimes, children and housing. The findings of this study indicate a need to increase efforts to promote awareness of and participation by all residents in issues of the Anacostia River. Few residents in the study area have participated in meetings or discussions about the River or clean up campaigns. Additionally, many more were not aware of the Anacostia waterfront redevelopment plans. It is important to note however, that since the telephone survey, the Office of Planning, DC government has held community meetings on the waterfront initiative in an effort to promote community involvement and awareness. The impact of this effort has yet to be evaluated and provides an opportunity for further study. It has been the consistent notion throughout numerous studies examined during this research that public awareness and involvement of residents in the restoration activities of the Anacostia watershed are important to monitoring abuse and insuring the future of the River. This study indicates that there is an "impact gap", especially among the residents in the communities near the River. There is a need for a concerted, focused effort that targets all residents, especially those in southeastern and northeastern quadrants of the District of Columbia, to become informed and involved. Education outreach initiatives that convince them of their vested interest will go a long way in insuring their commitment to the protection of the River.

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TELEPHONE SURVEY INSTRUMENT

Background Information

Gender M F

Educational Level HS Some College College Graduate Graduate School
Technical School

Race

Employment Status

KNOWLEDGE AND PERCEPTION ABOUT THE ANACOSTIA RIVER

How do you rate the Anacostia River:
Good___________ Fair_________ Poor__________ No Opinion_________

I will provide you with some statements related to the Anacostia River, please tell me whether you agree or disagree.

1. The Anacostia River is polluted.

2. The fish in the Anacostia River is contaminated.

3. The government of the District of Columbia has neglected to clean up the Anacostia River.

4. The Federal government has neglected to clean up the Anacostia River.

5. Mayor Anthony Williams'plan to develop the Anacostia Waterfront will benefit the residents living near the River.

6. Efforts to clean up and improve the Anacostia River should be the major priority of government officials for the residents of this area.

Please tell me which of the following, do you think is responsible for polluting the Anacostia River:

1. Waste Materials dumped into the River by government and/ or businesses.
2. Trash dumped into the River by DC, Maryland & Virginia residents.
3. Industrial pollution from farms on the eastern shores of Maryland, especially chicken farms.
4. All of the above
5. I don't know.

In your opinion, who should be responsible for the clean-up efforts of the Anacostia River?

DC Government
Federal Government
DC and Federal Governments
Partnership of governments (DC, Maryland and Federal) and private businesses

Have you ever attended a community meeting or conference that focused on a discussion about the Anacostia River? Yes No

Have you ever participated in a clean up campaign of the Anacostia River?

Yes No

Before this call, did you know that Mayor Williams has proposed to develop the Anacostia Waterfront? Yes No

If the answer, is Yes, follow up with:

How did you hear about the proposed project?
Television Neighborhood Meeting
Radio
Newspaper
City Council Representative

In your opinion, which of the following issues is more important to your community than cleaning and improving the Anacostia River?

Education Housing/ Homelessness
Crime
Children Issues
Anacostia River
All of the Issues

Basic Information

Title:	Nutrient Testing and Impact of Environment on the Nutrient Content in The Chesapeake Bay
Project Number:	00-14
Start Date:	3/1/2000
End Date:	2/28/2001
Research Category:	Water Quality
Focus Category:	None, None, None
Descriptors:	Wastewater, Nitrate, Phosphate, Water Quality
Lead Institute:	D.C. Water Resource Research Center
Principal Investigators:	Charles C. Glass

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NUTRIENT TESTING AND IMPACT OF ENVIRONMENT ON THE NUTRIENT CONTENT IN THE CHESAPEAKE BAY

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I – Abstract

Nitrogen and phosphorous removal play an important role in wastewater treatment processes as the presence of these nutrients in water bodies cause negative effects in both aquatic organisms as well as humans. Nitrogen and phosphorous enter water bodies due to either point sources, such as wastewater treatment plants, or non-point sources such as contaminated groundwater flow. A major point source of nitrogen in the Chesapeake Bay, the largest watershed in the United States, is the Blue Plains Wastewater Treatment Plant. This facility processes approximately 370 million gallons of sewage per day, and as such has to be able to remove these nutrients efficiently. Many biological removal techniques are being studied, one of which is being tested currently at this facility in order to remove both nitrogen and phosphorous efficiently, as opposed to the traditional chemical procedures. A test of the concentration levels of these nutrients upstream and downstream of the plant was performed to see the effect that the plant is having on the system, as well as the effect that the urban activities is having on the concentration of these nutrients in the Bay.

II – Background on the Project

The Anacostia River flows from Montgomery and Prince George's counties in Maryland, to the District of Columbia where it empties into the Potomac River and eventually the Chesapeake Bay. The presence of toxics such as polychlorinated biphenyls (PCBs), chlordane, metals, and polycyclic aromatic hydrocarbons (PAHs) in the Anacostia River has had a detrimental impact on the ecological health of the river. There are many major environmental problems that directly affect the health of the river such as non-point source runoff (heavy loads of pollutants from the urban and suburban watershed near the river; metals and waste from industry), storm water problems (overflow from sewers empty into the river during heavy periods of rain), toxic contamination of sediments, and a loss of the natural habitat for the fish. There is a paucity of information about the effects of the contaminants on the Anacostia River.

Because of the large amount of urban activity inside the District of Columbia, and the rest of the watershed that feeds the Potomac and Anacostia Rivers, nitrogen and phosphorus concentrations in the Anacostia and Potomac Rivers may be a public health concern. This research study was conducted by taking water samples in the Anacostia River and the Potomac River, prior to confluence, and also after the two rivers has combined. Four key positions along the rivers were designated as the sample locations;

(1) Jones Point: After the Potomac and Anacostia Rivers have combined; after the Blue Plains Wastewater Treatment Plant.
(2) Gravely Point: After the Potomac and Anacostia Rivers have combined; before the Blue Plains Wastewater Treatment Plant.
(3) Georgetown Area: Potomac River
(4) Anacostia Park: Anacostia River

Locations 3 and 4 were selected because readings at these locations would be based on that sole river and activities that affect that river alone. Location 2 was chosen because this area is after the two rivers have combined and before the impacts of the wastewater treatment plant. Location 1 was selected because this is also a point after the two rivers have combined but this location is after the Blue Plains Wastewater Treatment Plant.

III – Introduction

Eutrophication is the growth of algae and other organisms in lakes. Phosphate is generally regarded as the key nutrient in the eutrophication of rivers and lakes. Unlike nitrogen, phosphorous is not abundantly available in nature and because of this phosphorous tends to be the limiting factor in biological productivity. Pure "elemental" phosphorous is rare, and is usually found in one of two forms, organic or inorganic, which is either dissolved in water or suspended. Approximately 90% of the phosphorous found in fresh waters occur as organic phosphorous. Organic phosphorus is usually the phosphate molecule bound with carbon-based molecules; this is the form that can be found in plant and animal tissue, and inorganic phosphorus is the form that is required by plants.

Surface drainage tends to be the most major source of phosphorous. Orthophosphates are applied to residential and agricultural land as fertilizer and is then carried to the surface waters with rain (Leeuw and de Jong, 1993). Cleaning detergents were, up until recently, a major source of orthophosphates because of its significant phosphorous content. Organic phosphates are introduced into the waters by effluents from wastewater, food residues, and can also be formed from orthophosphates in biological treatment processes. Dissolved inorganic phosphorus is formed by dust generated from soil erosion forming the nuclei for precipitation, taken in by plants and converted into organic phosphorus. Animals then get the organic phosphorus by eating the plants and or other animals. The animals excrete waste and bacterial decomposition converts the organic phosphorus back into inorganic phosphorus (Standard Methods for the Examination of Water and Wastewater. 20th edition, 1998).

Bog lakes tend to contain high levels of phosphorous, as the ability of bottomland hardwood forest wetland soil to retain phosphorous is great. These types of soils act as a sink for phosphorous, while freshwater marsh soil tend to be a source of phosphorous under natural conditions and can actually change the inorganic phosphorous entering the marsh into organic phosphorous. (Masscheleyn et. al, 1992).

Nitrogen is the most abundant gas occurring naturally in the atmosphere as it comprises approximately 70% of the atmosphere. It is with ease that lakes therefore gain nitrogen by absorption, called "nitrogen fixation", and is done via bacteria, algae, etc. Nitrogen is also introduced to the agricultural environment through the use of fertilizer, septic systems, and the accumulation and application of animal manure, which can leak into the groundwater and contaminate it (Gelberg et. al, 1999). Nitrogen occurs in many forms: as dissolved molecular nitrogen (N_2), as organic compounds such as amino acids, as ammonia, nitrate and nitrite.

Nitrogen undergoes quite an interesting and complex cycle in lakes, which begins with the intake of nitrogen by the lake, and ends with the loss of nitrogen by the lake as outflow from the basin, sedimentation of nitrogen containing compounds and the reduction of nitrates to nitrogen gas. This reduction process begins with the production of ammonia by heterotrophic bacteria as they decompose organic matter, as well as, though in significantly quantities, the excretion of aquatic mammals. This ammonia is then oxidized to nitrate in a process called nitrification

(overall reaction: $NH_4^+ + 2O_2 \rightarrow NO_3^- + H_2O + 2H^+$)

and the nitrate is then reduced to nitrogen in the process known as denitrification

(general sequence: $NO_3^- \rightarrow NO_2 \rightarrow N_2O \rightarrow N_2$).

Nitrification and denitrification can take place simultaneously, and the actual nitrogen and phosphorous cycle do not completely work independent of each other as the concentration of one may in some cases affect the cycle of another. For example, algal growth has been linked to the concentration of phosphorous in the system, however, it has also been shown that the growth of algae are optimized not only at high phosphorous concentrations, but also when the nitrogen source is nitrate as opposed to ammonia. The influence of one element on another can further be seen in the removal techniques as well, highlighted in the fact that in phosphorous removal nitrate inhibits the biological process in the aerobic zone, however, if the concentration is high enough both phosphorous removal and denitrification can occur at the same time. (Van Starkenburg et. al 1993).

The necessity for nitrogen and phosphorous removal lies in the effect that high levels of these elements have on aquatic life as well as humans. Both promote the growth of algae (eutrophication) which uses up the dissolved oxygen necessary for the respiration of fish and other organisms in the ecosystem. Hence nitrogen removal from wastewater is becoming increasingly important to avoid the problems of eutrophication in receiving water bodies (Karnchanawong et. al, 1990). It is for these reasons that the government in conjunction with the Environmental Protection Agency (EPA) have set standards for water quality and limits on the content of the treated wastewater effluent disposed into streams by wastewater treatment plants. In an effort to further reduce phosphorous levels the EPA has put into effect a ban that reduces the allowable phosphorous content in detergents effectively reducing the sources of phosphorous for lakes. Some wastewater treatment plants use biological nitrification (mediated by aerobic, chemoautotrophic bacteria) and denitrification (reduction of NO_3^- to N_2 carried out by facultatively anaerobic, heterotrophic bacteria) to reduce the amounts of nitrogen discharge into receiving water bodies because of its effectiveness and economic advantage. Studies have mainly concentrated on the trends of the different forms of nitrogen concentrations because of the increasing concerns over health impacts. The primary health effect from high nitrate levels is methemoglobinemia (Shih et. al, 1997). Cancer and spontaneous abortion are also health concerns associated with high nitrate levels. Immuno-compromised people- such as those undergoing chemotherapy, people who have undergone organ transplants, people with HIV/ AIDS, and some older adults and infants are more at risk to the contaminants in drinking water than the general population (Gelberg et. al, 1997).

The Chesapeake Bay area watershed includes six states and the District of Columbia making it the largest in the United States. Many rivers flow into the Chesapeake Bay, the three largest being the Susquehanna, the James and the Potomac Rivers, the Potomac contributing 24% of the total inflow to the bay. The Chesapeake Bay therefore has various sources of nitrogen and phosphate, specifically shallow groundwater found below agricultural fields due to soil infiltration by nitrates due to heavy fertilizer use. These non-point sources of nitrates contribute significantly to the decline in water quality of the bay.

The Anacostia River, a smaller river in the Chesapeake Bay area runs through the District of Columbia and discharges in the Potomac Bay at a point not far upstream form the Blue Plains Waste Water Treatment Plant. The Blue Plains Waste Water Treatment Plant services approximately 2 million people in the District of Columbia and is the largest point source of nitrogen into the Potomac River as it is believed to contribute 95% of the nitrogen and 53% of the phosphorous into the Potomac River. (EPA, 1999).

In an effort to improve nitrogen removal capabilities at Blue Plains a post-denitrification demonstration was set up with the hopes of implementing the process throughout the whole plant in the future, the main compound involved in the process being methanol used as a carbon source. As mentioned earlier phosphorous content can affect the denitrification process. We see this especially in the use of methanol as reduced phosphorous levels upstream, due to the phosphorous detergent ban and increased phosphorous removal at other wastewater treatment plants, can affect denitrification as this is the limiting reagent in the process. Soluble phosphorous is used in the development of nitrifying culture, and the low levels of phosphorous in the system can cause poor nitrogen removal and ultimately methanol usage will not be optimized. (W. Bailey et. al, 1998).

Many efforts have been made to find better, more efficient ways of removing phosphorous and nitrogen from wastewater. For the most part these efforts have been fruitful in yielding alternative methods of nitrogen and phosphorous removal. Phosphorous is slightly easier to remove from water than nitrogen because of its chemical reactivity and the fact that it is not in abundance in the atmosphere as is nitrogen.

Watanabe, Masuda and Ishiguro (1992) have done research on simultaneous nitrification and denitrification (SND) in micro-aerobic films using a rotating biological contactor (RBC). This rotating disk is semi-immersed in water therefore the organisms present are exposed to both air and water. The biofilm formed is the medium in which the SND process takes place. It was shown that nitrification takes place when the disk (and hence the biofilm) is in the air phase, while denitrification takes place in the water phase. The SND process is dependent on the carbon/nitrogen ration of the wastewater, hydraulic loading and oxygen partial pressure as an increased C/N ratio and decreased oxygen partial pressure brought an increase in the nitrogen removal efficiency. One part of the process was often limited by the other, so, for example even though the oxygen level increased denitrification it impeded the nitrification rate at the same time. The disk rotating speed was also a factor as the decrease in rotating seed gave an increase in the SND removal efficiency.

In small wastewater treatment plants nitrogen removal is done using the re-circulation method while phosphorous removal is done using the method of simultaneous precipitation whereby ferrous sulphate is used as the precipitating chemical. The re-circulation method for nitrogen removal is influenced by temperature, low BOD/nitrogen ratios and highly oxidized rainwater. (Niels Skov Olesen, 1990).

Benthic animals, specifically "Monoporeia Affinis" have also been researched to study the effect they have on the removal of nitrogen. The fact that these organisms create burrows in the sand on the sea floor which improves the oxygen conditions by increasing the oxidized surface area; and that their excretions consist of ammonium which contributed to approximately 5 – 10% of total ammonium flux in the system, both assist in the nitrification process. Denitrification was also increased due to the increased nitrate produced in the sediment and the fact that their ammonium production and the improved oxygen conditions suppressed the negative effects that algae has on such a system. (Tuominen et. al, 1999).

The implementation of phosphate removal technologies in water treatment plants have classically consisted of chemical precipitation, biological processes, and combinations of biological processes with chemical processes. (Leeuw and de Jong, 1993). In biological phosphate removal acinetobacter is the medium by which phosphorous is removed. Acinetobacter is present in sludge and is able to absorb phosphates in excess of what it needs for cell production and growth. It in effect soaks up phosphates like a sponge and is then discarded along with the sludge. (Van Starkenburg et. al, 1993) Sequencing batch reactors (SBR) has been used to remove phosphorous. It has been found that biological phosphorous removal using nitrate as a substrate without aerobic zones is possible. Furthermore using anaerobic/anoxic and anaerobic/aerobic SBRs can achieve 100% phosphorous removal. (Leeuw and de Jong, 1993).

IV – Objectives

In a effort to halt deterioration in the quality of the water, states in the Bay's drainage area and the District of Columbia agreed in 1987 to reduce nutrient loading to the Bay by at least 40% from 1985 levels by the year 2000 (Chesapeake Bay Agreement, 1987). This study focuses on the chemical measurement of nitrogen and phosphorus species in the Potomac and Anacostia rivers within the boundaries of the District of Columbia, a thorough understanding of the point and non-point sources of nitrogen and phosphorus, and how activities within the District of Columbia affect the concentration of nitrogen and phosphorus in the Anacostia and Potomac Rivers.

V – Materials and Methods

There are many methods by which element content of water can be measured, two of which are the Ion Chromatography Method and the Colorimetric Method.

As the word Chromatography suggests, ion chromatography is the separation of ions by their charge. It is a simple procedure whereby a column is lined with an inert element. To this inert surface are bound ions that will serve to remove the desired ion from water. These ions bound to the surface are called either "cation exchangers" if they are trying to remove positive charged particles, or "anion exchangers" if they are trying to remove negative particles. To these ions are added counterbalancing ions – ions of opposite charge – to make the net charge on the column wall zero. If say the ion to be measured were negative, then we would use an anion exchanger, bound to a counterbalancing negative ion. The water will be passed through the column and negative ions in the water will displace the negative counterbalancing ion on the wall surface, leaving on the wall surface the cation exchanger bound to the negative ion to be measured, and in the water the negative counterbalancing ion and all other ions that were present initially.

The colorimetric method is an indirect method used to measure phosphate content. There are three methods that can be used: vanadomolybdophosphoric acid method, stannous chloride method, and ascorbic acid method. The vanadomolybdophosphoric acid method employs the reaction of ammonium molybdate with orthophosphate in acidic solution to form molybdophosphoric acid. When vanadium is added the solution turns yellow. The intensity of this color is proportional to the phosphate concentration.

Both methods are advantageous, however, ion chromatography may be the better of the two as there is no limit as to what element can be bound. The key is the type of exchanger that is used. Once an exchanger can bind to the desired ion in a short time and can produce a strong bond then any ion can be separated using this method. Molecules can be bound by changing the ionic strength or pH of the solvent being passed through the column. The colorimetric method is a satisfactory method for measuring phosphate content, however, as stated before it is an indirect method and so the measurement made may not always be exact. Also, the vanadomolybdophosphoric acid method is limited to phosphorous content as low as 4.0mg/L. If the content is lower than that then the other two colorimetric methods mentioned would be better.

TABLE 1. Summary of the methods used to analyze water samples

Indicator	Method Reference
Nitrate	Cadmium Reduction Method (Powder Pillows) HACH DR/2010 Spectrophotometer, 1996-1999

Cadmium metal reduces nitrates present in the sample to nitrite. The nitrite ion reacts in an acidic medium with sulfanilic acid to form an intermediate diazonium salt. This salt couples to gentisic acid to form an amber colored product that can be measured in the visible range, 505 nm.

Nitrite	Ferrous Sulfate Method HACH DR/2010 Spectrophotometer, 1996-1999

This method uses ferrous sulphate in an acidic medium to reduce nitrite to nitrous oxide. Ferrous ions combine with the nitrous combine with the nitrous oxide to form a greenish-brown complex in direct proporiton to the nitrite present in the sample and can be measured with a spectrophotometer in the visible range.

Nitrogen, Ammonia	Nessler Method HACH DR/2010 Spectrophotometer, 1996-1999

The mineral stabilizer complexes hardness in the sample to allow the polyvinyl alcohol dispersing agent aid the formation of reaction of Nessler reagent with ammonia. A yellow color is formed proportional to the concentration of ammonia

Total Phosphorus	PhosVer 3 with Acid Persulfate Digestion Test 'N Tube Method, HACH DR/2010 Spectrophotometer, 1996-1999

Phosphates present in organic and condensed inorganic forms (meta-, pyro-, or other polyphosphates) must be converted to reactive orthophosphate before analysis. Pretreatment of the sample with acid and heat provides the conditions for hydrolysis of the condensed inorganic forms. Organic phosphates are converted to orthophosphates by heating with acid and persulphate.

pH	Fisher Scientific pH/ Conductivity Meter, AR20
Conductivity	HACH sension™5 Conductivity meter

Michelle's sampling dates: teal
Tamisha's sampling dates: pink

Schedule for Sampling; Summer 2000

July

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

August

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
	1	2	3	4	5	6

Sample containers and glassware used in the experiment were cleaned and rinsed before the initial run and also after each run to ensure that contaminants did not interfere with testing results. When collecting the samples for testing of Phosphorus and Nitrogen concentrations, an acid wash procedure was used in the preparation of the sampling containers. A standard preparation was followed for the containers used in collecting samples being tested for turbidity and pH.

Acid Wash Procedure

1. Wash each sample bottle with a brush and phosphate-free detergent.
2. Rinse sample bottle three times with cold tap water.
3. Rinse sample bottle with 10% hydrochloric acid.
4. Rinse sample bottle three times with deionized water.

Standard Preparation Procedure

1. Wash each sample bottle with a brush and phosphate-free detergent.
2. Rinse sample bottle three times with cold tap water.
3. Rinse sample bottle three times with deionized or distilled water.

Because both the Potomac River and Anacostia River are deep sites, we were required to go out on a boat and maneuver it into the center of the main current to collect water samples.

Collecting Samples (250 mL Erlenmeyer flasks)

1. Label the bottle with the site name, date and time.
2. Remove the parafilm from the bottle right before sampling. Do not touch the inside of the flask. When the inside of the cap or bottle, use another one.
3. Carefully reach over the side of the boat and collect water on the upstream side of the boat.
4. Hold the bottle near its base and plunge it downward into the water; turn the bottle into the current (Figure 1-a & Figure 1-b).
5. Do not fill the bottle completely; leave a 1-inch air space so that the sample can be shaken before analysis (Figure 1-c & Figure 1-d).
6. Recap the bottle remembering not to touch the inside of the flask and using clean parafilm to seal the flask.
7. Because the samples are to be examined in the lab, place them in a cooler to be transported back to the lab.

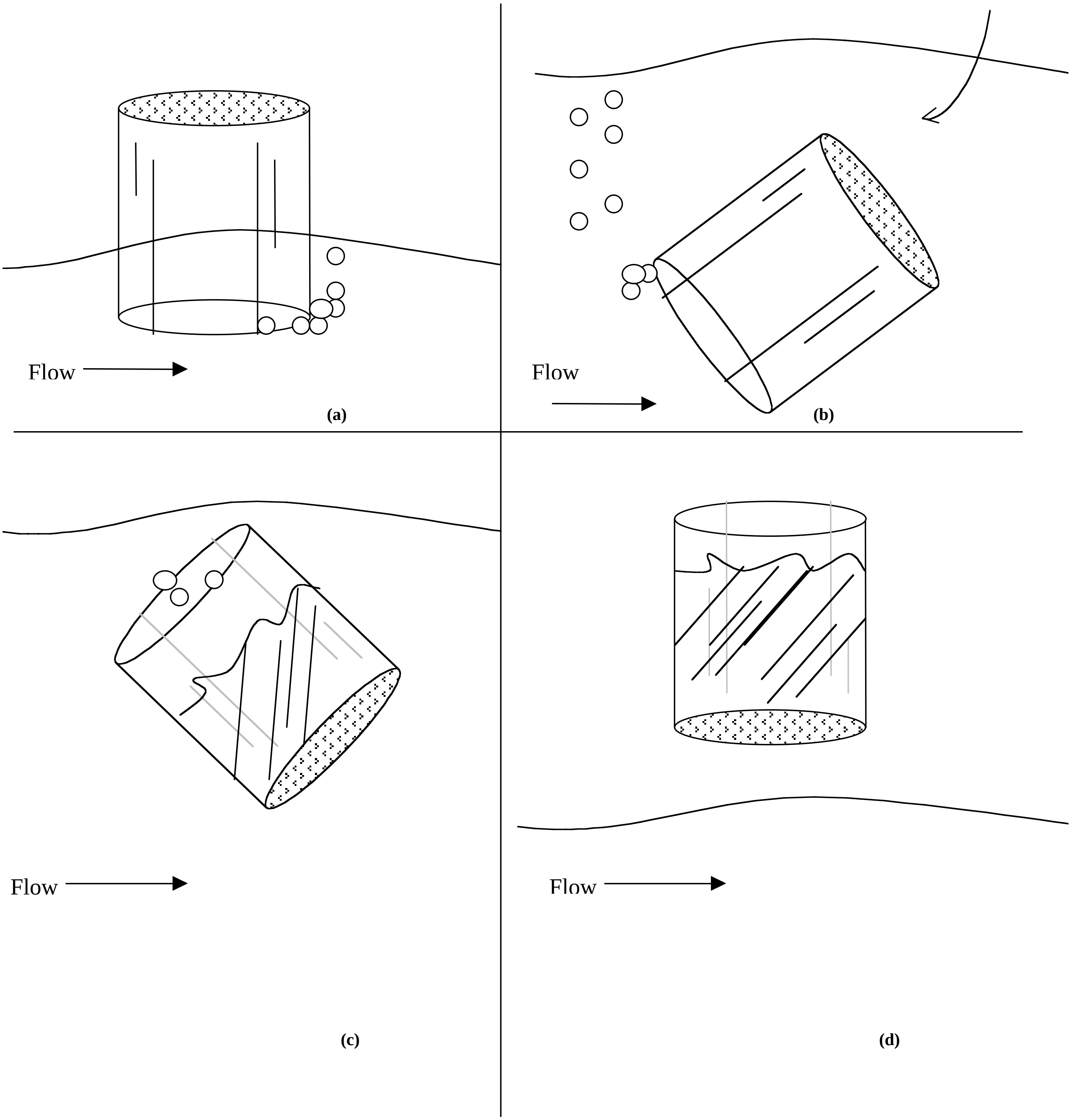


Figure 1

Safety Considerations

There are some basic safety rules that should always be followed when sampling on a boat in the field:

1. When monitoring the site, there should always be at least two people. If possible teams of four to five are better. Make sure that someone else who will not be on site knows where you are, the time you intend to return, and emergency contact information for everyone involved at the monitoring site.
2. Develop a safety plan to follow in case of an emergency. Have the phone number and location of the nearest medical center on hand. Also have each member of the sampling team complete a medical form that includes emergency contact phone numbers and names, insurance information, allergies, etc. Have a first aid kit handy at all times.
3. Make sure that the weather permits for a safe and effective sampling environment.
4. Place your wallet and keys in a safe place and secure the pouch tightly to yourself so that your items won't end up downstream.
5. Check maps and directions before leaving to effectively and efficiently use your time.
6. Be aware of the wildlife and vegetation around the area you are testing and prepared to handle encounters.
7. Do not monitor if the stream is posted as unsafe for body contact.
8. Know your equipment and procedures before beginning sampling. Prepare labels and clean equipment before you get started.
9. Know how to use and store chemicals.
10. Avoid contact between chemical reagents and skin, eyes, mouth, and nose. Wear safety goggles and gloves at all times when handling chemicals.
11. Know the procedure for chemical cleanup and disposal.

Basic Equipment

- ✓ Life jackets
- ✓ Stick of known length
- ✓ Rubber gloves
- ✓ Insect repellent/sunscreen
- ✓ First aid kit, flashlight, and extra batteries
- ✓ Whistle to use in case of emergency to summons for help
- ✓ Refreshments and drinking water for the participants
- ✓ Clipboard
- ✓ Pencils
- ✓ Tape measure
- ✓ Thermometer
- ✓ pH meter
- ✓ Cooler to store collected samples
- ✓ Containers to store samples from the river

Temperature

The kinetics of the chemical and biological processes in the water depends partially on the temperature. A change in the temperature of the body of water can be caused by the weather, discharge of cooler or warmer water, and a number of other factors.

1. Reach out from the boat as far and as safely as possible. Place the thermometer or meter probe in the water.
2. Read the temperature with the thermometer bulb or meter probe beneath the water surface. If using a thermometer, allow enough time for it to reach a stable temperature (app. 1 minute). If using a meter probe allow the temperature reading to stabilize.
3. Record the temperature.

pH

pH determines the alkalinity or acidity of a substance and it may affect some of the chemical and biological processes in the water. For example, different organisms flourish within different pH ranges. The pH scale measures the logarithmic concentration of hydrogen and hydroxide ions. When the pH is 7.0 it is considered neutral. Below 7.0 is considered acidic and above 7.0 basic. pH can either be analyzed in the field or lab, but if measured in the lab it must be done so within 2 hours of the sample collection.

1. Rinse the electrode well with deionized water.
2. Place the pH electrode into the sample and press the appropriate button to start the measurement. Wait the appropriate amount of time to ensure a stable reading.
3. Read and record the pH.
4. Rinse the electrode well with deionized water.

Conductivity

Conductivity is a measure of the ability of water to pass an electric current. In water, conductivity is affected by inorganic dissolved solids (such as nitrate, phosphate anions, and aluminum cations), and temperature (the warmer the water the higher the conductivity).

1. Prepare the conductivity meter for use according to the manufacturer’s directions.
2. Rinse the conductivity meter with deionized water.
3. Reach out from the boat as far and as safely as possible. Place the conductivity meter in the water.
4. Read and record the conductivity.
5. Rinse the conductivity meter with deionized water.

RESULTS AND DISCUSSION

Weather conditions and special events in the District of Columbia during the summer month of July, 2000 contributed to the concentration levels of nutrients in the Anacostia and Potomac Rivers inside the District of Columbia boundary. During the sampling and testing period there were days of continuous rain as well as weeks of no rain at all. The Capitol of the United States celebrated the Countries Independence and welcomed many tourists to its lovely city. All of these extracurricular activities along with the everyday wear and tear of the city are bound to have some impact on the natural water bodies in the area. Figure 1 shows the places where the samples were drawn along the Potomac and Anacostia Rivers. Samples were collected and tested in triplicate form to ensure the accuracy of the sampling procedure and equipment. Figure 2 shows the concentration data for Ammonia Nitrogen measured as nitrogen in the four different sampling locations.

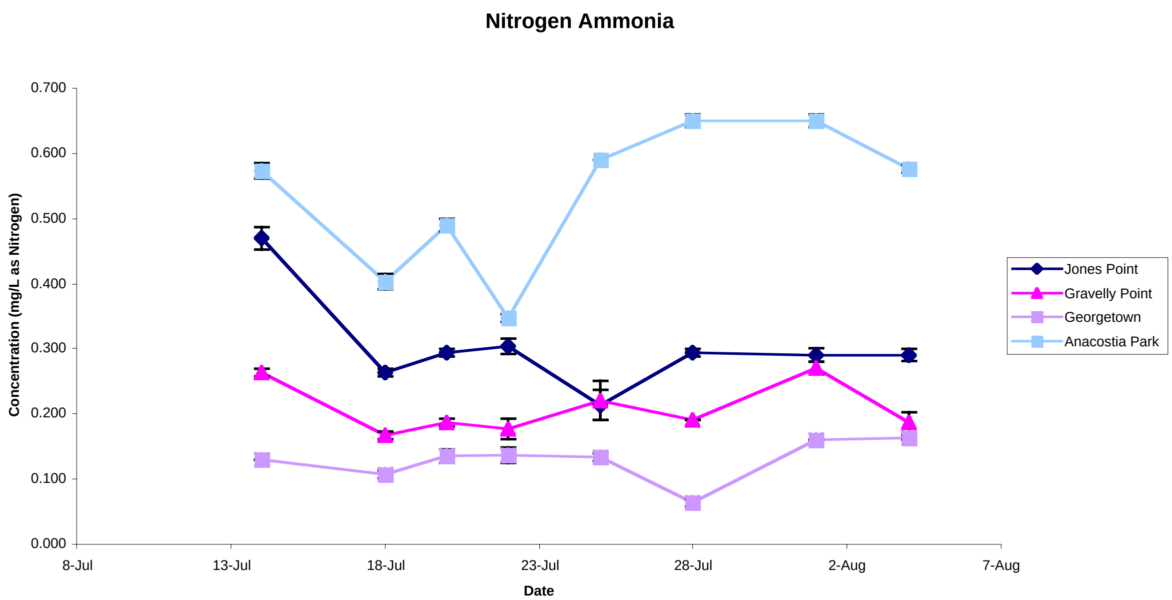


Figure 2

As seen in Figure 2, the Anacostia Park area had the highest concentrations of ammonia nitrogen ranging from a high of 0.650 mg/L to a low of 0.347 mg/L. The Jones Point area was second with concentrations ranging from a high of 0.470 mg/L to a low of 0.213 mg/L. Gravely Point had concentrations ranging from a high of 0.270 mg/L to a low of 0.167 mg/L, and the Georgetown area had the lowest concentrations of ammonia nitrogen measured as nitrogen with a high of 0.163 mg/L and a low of 0.063 mg/L. The concentration levels in the Anacostia Park area were almost 4 times greater than those in the Georgetown area.
Figure 3 displays the concentration data for nitrate measured as nitrogen at the four different sampling locations.

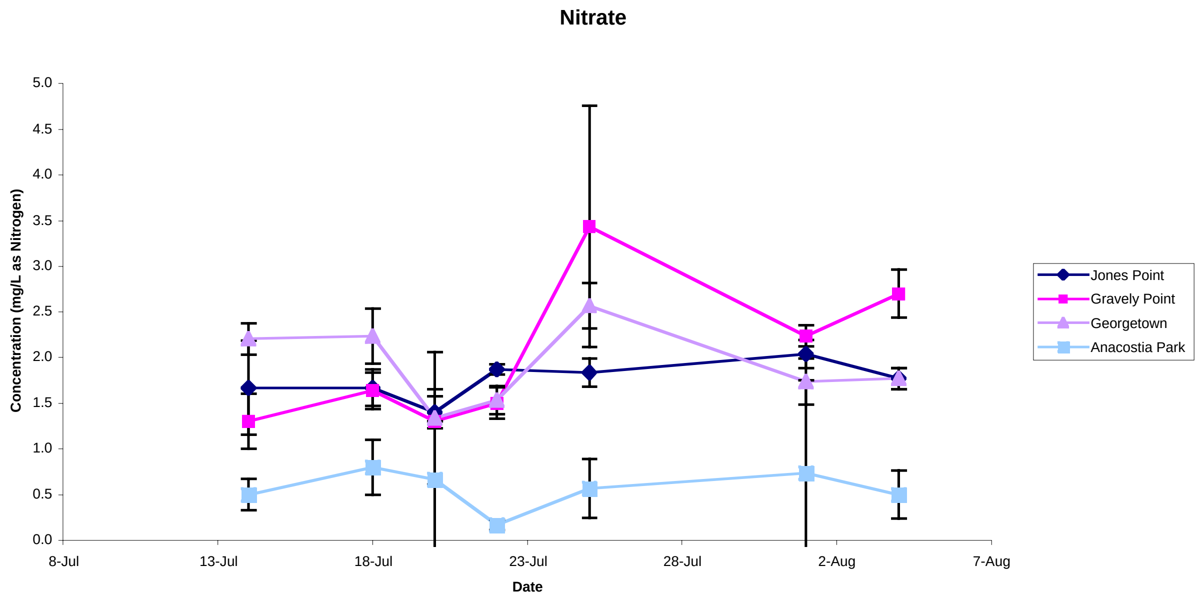


Figure 3

As seen in Figure 3, the Georgetown, Jones Point, and Gravely Point concentrations were similar with averages of 2.0 mg/L, 1.7 mg/L, and 1.9 mg/L respectively. The Anacostia Park area had an average of 0.56 mg/L nitrate measured as nitrogen, approximately 3 times less than the concentrations at the other sampling locations.

In Figure 4 the concentration data for nitrite measured as nitrogen at the four different sampling locations is presented.

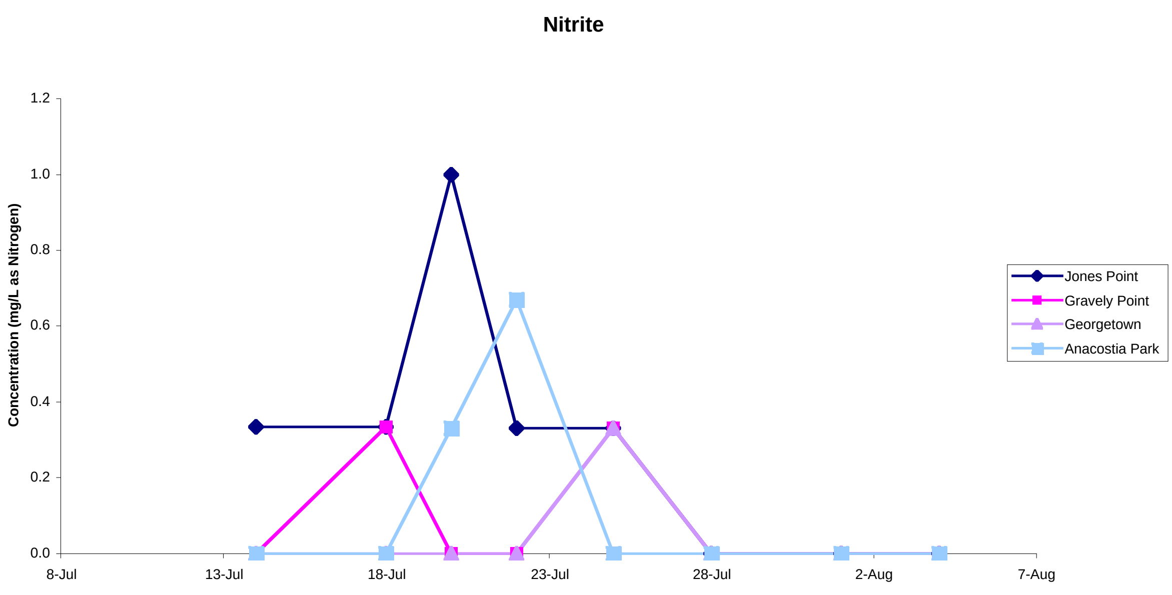


Figure 4

As seen in Figure 4, the nitrite concentrations were below the detection limit on the majority of sampling days. For the days that the nitrite concentrations were detected it is believed that rain events, that caused storm water to enter the waterways contained higher nitrite concentrations, were the cause of the elevated concentrations.
Figure 5 shows the concentration data for phosphorus at the four different sampling locations.

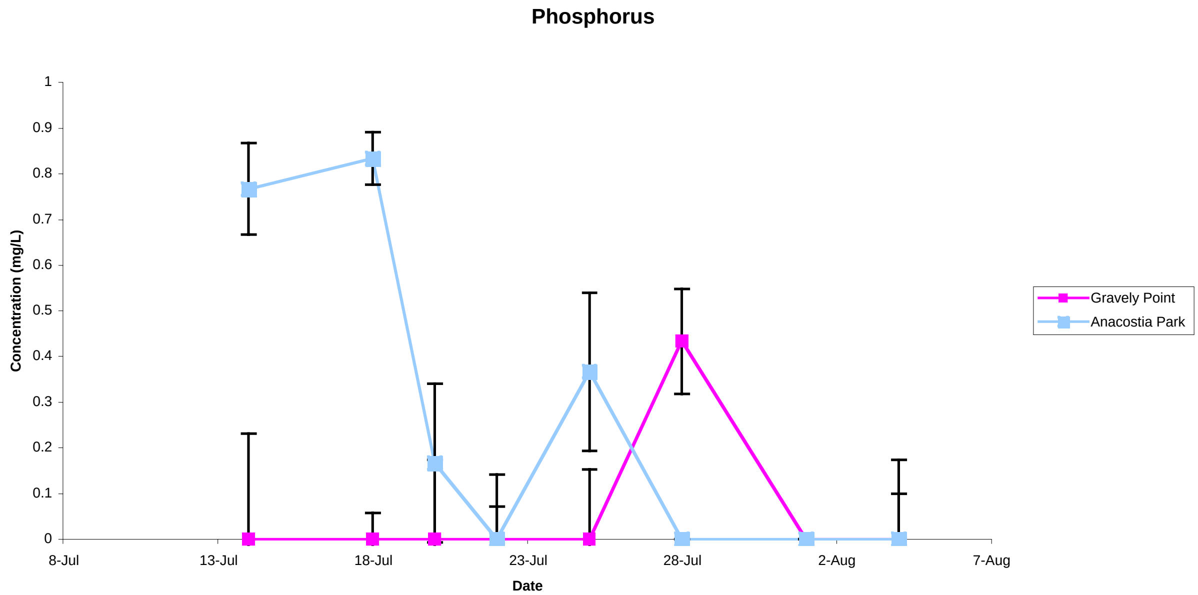


Figure 5

The phosphorus concentrations were consistently below the detection limit for this test at the Jones Point and Georgetown locations. As seen in Figure 5, the concentration of phosphorus was zero for the Gravely Point location also except for one sampling day. After going back and reviewing the conditions of this sampling day it was discovered that this was during a period of intermittent rain for 3 days in the District of Columbia. Also, Gravelly point is where the two rivers combine and this could also be a reason for the spike in the phosphorus concentrations. The phosphorus concentrations in the Anacostia River fluctuated, with initial readings around .77 mg/L PO^{3-}_4 then plunging to zero, then rising, and finally leveling out at a zero concentration.
Figures 6-9 display the concentrations of nitrate, nitrite, ammonia nitrogen, and phosphorus at the respective locations.

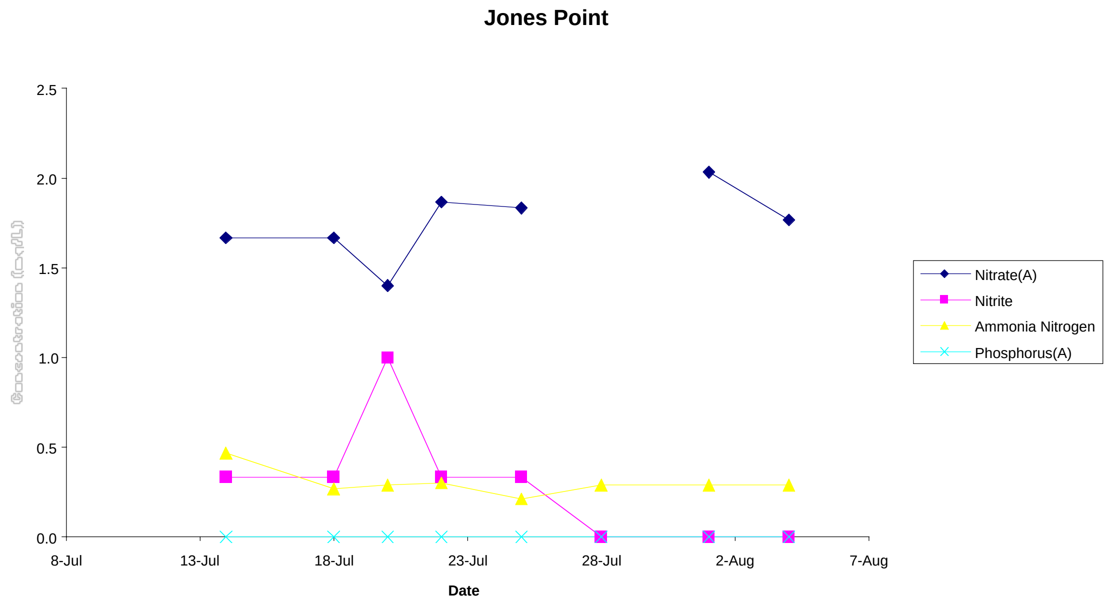


Figure 6

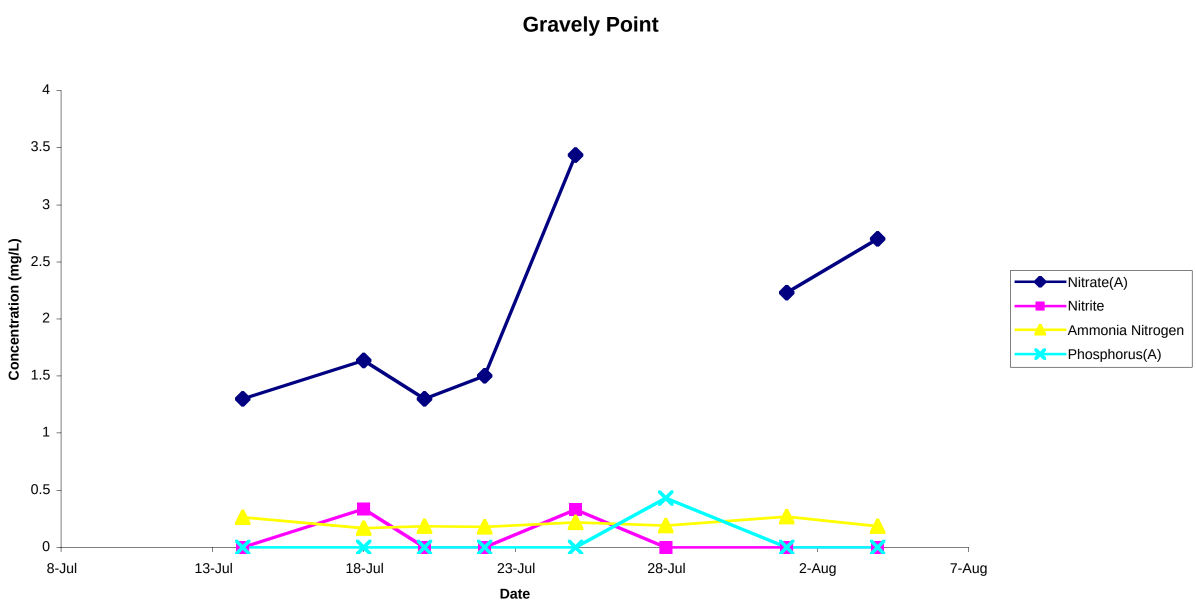


Figure 7

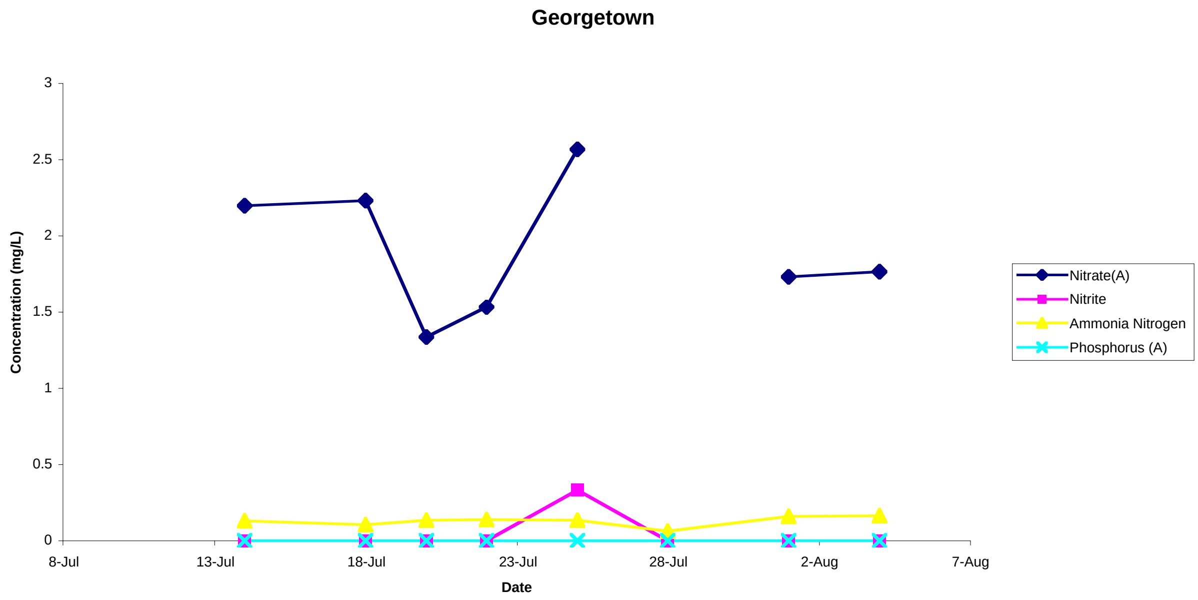


Figure 8

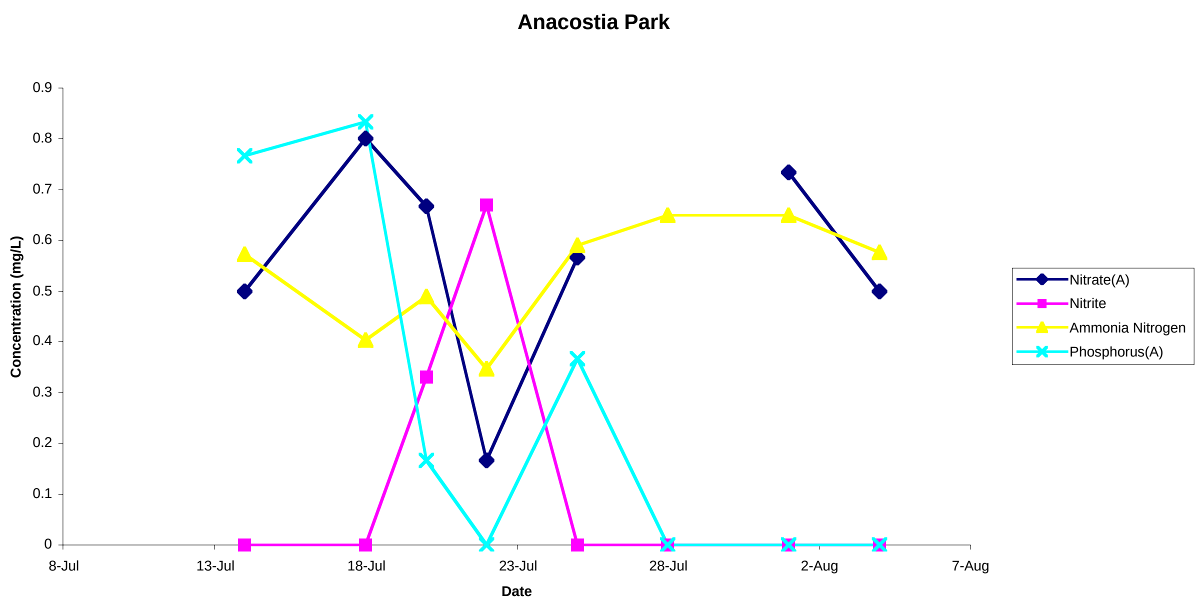
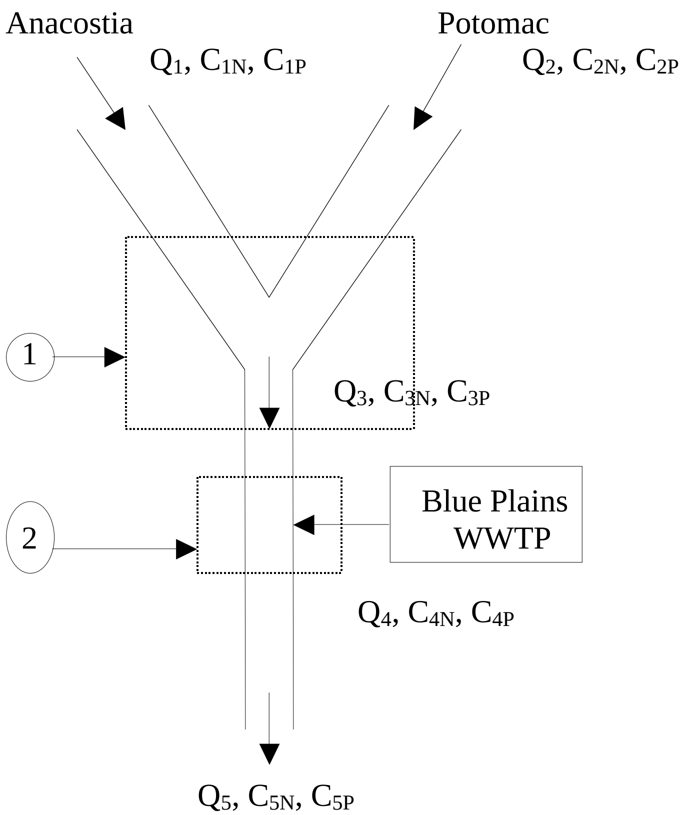


Figure 9

In Figures 6, 7, 8, and 9 all of the nutrient information for each of the sampling sites is presented. As seen in the above Figures, the Jones Point, Gravely, and Georgetown locations have similar concentrations of the different nutrients tested in the water samples. All three locations had nitrate as the highest nutrient present in the water samples. Ammonia-nitrogen was consistent at all three locations with Jones Point showing higher concentrations than the Gravely and Georgetown locations (which seemed to be similar to each other). Nitrite concentrations at the Gravely and Georgetown locations were below detection, only showing signs of fluctuation after rain events. Jones Point initially showed concentrations of nitrite but eventually tapered off to zero. Phosphorus concentrations at all three locations were below the detection limit for the test. Anacostia Park showed concentrations of all four nutrients measured on various sampling days. Nitrite concentrations peaked after rain conditions, nitrate and ammonia nitrogen concentrations were the highest in the water samples, and phosphorus concentrations started off strong but eventually decreased to zero.

CONCLUSIONS

MASS BALANCE



Point of Flow		Flow Rate, Q (MGD)	Avg. Effluent Concentration (mg/L)	
			N	P
Anacostia River	(pt. 1)	58.73	0.535	0.267
Potomac River	(pt.2)	4507.74	0.12854	0
Point of Confluence	(pt.3)	TBD	0.2075*	0.0547*
Blue Plains	(pt.4)	323.66	0.49	0.13
Downstream	(pt.5)	TBD	0.30208*	0*

* - from experimentation

VII – Conclusions

From the data and subsequent graphs and table we see that the Anacostia River has a higher nutrient content than the arm of the Potomac River tested. This would suggest a higher urban activity in the Anacostia Park region. This activity could definitely be from agricultural land use, hence the increased nitrogen and phosphorous levels, as well as from some domestic use. The influence of the Potomac River on the flow from the Anacostia is a lower overall nitrogen concentration.

The effluent form the Blue Plains Wastewater Plant actually had lower nitrogen and phosphorus concentrations than were recorded for the Anacostia River. The net effect being a zero phosphorous concentration, and a nitrogen concentration less than 0.4mg/L. This implies that the nutrient removal process at the Blue Plains WWTP is highly effective in treating the waste from the District of Columbia, however, the nitrogen level of the water increases by approximately 50% after the discharge from Blue Plains.

In comparing the results of the testing methods employed, with the results that should have been achieved (when calculated theoretically), we see that the nitrogen testing method was accurate to approximately 60%. This error could be attributed to error during sampling and testing of sample. The methods employed for the phosphorous measurement were satisfactory, however, for some of the experimental data accurate values could not be achieved because of the limitations on the testing method.

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Appendix A: Data from all Sampling Days

7/14/00	Parameters	Location 1	Location 2	Location 3	Location 4
	Nitrate	1.8	1.6	2.3	0.4
	(mg/L NO_3--N)	1.1	1.0	2.3	0.7
		2.1	1.3	2.0	0.4
	STD	0.5	0.3	0.2	0.2
	average	1.7	1.3	2.2	0.5
	Nitrite (mg/L as N)	0	0	0	0
	(mg/L NO_2--N)	1	0	0	0
		0	0	0	0
	STD	0.6	0	0	0
	average	0.3	0	0	0
	Ammonia Nitrogen	0.49	0.27	0.13	0.58
	(mg/L NH_3--N)	0.46	0.26	0.13	0.58
		0.46	0.26	0.13	0.56
	STD	0.02	0.006	1.86E-09	0.01
	average	0.47	0.263	0.13	0.57
	Total Phosphrous	0.1	0.1	0	0.9
	(mg/L $PO_4$3-)	0	-0.3	0.3	0.8
		-0.1	0.1	-0.2	0.6
	STD	0.1	0.2	0.3	0.2
	average	0	-0.03	0.03	0.77
	Conductivity	50	36.2	46	37.3
	(mS/cm)	50.7	33.2	47.6	34.8
	(taken in lab)	49.2	35.2	45.8	36.1
	average	49.97	34.87	46.47	36.07
	Temp. (Celcius)	20	20	20	20
	pH				
	(taken on the river)	8.59	8.26	8.67	7.47

7/18/00	Parameters	Location 1	Location 2	Location 3	Location 4
	Nitrate	1.8	1.5	2.6	0.6
	(mg/L NO_3--N)	1.7	1.8	2	1.1
		1.5	1.6	2.1	0.7
	STD	0.2	0.2	0.3	0.3
	average	1.67	1.63	2.23	0.8
	Nitrite	1	1	0	0
	(mg/L NO_2--N)	0	0	0	0
		0	0	0	0
	STD	0.58	0.58	0	0
	average	0.3	0.3	0	0
	Ammonia Nitrogen	0.27	0.17	0.11	0.39
	(mg/L NH_3--N)	0.26	0.17	0.11	0.41
		0.26	0.16	0.10	0.41
	STD	0.006	0.006	0.01	0.01
	average	0.263	0.167	0.107	0.403
	Total Phosphrous	-0.2	-0.4	-0.1	0.4
	(mg/L $PO_4$3-)	-0.3	-0.3	-0.3	0.4
		-0.2	-0.4	-0.3	0.5
	STD	0.06	0.06	0.1	0.06
	average	-0.23	-0.367	-0.23	0.83
	Conductivity (mS/cm) (taken on the river)	64.1	58.9	60.5	39.9
	Temp. (Celcius)	25	25	25	25
	pH (taken in the lab)	7.422	7.462	8.166	7.371

7/20/00	Parameters	Location 1	Location 2	Location 3		Location 4	
	Nitrate	1.6	1.3	1.7		1.8	
	(mg/L NO_3--N)	1.3	1.3	1.8		0.1	
		1.3	1.3	0.5		0.1	
	STD	0.2	0.0	0.7		1.0	
	average	1.4	1.3	1.33		0.667	
	Nitrite	1	0	0		0	
	(mg/L NO_2--N)	1	0	0		1	
		1	0	0		0	
	STD	0	0.0	0.0		0.6	
	average	1	0	0		0.33	
	Ammonia Nitrogen	0.29	0.19	0.14			0.15
	(mg/L NH_3--N)	0.3	0.19	0.13		0.52	
		0.29	0.18		0.45	0.46	
	STD	0.01	0.0	0.0		0.0	
	average	0.293	0.187	0.135		0.490	
	Total Phosphrous	-0.1	-0.6	-0.7		-0.5	
	(mg/L $PO_4{}^{3-}$)	0.2	-0.3	-0.5		0.7	
		-0.1	-0.3	0.3		0.3	
	STD	0.2	0.2	0.5		0.6	
	average	0	-0.4	-0.3		0.167	
	pH (taken in the lab)	7.613	7.752	7.201		7.978	
	Conductivity (mS/cm) (taken on the river)	60.1	54.9	61		39	
	Temp. (Celcius)	25	25	25		25	

7/22/00	Parameters	Location 1	Location 2	Location 3	Location 4
	Nitrate	1.9	1.6	1.7	0.2
	(mg/L NO_3--N)	1.8	1.6	1.5	0.1
		1.9	1.3	1.4	0.2
	average	1.87	1.5	1.53	0.17
	STD	0.06	0.17	0.153	0.058
	Nitrite	1	0	0	1
	(mg/L NO_2--N)	0	0	0	0
	average	0	0	0	1
	STD	0.33	0	0	0.67
		0.58	0	0	0.58
	Ammonia Nitrogen	0.31	0.18	0.15	0.34
	(mg/L NH_3--N)	0.29	0.16	0.13	0.35
		0.31	0.19	0.13	0.35
	average	0.30	0.177	0.137	0.347
	STD	0.01	0.02	0.012	0.0058
	Total Phosphrous	-0.4	-0.4	-0.5	0
	(mg/L $PO_4$3-)	-0.3	-0.6	-0.6	0
	average	-0.35	-0.5	-0.55	0
	STD	0.07	0.14	0.071	0
	pH	7.344	7.89	7.713	7.24
	(taken in the lab)				
	Conductivity	63	57.4	64.5	45
	(mS/cm)				
	(taken on the river)				
	Temp. (Celcius)	25	25	25	25

7/25/00	Parameters	Location 1	Location 2	Location 3	Location 4
	Nitrate	1.7	2	2.3	0.7
	(mg/L NO_3--N)	2	3.7	2.6	0.8
		1.8	4.6	2.8	0.2
	average	1.83	3.43	2.57	0.57
	STD	0.153	1.32	0.25	0.32
	Nitrite	0	1	1	0
	(mg/L NO_2--N)	1	0	0	0
		0	0	0	0
	average	0.33	0.33	0.33	0
	STD	0.58	0.58	0.58	0
	Ammonia Nitrogen	0.24	0.22	0.14	0.59
	(mg/L NH_3--N)	0.2	0.19	0.13	0.59
		0.2	0.25	0.13	0.59
	average	0.213	0.22	0.13	0.59
	STD	0.02	0.03	0.0058	0
	Total Phosphrous	-0.3	-0.6	-0.7	0.5
	(mg/L $PO_4$3-)	-0.3	-0.8	-0.7	0.2
		-0.6	-0.5	-0.6	0.4
	average	-0.4	-0.63	-0.67	0.367
	STD	0.17	0.153	0.058	0.153
	pH	7.39	7.422	7.99	7.196
	(taken in the lab)				
	Conductivity	57.3	59	58.1	39.3
	(mS/cm)				
	(taken on the river)				
	Temp. (Celcius)	25	25	25	25

7/28/00	Parameters	Location 1	Location 2	Location 3	Location 4
	Nitrate Note: No nitrate pillow packets.				
	Nitrite	0	0	0	0
	(mg/L NO_2--N)	0	0	0	0
		0	0	0	0
	average	0	0	0	0
	STD	0	0	0	0
	Ammonia Nitrogen	0.3	0.19	0.06	0.65
	(mg/L NH_3--N)	0.29	0.19	0.06	0.64
		0.29	0.19	0.07	0.66
	average	0.293	0.19	0.06	0.65
	STD	0.006	0	0.006	0.01
	Total Phosphrous	-0.7	0.5	-0.3	-0.6
	(mg/L $PO_4$3-)	-0.7	0.3	-0.3	-0.7
		-0.7	0.5	-0.5	-0.8
	average	-0.7	0.43	-0.37	-0.7
	STD	1.05E-08	0.1	0.12	0.1
	pH (taken in the lab)	7.531	7.584	8.18	7.361
	Conductivity (mS/cm) (taken on the river)	59.3	56.4	61.0	32.2
	Temp. (Celcius)	25	25	25	25

8/1/00	Parameters	Location 1	Location 2	Location 3	Location 4
	Nitrate	2.2	2.1	1.5	0.2
	(mg/L NO_3--N)	2.0	2.3	1.7	1.9
		1.9	2.3	2	0.1
	average	2.03	2.23	1.73	0.73
	STD	0.15	0.12	0.25	1.01
	Nitrite	0	-1	0	0
	(mg/L NO_2--N)	0	0	0	0
		0	0	0	0
	average	0	-0.3	0	0
	STD	0	0.6	0	0
	Ammonia Nitrogen	0.28	0.26	0.16	0.64
	(mg/L NH_3--N)	0.3	0.27	0.16	0.66
		0.29	0.28	0.16	0.65
	average	0.29	0.27	0.16	0.65
	STD	0.01	0.01	2.6E-09	0.01
	Total Phosphrous (mg/L $PO_4$3-) Note: HACH machine would not give readings; all stated under-range.				
	pH (taken in the lab)	7.903	7.967	8.268	7.459
	Conductivity (mS/cm) (taken on the river)	66.0	66.5	70.5	36.3
	Temp. (Celcius)	25	25	25	25

8/4/00	Parameters	Location 1	Location 2	Location 3	Location 4
	Nitrate	1.9	2.5	1.7	0.8
	(mg/L NO_3^--N)	1.7	2.6	1.9	0.4
		1.7	3	1.7	0.3
	average	1.77	2.7	1.77	0.5
	STD	0.1	0.3	0.1	0.3
	Nitrite	0	0	0	0
	(mg/L NO_2^--N)	0	0	0	0
		0	0	0	0
	average	0	0	0	0
	STD	0	0	0	0
	Ammonia Nitrogen	0.31	0.18	0.17	0.58
	(mg/L NH_3^--N)	0.29	0.19	0.16	0.58
		0.27	0.19	0.16	0.57
	average	0.29	0.19	0.16	0.58
	STD	0.02	0.006	0.006	0.006
	Total Phosphrous	-0.1	-0.8	-0.2	-0.3
	(mg/L PO_4^{3-})	-0.3	-0.8	-0.3	-0.6
		-0.2	-0.5	-0.3	-0.1
	average	-0.2	-0.7	-0.27	-0.33
	STD	0.1	0.2	0.06	0.3
	pH (taken in the lab)	7.754	8.028	8.231	7.42
	Conductivity (mS/cm) (taken on the river)	63.9	68.4	68.3	41.1
	Temp. (Celcius)	25.0	25.0	25.0	25.0

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Series Approximations in Analysis of Risk

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Abstract. We consider a multiplicative risk function, $R = \prod_{i=1}^{p} x_i^{a_i}$, where x_i are positive random variables, independent but not identically distributed. We discuss and compare the simulated distribution of $S_p = \ln(R)$ with several asymptotic approximation methods. The Generalized Central Limit Theorem is used and conditions under which it is valid are studied to obtain a normal approximation. The Edgeworth expansion of the distribution of S_p and the saddlepoint approximations are obtained. The accuracies of each of the above approximations are illustrated in several examples where they are compared to the exact and the Monte Carlo results.

Keywords: Series Approximation; Edgeworth Expansion; Saddlepoint Method; Multiplicative Risk Model; Monte Carlo Simulation.

1. Introduction

1.1 The problem

A basic problem in quantitative risk assessment is to provide an accurate estimate and a measure of confidence in that estimate for different aspects of the risk function $R = h(\vec{X}) = h(x_1, \ldots, x_p)$. The joint occurrence of the risk factors is modeled by a p-dimensional probability distribution function $f_\theta(x_1, \ldots, x_p)$. The parameter θ is usually vector valued and it is assumed that the functional form of h is known. The estimation of the entire distribution function $G_R(r) = P(R \leq r)$ and its inverseΓthe quantile function $Q_R(u) = G_R^{-1}(u)$ for $0 < u < 1$Γare of primary concern in the Monte Carlo

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estimation of risk. Often, interest centers on accurate estimation of the upper or lower quantiles of R and their standard errors. In general, it is desired to place confidence bands around the distribution or quantile functions and provide accurate bounds on tail probabilities.

In many cases of practical interest, risk is a function of several variables. It is also often the case that the data are only available separately for each of the risk factors; sometimes from different sources (surrogate or proxy data source, Hodges, 1987). A common strategy is to assume independence among the risk factors and consider the possible effects of dependence in a subsequent sensitivity analysis.

In many environmental applications the distribution of risk factors such as body weight, total skin area, concentration, inhalation, digestion, and consumption rates are positive and skewed to the right. A log transformation will then provide a more natural scale to analyze such measurements. More generally, if the logarithm of the risk factor, $y_i = \ln(x_i)$, has a symmetric distribution with location parameter μ_i and scale parameter σ_i^2, then $x_i = \exp(y_i)$ has a positively skewed distribution. Log-normal, log-logistic, log-uniform and log double-exponential provide examples of distributions whose logarithm is symmetric.

In the multiplicative risk model the distribution of R is obtained from multiplication, division or exponentiation of the risk factors (Slob, 1994). If we let $R = \prod_{i=1}^{p} x_i^{a_i}$, then $R = x_1 \times x_2 \times \ldots \times x_p$ is the case considered in Hoffman and Hammonds (1994) with $a_i = 1$, $i = 1, \ldots, p$. Assuming that the risk factors are positive, one can transform the variables to the log-scale and consider an additive risk model $S_p = \sum_{i=1}^{p} a_i \ln(x_i)$, which is generally more amenable to analysis.

1.2 Motivating Examples

The exposure factors handbook (USEPA, 1997) is a three-part volume dedicated to information about human behavior and characteristics. The handbook includes a span of risk factors, including: drinking water intake rate, soil ingestion rate, life expectancy, body weight, inhalation rate, time spent indoors and outdoors for several age groups, etc. Other measured factors include population mobility, showering time, total fruit, dairy and fish intake rates. Other information such as breast milk intake rates or the amount of reduction by cooking are also included. Information on such factors is often utilized in multiplicative risk models to provide estimates of risk to human health.

For exampleΓ USEPA (1992) computes Average Daily Dose (ADD) by averaging the Total Potential Dose (TPD) over Body Weight (BW) and an Averaging Time (AT); that isΓ $ADD = \frac{TPD}{BW \times AT}$. TPD is defined as $TPD = C \times IR \times ED$ where C is the contaminant concentration in the medium (airΓ foodΓ soilΓ etc.)Γ IR is the intake rate such as rate of inhalationΓ ingestion or dermal contact and ED is the exposure duration or the amount of time that the contaminated contact lasts; e.g. the length of stay in an areaΓ the time spent showeringΓ etc. We would like to characterize the distribution of ADD when distributional forms have been assumed for the individual risk factors such as BWΓ C and IR.

As another exampleΓ consider characterizing the distribution of a Hazard Index (HI) for a specified chemical in consumed fish where $HI = \frac{C \times IR}{BW \times RfD}$. HereΓ C represents the concentration of a chemical contaminant in fishΓ IR is the ingestion rate of fish and RfD is the chemical-specific reference dose. McKone (1990) considers a multiplicative model to estimate the uptake of chemicals from a soil matrix deposited onto the skin surface.

Burmaster and Von Stackelberg (1991) define more complex models. They illustrate the use of Monte Carlo simulation to estimate the distribution of health risk as measured by the Incremental Lifetime Cancer risk (ILCR) due to dermal exposure to benzo(a)pyrene (BaP) in soils. The model defines ILCR as the product of CPF and ADD_{Life}Γ where CPF is the Cancer Potency Factor of BaP and ADD_{Life} measures exposure by the average daily dose of BaP that one receives. The exposure model is defined as $ADD_{Life} = \prod_{i=1}^{p} x_i$ where x_i's represent random variables with a variety of distributional shapes.

2. Methods of Solution

2.1 Exact

One can attempt to find an exact answer to the distribution of RΓ approximate it using methods based on Monte Carlo simulationΓ or asymptotic approximations. The exact method uses the joint density function f and finds the distribution of R after a p-variate transformation followed by $p-1$ subsequent integrations. For exampleΓ let x_i be independent and identically distributed (i.i.d.) uniform random variables on the interval $(0,1)$ for $i = 1, \ldots, p$. It is straightforward to show that $-\alpha \sum_{i=1}^{p} \ln(x_i) = -\alpha \ln(R)$ has a $\Gamma(\alpha, p)$ distribution. FurthermoreΓ using the reproductive property of chi-square random variables one can show that the sum of p independent chi-square random variables x_i with α_i degrees of freedom has a chi-square distribution with $\sum_{i=1}^{p} \alpha_i$ degrees of freedom. Such results have been used to model dilution of pollutants in the environment (OttΓ1995; Chapter 8). HoweverΓwhen $\vec{X}$ consists of several types of distributionsΓthe exact distribution of R is difficult to derive and Monte Carlo simulation is used to provide an approximation.

The exact distribution function of $R = x_1 \times x_2 \times \ldots \times x_p$ under independence of the risk factors is $G_R(r) = \int \ldots \int dF(x_1) \ldots dF(x_p)$ where the region of integration is over the domain of the risk factors subject to $\prod_{i=1}^{p} x_i \leq r$. In principleΓby evaluating this multiple integral for different values of r we can characterize the distribution of R exactly. The quantile function of R requires inversion of this integral. Springer (1979) discusses the use of Laplace and Fourier transforms to calculate sums and differences of two independent random variables. Even though in some cases the distribution of R and its quantile function can be derived analyticallyΓin most casesΓthis distribution can become extremely complex and one must resort to computer intensive techniques.

2.2 Monte Carlo Simulation

A Monte Carlo distribution of R can be obtained by generating a large number of replications of the random vector $\vec{X}$ from $f_\theta(\vec{x})$ and recording R for each. The resulting empirical distribution function for R serves as an estimate of its true distribution function. Ordered samples of R provide an estimator of the quantile function and the tail probabilities are estimated as the proportion of the $\vec{X}$ vectors that fall in the upper tail area. Monte Carlo simulation has been an effective tool in computing the distribution of R in most cases. It is possible to write routine programs to compute the Monte Carlo distribution of risk given several specified risk factors. A number of software packages (@RiskΓ1996; Crystal BallΓ1997; AnalyticaΓ 2000; DecisionproΓ2000) have been developed to find the distribution of risk using Monte Carlo simulation.

The main disadvantage of this technique is the number of replications necessary to obtain credible results. For exampleΓcomputing $Q_R(u) = F_R^{-1}(u)$ for u close to zero or one may require a huge number of replicationsΓeach of which may require random number generation or resampling. There have been substantial efforts exerted in reducing the computational time needed to carry out Monte Carlo simulation and a rather large body of work (RipleyΓ 1987; FishmanΓ 1996) has been compiled on the variance reduction techniques. The main objective of such techniques is to reduce the number of required Monte Carlo simulations. Some software packages allow for more efficient Latin Hyber-Cube Sampling to reduce the number of replications.

There are cases for which one should pay particular attention to certain Monte Carlo realizationsΓ corresponding to the values of $\vec{X}$. For exampleΓ consider the distribution of $h(x_1, \ldots, x_p)$Γ which may involve the reciprocal of a risk factor that passes through the origin. Values close to zero will have a large effect on the distribution of R. These values will probably define the extreme quantiles. If such values are generated infrequently due to low probability of the risk factor in the region close to zeroΓ the extreme tail may not be observed at all in limited simulations.

More specificallyΓ consider the risk function defined by $R = x_1 \times x_2 \times x_3$ where the risk factors have a log-normal distribution with $x_1 \sim LN(267, 4.518)$Γ $x_2 \sim LN(191.99, 1.92)$ and $x_3 \sim LN(1.24E - 11, 2.42)$ where the values in parentheses are the geometric means and variancesΓ respectively. Rai and Krewski (1998) and Brattin (1994) use a more complex model to study of cancer risk due to ingestion of Radon in drinking water. HereΓ x_1 represents the concentration of radon in drinking waterΓ x_2 the ingestion rate of water and x_3 the carcinogenic potency of radonΓ its CPF. Using the basic relationships between mean and variance of log-normal and normal distributionsΓ one finds $E(y_i) = \ln(\frac{\mu_i^2}{\sqrt{\sigma_i^2+\mu_i^2}})$ and $var(y_i) = \ln(\sigma_i^2/\mu_i^2 + 1)$Γ where $y_i = \ln(x_i)$ for $i = 1, 2, 3$. The exact distribution of $\ln(R)$ is normal with mean $5.587 + 5.257 - 50.66 = -39.824$ and variance $6.3E - 5 + 5.2E - 5 + 51.11 = 51.1105$. ClearlyΓ x_3 is the dominant term and due to its extreme skewnessΓ it is highly unlikely to capture any value above the mean of the distribution of x_3. Standard calculations (MAPLEΓ 1998) show that $P(x_3 < 1.24E - 11) = .9998441336$Γ placing the mean at the extreme tail of the distribution. As a result this approach consistently underestimates the average risk. Note that $E(R) = E(x_1) \times E(x_2) \times E(x_3) = 6.3564E - 7$ but the average of R based on 1000Γ 10Ï000 and 50Ï000 simulations are 5.90E-12Γ 5.58E-11 and 8.24E-8Γ respectively (@RiskΓ 1996). Capturing the average behavior of risk may require a formidable number of simulations.

In the next sectionsΓ we discuss three asymptotic approximation methods for computing the distribution of R. We discuss the normalΓ Edgeworth's and saddlepoint approximations to the distribution function of the risk function $R = \prod_{i=1}^{p} {x_i}^{a_i}$ where $\vec{X}$ consists of independent random variables with density $f_i(x_i)\Gamma i = 1, \ldots, p$. In this caseΓ $S_p = \sum_{i=1}^{p} a_i \ln(x_i)$ represents the sum of p independent and non-identically distributed random variables. We discuss suitable conditions for valid approximations and illustrate the techniques for several cases and compare with the exact or Monte Carlo results.

3. Asymptotic Approximations

In this section we present the normal and Edgeworth and saddlepoint approximations to the distribution of

$$S_p = \ln(R) = \sum_{i=1}^{p} a_i \ln(x_i) = \sum_{i=1}^{p} y_i. \tag{1}$$

Asymptotic expansions allow us to expand the distribution function of S_p in terms of the normal distribution function and additional terms that depend on the moments of S_p and the normal density. We assume that the cumulative generating function of each risk factor is known. A standard assumption in Monte Carlo analysis of risk is knowledge of the form of the underlying distribution of risk. These assumptions are equivalent whenever the moments uniquely characterize the distribution.

3.1 The Normal Approximation

One can justify the normal approximation of S_p based on the assertion that the observations x_i are log-normal. There is much support in the literature for this claim. Johnson et al. (1994) discuss the applications of the log-normal distribution to model positive random variables. ModarresΓ Nayak and Gastwirth (2000) assume that the risk factor y_i is such that the distribution of its logarithm belongs to a symmetric location-scale family and study the log-normalΓlog double exponential and log logistic distributions. If we assume y_i is normalΓthen the normal approximation of S_p will be exact. Being a continuous and increasing functionΓthe log transformation alters the spacing of the observations while preserving their order. The inverse transformation clearly leads to distributions that are unimodal and right skewed. One can see that the log transformation will reduce the magnitude of the extreme observations and reduce the size of the right tail. Log transformation is a prominent member of the class of Box-Cox transformations to normality. A more accurate approximation of the distribution of R was considered by

Broadbent (1956)Γwho proposed the use of a log-normal approximation to the distribution of products and quotients.

One can also note that S_p is the sum of p independent factorsΓwhich may not have identical distributions. The Central Limit TheoremΓwhich justifies the use of this method of approximationΓis then stated under different conditions. Generalized Central Limit Theorem (SerflingΓ1980) states conditions under which this sum is approximately normal. Let y_i be independent with means μ_iΓfinite variances σ_i^2Γand distribution functions F_i. Suppose that $B_p^2 = \sum_{i=1}^{p} \sigma_i^2$ satisfies the following conditions:

1. $max\ _{i \leq p} \frac{\sigma_i^2}{B_p^2}$ tends to zero and
2. B_p tends to ∞ as p tends to ∞.

ThenΓthe asymptotic distribution of S_p as p tends to ∞ is normal with mean $\mu = \sum_{i=1}^{p} \mu_i$ and variance B_p^2 if and only if the Lindeberg condition

$$\lim_{p \to \infty} \frac{1}{B_p^2} \left[\sum_{i=1}^{p} \int_{|t-\mu_i| > \epsilon B_p} (t - \mu_i)^2 dF_i(t) \right] = 0$$

is satisfied. The first condition ensures that no single term of B_p^2 plays a significant role in the limit. Note that conditions 1 and 2 follow from the Lindeberg condition. One way to verify the Lindeberg condition is to show $\sum_{i=1}^{p} E|y_i - \mu_i|^v = o(B_p^v)$ for some $v > 2$ as p tends to infinity.

3.2 Edgeworth Approximation

One may consider the normal approximation of as the first term of a series. One can often improve the normal approximation by considering higher order terms in the expansion of the characteristic function in the i.d.d. case. HeuristicallyΓmost series expansions seek to represent the distribution function of the variable of interest in terms of its moments and the distribution function of a target distributionΓwhich is usually well-studied with known properties. When the target distribution is normal such an expansion uses the Hermite polynomials and is due to Edgeworth (1904).

Hall (1992) gives the following Edgeworth expansion for the average of p i.i.d. random variables $\{y_i\}$ with mean μ and variance σ^2

$$P\left(\frac{\sqrt{p}(\bar{Y} - \mu)}{\sigma} \leq w \right) = \Phi(w) + \phi(w) \left[\frac{-1}{6\sqrt{p}} \kappa (w^2 - 1) + O(p^{-1}) \right] \qquad (2)$$

where Φ and ϕ are the distribution and density function of a standard normalΓ respectivelyΓand κ is the skewnessΓ$E(Y-\mu)^3$. As noted (Goutis and CasellaΓ 1999)Γthe first term of the above formulation is the normal approximationΓ which is accurate to $O(p^{-1/2})$. When $\kappa = 0$ the accuracy improves to $O(p^{-1})$.

Let $y_1, y_2, \ldots, y_p$ be independent random variables with density f_{y_i}Γmean μ_iΓ and variance σ_i^2. The moment generating function of y_i is $M_{y_i}(t) = E(\exp(ty_i))$ and its cumulative generating function is $K_{y_i}(t) = \ln(M_{y_i}(t))$. Most distributions considered in analysis of risk are members of the natural exponential family. If f_{y_i} is a member of the familyΓthen from Stuart and Ord (1994) we have $f(y_i) = \exp(\theta y_i - w_i(\theta) + a_i(y_i))$ where the exact form of w_i and a_i depend on f_{y_i}. One can show by differentiating the normalizing condition $\int f_i(y_i)dy_i = 1$ that $M_{y_i}(t) = \exp(w_i(\theta_i + t) - w_i(\theta_i))$ and $K_{y_i} = w_i(\theta_i + t) - w_i(\theta_i)$.

One can obtain the moments of a distribution from the knowledge of its moment generating function as they are the coefficients of $t^r/r!$ in the Taylor series expansion of the m.g.f. SimilarlyΓwe denote the rth cumulant of y_i by $\kappa_{r,i}$ which is formally obtained as the rth coefficient of $t^r/r!$ in the Taylor series expansion of the cumulant generating function of y_i. Note that $E(y_i^r) = \frac{d^r M_{y_i}(t)}{dt^r}|_{t=0}$. ThusΓafter a Taylor series approximation around $t = 0$ one has $K_{y_i}(t) \approx \kappa_{1,i}t + \frac{1}{2}\kappa_{2,i}t^2 + \frac{1}{3!}\kappa_{3,i}t^3$ and one can obtain a relationship between the moments and cumulants by noting that $K_{y_i}(t) = \ln((M_{y_i}(t)))$ and thus $\kappa_{1,i} = \frac{M'_{y_i}(t)}{M_{y_i}(t)}$ and $\kappa_{2,i}(t) = \frac{M''_{y_i}(t)M_{y_i}(t) - M'^2_{y_i}(t)}{M^2_{y_i}(t)}$ where prime denotes partial derivative with respect to t and the expressions are evaluated at $t = 0$. These relationships yield $\kappa_{1,i} = \mu_i = E(y_i)$ and $\kappa_{2,i} = E({y_i}^2) - E^2(y_i) = \sigma_i^2$. Continuing in the same fashion one can write down the relationship between the moments and the cumulants. Stuart and Ord (1994Γp. 88) present the first 10 moments and cumulants in terms of each other.

In order to obtain the Edgeworth expansion of $R = \prod_{i=1}^p x_i$ let $\rho_{r,i} = \kappa_{r,i}/\sigma_i^r$ denote the standardized cumulants of $\ln(x_i)$. We will use (1) to obtain an Edgeworth expansion to the distribution function of S_p. Let $\mu = E(S_p) = \sum_{i=1}^p \mu_i$ and $\sigma^2 = Var(S_p) = \sum_{i=1}^p \sigma_i^2$. One develop the approximation in terms of the standardized variable $S_p^* = (S_p - \mu)/\sigma$. Since $M_{S_p^*}(t) = \exp(-t\mu/\sigma)\prod_{i=1}^p M_{y_i}(t/\sigma)$. the c.g.f of S_p^* is $K_{S_p^*}(t) = \ln[M_{S_p^*}(t)] = -t\mu/\sigma + \sum_{i=1}^p K_{y_i}(t/\sigma)$.

Note that $K_{y_i}(t) \approx \mu_i t + \frac{1}{2}\sigma_i^2 t^2 + \frac{1}{6}\rho_{3,i}\sigma_i^3 t^3 + \frac{1}{24}\rho_{4,i}\sigma_i^4 t^4$. Let $C_r = \sum_{i=1}^p \kappa_{r,i}/\sigma^r$. One can show $K_{S_p^*}(t) \approx \frac{1}{2}t^2 + \frac{1}{6}C_3 t^3 + \frac{1}{24}C_4 t^4$. It follows from $M_{S_p^*}(t) =$

$\exp[K_{S_p^*}(t)]$ that $M_{S_p^*}(t) \approx \exp(\frac{1}{2}t^2)\Big(1 + \frac{1}{6}C_3t^3 + \frac{1}{24}C_4t^4 + \frac{1}{72}C_3^2t^6\Big)$. To obtain the distribution function of S_p^* we need to invert $M_{S_p^*}(t)$. One can use the identity $\int \exp(tx)\phi(x)H_r(x)dx = t^r \exp\Big(\frac{1}{2}t^2\Big)$ in the formal expansion of the m.g.f. of S_p^*. HereΓ $\phi(x) = \frac{1}{\sqrt{2\pi}}\exp(-x^2/2)$ and $H_r(x)$ is the Hermite polynomial of degree r as defined by $(\frac{d}{dx})^r\phi(x) = (-1)^r H_r(x)\phi(x)$. The first few Hermite polynomials are $H_0(x) = 1$, $H_1(x) = x$, $H_2(x) = x^2 - 1$, $H_3(x) = x^3 - 3x$, $H_4(x) = x^4 - 6x^2 + 3$, and $H_5(x) = x^5 - 10x^3 + 15x$.

The formal inversion of $M_{S_p^*}(t)$ obtains

$$f_{S_p^*}(s_p^*) \approx \phi(s_p^*)\Big[1 + \frac{1}{6}C_3H_3(s_p^*) + \frac{1}{24}C_4H_4(s_p^*) + \frac{1}{72}C_3^2H_6(s_p^*)\Big] \qquad (3)$$

and by integration

$$F_{S_p^*}(s_p^*) \approx \Phi(s_p^*) - \phi(s_p^*)\Big[\frac{1}{6}C_3H_2(s_p^*) + \frac{1}{24}C_4H_3(s_p^*) + \frac{1}{72}C_3^2H_5(s_p^*)\Big]. \qquad (4)$$

Note that $F_{S_p}(s_p) = F_{S_p^*}(s_p^*)$. The formal Edgeworth expansion requires that $\lambda_j = \kappa_{r,S_p}/\kappa_{2,S_p}^{3/2}$ for $j = 2, 3$ are bounded as $p \to \infty$.

3.3 Saddlepoint Approximation

One can improve the normal approximation to the distribution of the mean of a random sample by using the one-term or two-term Edgeworth expansion to correct for non-normality of the parent distribution. Consider (2) and Change the variable to $y = \sigma w + \mu$. Differentiation yields

$$f_{\bar{y}}(y) = \frac{\sqrt{p}}{\sigma}\phi\Big(\frac{y-\mu}{\sigma/\sqrt{p}}\Big)\Big\{1 + \frac{\kappa}{6\sqrt{p}}\Big[\Big(\frac{y-\mu}{\sigma/\sqrt{p}}\Big)^3 - 3\Big(\frac{y-\mu}{\sigma/\sqrt{p}}\Big)\Big] + O(p^{-1})\Big\}. \qquad (5)$$

ClearlyΓ the normal approximation has error $O(p^{-1})$ when $\kappa = 0$. It also yields an order of accuracy of $O(p^{-1})$ for values of y near the mean as the term in bracket will be close to zero. ThusΓ one would expect better approximations near the center. This observation leads to the method of tilted Edgeworth expansion or saddlepoint approximation where a more accurate estimate for the distribution of a sum is obtained.

In order to obtain the saddlepoint approximation to the distribution of S_p we assume that S_p is a member of the natural exponential family with density f_{S_p}Γ mean μ_{s_p} and variance $\sigma_{s_p}^2$. There have been two distinct approaches in describing the method of saddlepoint approximation for the mean of a random sample. Daniel (1954) describes an accurate approximation of the density of the mean of a sample through the direct inversion of the Fourier transform. We will sketch this approach in the i.i.d. case. The extension to the case where y_i's are not identically distributed will follow immediately by considering the Edgeworth expansion for this case.

Let $y_1, y_2, \ldots, y_p$ be independent random variables with density $f_y(y)$Γ mean μΓ variance σ^2Γ moment generating function $M_y(t)$ and cumulative generating function $K_y(t) = \ln(M_y(t))$. Using the inversion theorem (FellerΓ 1971) and noting that $M_y(it)$ is the characteristic function of yΓwe have

$$f_y(y) = \frac{1}{2\pi}\int_{-\infty}^{\infty} M_y(it)\exp(-ity)dt = \frac{1}{2\pi}\int_{-\infty}^{\infty} \exp(K_y(it) - ity)dt.$$

One can write

$$f_y(y) = \frac{1}{2\pi i}\int_{\tau-\infty}^{\tau+\infty} \exp(K_y(t) - ty)dt$$

for τ around zero. Theory of complex variables enables us to deform the contour of integration without affecting the value of this integral. The closed curve theorem states that the above integral is the same over all paths that are parallel to the imaginary axis. ThereforeΓwe can do the integration over any τ. We choose $\tau = \hat{t}(y)$ such that $K_y'(t) = y$ and expand $K_y(t) - ty$ around $\hat{t}(y)$ to yield

$$K_y(t) - ty \approx K_y(\hat{t}(y)) - \hat{t}(y)y + \frac{1}{2}(t - \hat{t}(y))^2 K_y''(\hat{t}(y)).$$

NowΓif we substitute $K_y(t) - ty$ in the expression for $f_y(y)$ and integrate with respect to t along the line parallel to the imaginary axis through the point $\hat{t}(y)$Γwe obtain

$$f_y(y) \approx (\frac{1}{2\pi K''(\hat{t}(y))})^{1/2}\exp(K_y(\hat{t}(y)) - \hat{t}(y)y). \qquad (6)$$

The point $\hat{t}(y)$ is neither the maximum nor the minimum of $K_y(t) - ty$ in the complex plane. The function is constant in the imaginary direction and has a minimum in the real axis (Field and RonchettiΓ1990). The point $\hat{t}(y)$ is called the saddlepoint. The genesis of the saddlepoint technique is in the theory of the method of steepest descents of complex function theory.

The basic objective is to choose a contour of integration (a directed curve) whose tangent is always in the direction of maximal descent. Since the path of integration goes through the saddlepoint and the function is decaying with maximal rate as we move away from this point we get very accurate results to the integral. In other words the saddlepoint contributes the most to this integral and the surrounding points have little and diminishing influence.

Suppose $y_1, \ldots, y_p$ are i.i.d. with m.g.f. $M_y(t)$. The m.g.f. of the average $\bar{y}$ is $M_{\bar{y}}(t) = (M_y(t/p))^p$ and its c.g.f. is $K_{\bar{y}}(t) = pK_y(t/p)$. ThusΓusing (6)Γ we obtain

$$f_{\bar{y}}(\bar{y}) \approx (\frac{p}{2\pi K''(\hat{t}(\bar{y}))})^{1/2} \exp(p(K_y(\hat{t}(\bar{y})) - \hat{t}(\bar{y})\bar{y})). \tag{7}$$

Daniels (1954) used the direct inversion of the Fourier transform to study conditions under which the saddlepoint equation $K'_y(t) = y$ has a unique root. He showed that if $M_y(t)$ converges for $t \in I$ where $I = (a, b)$ is an interval containing the originΓthen $K'_y(t) = y$ has a unique solution $\hat{t}(y) \in I$ for each $y \in (y^*, y^{**})$ provided that $\lim_{t \to a} K'_y(t) = y^*$ and $\lim_{t \to b} K'_y(t) = y^{**}$ where $y^* = sup\{z|F(z)\} = 0$ and $y^{**} = inf\{z|F(z) = 1\}$.

There is also a more statistical treatment of the conceptsΓwhich avoids complex function theory. Let $M_y(t)$ be the moment generation function of y. For each value of t we will define a new density

$$f_y(y;t) = f_y(y)\exp(ty)/M_y(t) = f_y(y)\exp(ty - K_y(t)).$$

This is called the tilted version of f_y and the operation of forming the new density is called exponential tilting. Note that the m.g.f. is the required divisor to normalize the function $\exp(ty)f_y(y)$. We seek an expansion of the conjugate density. We can rearrange $f_y(y;t)$ to obtain

$$f_y(y) = f_y(y;t)\exp(-(ty - K_y(t))).$$

Given a value of yΓwe will choose t such that we get an accurate approximation to $f_y(y;t)$. We will use this approximation to obtain a good approximation for $f_y(y)$. As noted earlierΓthe Edgeworth expansion was very accurate near the center of the distribution and became less accurate as we moved away from the center. In fact this approximation was $O(p^{-1})$ at the center. ThereforeΓwe can expect accurate approximation to $f_y(y)$ when y is near the center. If y is away from the center we can choose t such that y

is near the mean of $f_y(y;t)$. The saddlepoint approximationΓfor each value of yΓchooses t such that y is the mean of $f_y(y;t)$. One can showΓBarndorff-Nielsen and Cox (1989)Γthat $K_y'(t) = y = E(y)$ and $var(y) = K_y''(t)$. To approximate $f_y(y)$ we choose $t = \hat{t}(y)$ which solves the saddlepoint equation $K_y'(t) = y$.

To obtain the distribution function of $\bar{y}$Γone proceeds as follow. For each value of $\bar{y}$Γone solves the saddlepoint equation and finds $\hat{t}(\bar{y})$. Since $y_1, \ldots, y_p$ are i.i.d. one obtains $K_{\bar{y}}(t) = pK_y(t/p)$ and $K_{\bar{y}}''(t)$. These are used in (7) to obtain $f_{\bar{y}}(\bar{y})$

One can integrate f_y to obtain an approximation to F_y. Lugannani and Rice (1980) provide a direct expansion of the integral as a series. Lugannani and Rice's formula uses the first term of the series $F_y(y) \approx \Phi(r) + \phi(r)[\frac{1}{r} - \frac{1}{q} + O(p^{-1})]$ where $r = sign[\hat{t}(y)][2(\hat{t}(y)y - K_y[\hat{t}(y)])]^{1/2}$ and $q = \hat{t}(y)(K_y''[\hat{t}(y)])^{1/2}$. Note that a more accurate approximation of $O(p^{-3/2})$ for the distribution at the origin exist (JensenΓ1995). If $y = E(Y)$Γthen $F_Y(y) \approx \frac{1}{2} - \frac{1}{6}(2\pi p)^{-1/2}K_y^{(3)}(0)/[K_y''(0)]^{3/2}$. The order of approximation holds uniformly in y. Since the c.g.f of the sum p independent random variables is the sum of the individual c.g.f.'s; that isΓ$K_{S_p}(t) = \sum_{i=1}^{p} K_{y_i}(t)$ one can obtain a saddlepoint approximation for the distribution function of the sum of p independent but not identically distributed random variables. Solving $K_{S_p}'(t) = s_p$ for $t = \hat{t}(s_p)$ one obtains

$$F_{S_p}(s_p) \approx \Phi(r) + \phi(r)\left[\frac{1}{r} - \frac{1}{q}\right] \tag{8}$$

where $r = sign[\hat{t}(s_p)][2(\hat{t}(s_p)s_p - K_{S_p}[\hat{t}(s_p)])]^{1/2}$ and $q = \hat{t}(s_p)(K_{S_p}''[\hat{t}(s_p)])^{1/2}$. If $s_p = E(S_p)$Γthen

$$F_{S_p}(s_p) \approx \frac{1}{2} - \frac{1}{6}(2\pi)^{-1/2}K_{S_p}^{(3)}(0)/[K_{S_p}''(0)]^{3/2}.$$

.

4. Examples

Gamma distribution has been used in life testingΓreliability theory and the theory of stochastic processes. This model allows us to consider the distribution of a variety of environmental factors that may enter the equation for risk. For exampleΓconsider the distribution of $S_p = \sum_{i=1}^{p} y_i$ where y_i

is $\Gamma(\alpha_i, \beta_i)$. Sim(1992) models processes with correlated gamma interarrival times and obtains the exact distribution of S_p as an infinite sum. The gamma distribution is a standard distribution in modeling and Johnson et al. (1994) cite a number of interesting application areas. For exampleΓ Dennis and Patil (1984) use the gamma distribution to model population abundance in statistical Ecology. Gamma distribution is a serious competing model any time log-normal or Weibull distributions are considered.

The log-gamma distribution has also been used to model a variety of physical phenomenon. It is a member of the generalized gamma distributions. SeeΓJohnson et al. (1994) section 8.7 for many properties and applications of this distribution. For exampleΓLawless (1980) uses the log-gamma distribution to model life-time data. Figure 1 shows 4 members of gamma-family for $\alpha = (0.5, 1, 1.5, 2.0)$ and $\beta = 1$. Figure 2 depicts the corresponding distribution of the log-gamma family.

Beta variables arise naturally as the distribution of an ordered variable from a uniform distribution. The beta family is multi-faceted and finds application in many fields. For interesting applications in risk analysis see Morgan and Henrion (1990). This distribution is often used to model proportions of contaminants in a medium; e.g. water since it is bounded by the same range as the distribution of concentrations. Ott (1995) discusses the modeling of dilution of pollutants in the environment using beta random variables and Johnson et al. (1994) discuss many of its properties and applications. They also discuss the use of log-beta in place of log-normal when modeling positively or negatively skewed data. Figure 3 shows 9 members of beta-family for $\vec{\alpha} = \vec{\beta} = (1/2, 1, 3)$. Figure 4 depicts the distribution of the log-beta family.

We will consider an Edgeworth and saddlepoint approximation for S_p when y_i's are $\Gamma(\alpha_i, \beta_i)$ in the following examples. Let $\kappa_{r,S_p} = \sum_{i=1}^{p} \kappa_{r,y_i}$ and note that the formal Edgeworth Expansion of S_p is obtained provided that standardized third and fourth cumulants of S_p are bounded as p tends to infinity. That isΓif $\lambda_3 = \kappa_{3,S_p}/\kappa_{2,S_p}^{3/2} = \sum_{i=1}^{p} \kappa_{3,y_i}/(\sum_{i=1}^{p} \sigma_i^2)^{3/2}$ and $\lambda_4 = \sum_{i=1}^{p} \kappa_{4,y_i}/(\sum_{i=1}^{p} \sigma_i^2)^2$ are bounded for large p.

For exampleΓconsider the case where y_i is distributed as $\Gamma(\alpha, \beta_i)$ for $i = 1, \ldots, p$. For the risk function $R = \prod_{i=1}^{p} x_i^{a_i}$Γwe assume $x_i = \exp(y_i/a_i)$ so that x_i has a log-gamma distribution. NowΓ $S_p = \sum_{i=1}^{p} y_i$ where y_i's have different scale parameters β_i but the same overall shape parameter α.

Note that $\kappa_{r,i} = (r-1)!\alpha\beta_i^r$ so that $\sigma_i^2 = \kappa_{2,i} = \alpha\beta_i^2$. One can show that $\lambda_3 = 2\sum_{i=1}^p \beta_i^3/\sqrt{\alpha}(\sum_{i=1}^p \beta_i^2)^{3/2}$. Assuming that S_p is the sum p valuesΓeach of which has a $\Gamma(\alpha, i)$ distribution; that isΓwhen $\beta_i = i$Γbasic relations on $\sum_{i=1}^p i^k$ show that λ_3 is of order $O(p^{-1/2})$. One can show the same asymptotic order when β_i is a fixed constant. To show λ_4 tends to zero as p tends to infinityΓnote that $\lambda_4 = 6\sum_{i=1}^p \beta_i^4/\alpha^{3/2}\sum_{i=1}^p \beta_i^2$. This ratio can be shown to be of $O(p^{-1/2})$ when $\beta_i = i$ or when β_i is any fixed constant.

As another exampleΓconsider the case where y_i's have gamma distributions with possibly different shape parameters α_i and the same scaleΓ β. In this case $\kappa_{r,y_i} = (r-1)!\alpha_i\beta^r$. ThereforeΓ $\lambda_3 = 2/\sum_{i=1}^p \alpha_i$ and $\lambda_4 = 6\sum_{i=1}^p \alpha_i/\beta^2(\sum_{i=1}^p \alpha_i)^2$. These are also of $O(p^{-1/2})$ when $\alpha_i = i$ or α_i is a fixed constant.

Example 1: This example considers approximating the distribution of the risk function $R = X$ where X has a log-gamma distribution with parameters α and β. From (1) we have $S_1 = \ln(R) = \ln(X) = Y$ has a gamma distribution. Let $\theta = E(Y) = \alpha\beta$ and $\sigma^2 = Var(Y) = \alpha\beta^2$. The normal approximation to the distribution function of Y is $\Phi(y^*)$ and its density is $\phi(y^*)$ where $y^* = (y-\theta)/\sigma$. The one and two-term Edgeworth approximations are obtained from

$$F_{Y^*}(y^*) \approx \Phi(y^*) - \phi(y^*)\left[\frac{1}{6}\kappa_{3,1}H_2(y^*) + \frac{1}{24}\kappa_{4,1}H_3(y^*) + \frac{1}{72}\kappa_{3,1}^2 H_5(y^*)\right]$$

where $\kappa_{r,1} = \alpha\Gamma(r)\beta^r$. The saddlepoint solution is obtained by solving the equation $K_y'(t) = \frac{\alpha\beta}{1-\beta t} = y$ for $t < 1/\beta$. The saddlepoint solution is $\hat{t}(y) = 1/\beta - \alpha/y$. ThusΓwe obtain $F_Y(y) \approx \Phi(r) + \phi(r)[\frac{1}{r} - \frac{1}{q}]$ as an approximation to the c.d.f. of Y where $r = sign(1/\beta - \alpha/y)[2(y/\beta - \alpha + \alpha\ln(\frac{\alpha\beta}{y}))]^{1/2}$ and $q = (y/\beta - \alpha)/\sqrt{\alpha}$.

Figures 1a-1c show how well the approximations perform for three distinct distributional shapesΓ$\alpha = 0.5, 1.0$ and 1.5Γrespectively. Since β is a scaling factor it does not affect the relative comparisons and is set to one. Since $p = 1$ is smallΓthe supports of the exact and approximating distributions are not the same and we observe poor performance in the lower tail. Figure 1a indicates that the normal and Edgeworth expansions should not be used in this case. All approximations converge to the exact values as α becomes larger. This effect is observed by comparing Figures 1a to 1c. Note that the saddlepoint approximation is indistinguishable from the exact result in these cases.

Example 2: We assume $R = \prod_{i=1}^{p} x_i$ where $\ln(x_i)$ is distributed as $\Gamma(\alpha_i, \beta_i)$. We are interested in obtaining approximations for the distribution function of $S_p = \ln(R) = \sum_{i=1}^{p} \ln(x_i) = \sum_{i=1}^{p} y_i$. In this caseΓ $\{y_i, i = 1, \ldots, p\}$ represent p independent but not identically distributed random variables. The moment generating function $\prod_{i=1}^{p}(1 - \beta_i t)^{-\alpha_i}$ can be inverted to obtain the distribution of S_p as an infinite series (Moschopoulos (1985)). Let $\theta = E(S_p) = \sum_{i=1}^{p} \alpha_i \beta_i$ and $\sigma^2 = Var(S_p) = \sum_{i=1}^{p} \alpha_i \beta_i^2$. The normal approximation to the distribution function of S_p is $\Phi(s_p^*)$ and its density is $\phi(s_p^*)$ where $s_p^* = (s_p - \theta)/\sigma$. One can apply (4) and (5) to obtain expressions for the one and two-term Edgeworth approximations as

$$F_{S_p^*}(s_p^*) \approx \Phi(s_p^*) - \phi(s_p^*)\left[\frac{1}{6}C_3 H_2(s_p^*) + \frac{1}{24}C_4 H_3(s_p^*) + \frac{1}{72}C_3^2 H_5(s_p^*)\right]$$

where $\kappa_{r,i} = (r-1)!\alpha_i \beta_i^r$.

When the variables have the same scale; i.e. $\beta_i = \beta$ one obtains $\hat{t}(s_p) = 1/\beta - \sum_{i=1}^{p} \alpha_i / s_p$. In this case the exact distribution of S_P is $\Gamma(\sum_{i=1}^{p} \alpha_i, \beta)$. More generallyΓ the saddlepoint solution $\hat{t}(s_p)$ is obtained by noting that $K_{S_p}(t) = -\sum_{i=1}^{p} \alpha_i \ln(1 - \beta_i t)$ and solving the saddlepoint equation $K'_{S_p}(t) = \sum_{i=1}^{p} \alpha_i \frac{\beta_i}{1-\beta_i t} = s_p$ for $t < min(1/\beta_i)$.

The solution is the unique root of the polynomial $h(t) = \sum_{i=1}^{p} \alpha_i \frac{\beta_i}{1-\beta_i t} - s_p$. For exampleΓwhen $p = 2$ the saddlepoint solution is obtained as the smaller root of the quadratic equation

$$\beta_1 \beta_2 w_2 t^2 + ((\alpha_1 + \alpha_2)\beta_1 \beta_2 - (\beta_1 + \beta_2) w_2) t + (w_2 - (\alpha_1 \beta_1 + \alpha_2 \beta_2)) = 0.$$

After finding the saddlepoint as the root of $h(t)$ we can obtain an approximation to the c.d.f. of S_p. We have $F_{S_p}(s_p) \approx \Phi(r) + \phi(r)[\frac{1}{r} - \frac{1}{q}]$ where r and q are obtained from (8) and $K''_{S_p}(\hat{t}(s_p)) = \sum_{i=1}^{p} \frac{\alpha_i \beta_i^2}{1-\beta_i \hat{t}(s_p)}$. Figures 2b-2c show how well the approximations perform for three distinct distributional shapes. Figure 2a is identical Figure 1a and not shown. This figure considers the case where $(\alpha_1, \beta_1) = (0.2, 1)$ and $(\alpha_2, \beta_2) = (0.3, 1)$. Note that in this case $\beta_i = \beta$ and we can compare against the exact distributionΓwhich is $\Gamma(0.5, 1)$. Figure 2b considers the case $(\alpha_1, \beta_1) = (0.5, 10)$ and $(\alpha_2, \beta_2) = (1, 0.5)$. The approximations are compared against results from simulation. Each simulation is based on a million replications. The distribution function is evaluated at 100 points along the horizontal axisΓmaking the entire process very computer intensive.

figure 2b considers the case $(\alpha_1, \beta_1) = (1, 1)$ and $(\alpha_2, \beta_2) = (3, 3)$. Figure 2c indicates that the normal and Edgeworth expansions should not be used in this caseΓespecially to approximate the lower tail probabilities and quantiles. Note that the saddlepoint approximation is indistinguishable from the exact result in these cases.

Example 3: Consider the case where $R = \prod_{i=1}^{p} x_i$ where $\log(x_i)$ is distributed as beta(α_i, β_i). One can show that the m.g.f. of $y_i = -\ln(x_i)$ is

$$M_{y_i}(t) = E(\exp(-t\ln(x_i))) = E(x_i^{-t}) = \beta(\alpha_i - t, \beta_i)/\beta(\alpha_i, \beta_i)$$

for $t < \alpha_i$ where $\beta(\alpha_i, \beta_i) = \frac{\Gamma(\alpha_i)\Gamma(\beta_i)}{\Gamma(\alpha_i+\beta_i)}$. The corresponding c.g.f. is

$$K_{y_i}(t) = \ln(\frac{\Gamma(\alpha_i + \beta_i)}{\Gamma(\alpha_i)}) - \ln(\frac{\Gamma(\alpha_i + \beta_i - t)}{\Gamma(\alpha_i - t)}). \tag{9}$$

The rth cumulant of y_i is $\kappa_{r,i} = (r-1)! \sum_{j=0}^{\beta_i - 1} (\alpha_i + j)^{-r}$ if β_i is an integer. In generalΓ

$$\kappa_{r,i} = (-1)^r (\psi^{r-1}(\alpha_i) - \psi^{r-1}(\alpha_i + \beta_i))$$

where $\psi^{r-1}(w) = (d^r/dx^r)\ln(w)$ is the $(r+1)$-gamma function (Johnson et al. (1994)). We will find normalΓEdgeworthΓand Saddlepoint approximations for the distribution of $W_p = -S_p = -\ln(R) = \sum_{i=1}^{p} -\ln(x_i) = \sum_{i=1}^{p} y_i$. Note that $K_{W_p}(t) = \sum_{i=1}^{p} \ln(M_{y_i}(t)) = \sum_{i=1}^{p} K_{y_i}(t)$. Let $\theta = E(W_p) = \sum_{i=1}^{p} \sum_{j=0}^{\beta_i - 1} (\alpha_i + j)^{-1}$ and $\sigma^2 = Var(W_p) = \sum_{i=1}^{p} \sum_{j=0}^{\beta_i - 1} (\alpha_i + j)^{-2}$ when β_i is an integer. The normal approximation is given by $\Phi(s_p^*)$ where $s_p^* = (w_p - \theta)/\sigma$. The Edgeworth and saddlepoint approximations are obtained from (3) and (8).

Consider the case where $\beta = 1$ for all values of α. One can verify that $f_i(x_i) = \alpha_i x_i^{\alpha_i - 1}$ for $0 < x_i < 1$Γso that Y_i is distributed as $\Gamma(1, 1/\alpha_i)$ and $K_{y_i}(t) = \ln \frac{\alpha_i}{\alpha_i - t}$ for $t < min(\alpha_i)$. The saddlepoint solution is the unique root of the polynomial $h(t) = \sum_{i=1}^{p} \frac{1}{\alpha_i - t} - w_p$. For exampleΓwhen $p = 2$Γit is the smaller root of $w_2 t^2 - (w_2(\alpha_1 + \alpha_2) - 2)t + w_2\alpha_1\alpha_2 - (\alpha_1 + \alpha_2) = 0$. The exact distribution of W_p is $\Gamma(p, 1/\alpha)$ when we add p i.i.d. y_i's $((\alpha_i, \beta_i) = (\alpha, 1))$. Note how αΓthe shape parameter of the beta distributionΓbecomes the scale parameter of the gamma distribution after the log transformation. Figure 3a considers the case where $(\alpha_1, \beta_1) = (0.5, 1)$ and $(\alpha_2, \beta_2) = (0.5, 1)$ and compares the approximations to $\Gamma(2, 2)$. In this case W_2 is the sum of two log-uniform (exponential) variables and the saddlepoint solution is $\hat{t}(w_2) =$

$\alpha - p/w_2$. The exact distribution function of $W_2 = -\ln x_1 - \ln x_2$ for $\alpha_1 \neq \alpha_2$ is

$$F(W_2) = 1 + \frac{\alpha_1\alpha_2}{\alpha_1 - \alpha_2}\left(\frac{1}{\alpha_1}\exp(-\alpha_1 w_2) - \frac{1}{\alpha_2}\exp(-\alpha_2 w_2)\right). \qquad (10)$$

Figure 3b considers the case where $(\alpha_1, \beta_1) = (1, 1)$ and $(\alpha_2, \beta_2) = (2, 1)$. In this case W_2 is the sum of a log-uniform and a log-triangular distribution. One finds from (10) the exact distribution of this sum for $w_2 > 0$ as

$$F(w_2) = 1 - 2exp(-w_2) + exp(-2w_2).$$

The saddlepoint solution is $\hat{t}(w_2) = (3w_2 - 2 - \sqrt{w_2^2 + 4})/2w_2$

Next, consider the case where $\beta_i = 2$. Note that

$$K_{y_i}(t) = \ln\left[\frac{\alpha_i(\alpha_i + 1)}{(\alpha_i - t)(\alpha_i + 1 - t)}\right].$$

for $t < min(\alpha_i)$. The saddlepoint is the unique root of the polynomial $K'_{W_p}(t) = \sum_{i=1}^{p}(\frac{1}{\alpha_i + 1 - t} + \frac{1}{\alpha_i - t}) = w_p$ for $t < min(\alpha_i)$. When $p = 2$ the saddlepoint is the smallest real root of $a_4t^4 + a_3t^3 + a_2t^2 + a_1t + a_0$ where a_i's are coefficients in terms of w_2 and α_i's. For example, one can show that if $\beta = 2$ and $\alpha_1 = \alpha_2 = \alpha$, then the saddlepoint is $\hat{t}(w_2) = (-4 + (2\alpha + 1)w_2 - \sqrt{16 + w_2^2})/2t$. Consider the case where $(\alpha_1, \beta_1) = (\alpha_2, \beta_2) = (2, 2)$. Distribution of $beta(2, 2)$ looks normal-like (see figures 4 and 5).

Figure 3c shows the simultaneous distribution function plots for the sum of two such log-normal like random variables. Figure 3d compares the exact and approximate distribution functions when the case x_i has a beta distribution with parameters $(\alpha_1 = 1, \beta_1 = 2)$ and $(\alpha_1 = 2, \beta_1 = 2)$. It is well known that the kth ordered value of a random sample of size p from a uniform distribution on $[0, 1]$ has a beta distribution with parameters $\alpha = k$ and $\beta = p - k + 1$. In this case x_1 represents the maximum of two uniforms and x_2 is the median of three uniforms. The exact distribution of S is the sum of the above maximum and median on the log scale. The exact distribution function of S for the sum of $beta(\alpha_1, 2)$ and $beta(\alpha_2, 2)$ is found to be

$$F(s) = \alpha_1\alpha_2(\alpha_1 + 1)(\alpha_2 + 1)(A + B + C + D)$$

where $A - D$ are defined as

$$A = \frac{1}{\alpha^2}(1 - \exp(-\alpha s)) - \frac{s}{\alpha}\exp(-\alpha s)$$

and

$$D = \frac{1}{(\alpha+1)^2}(1-\exp(-(\alpha+1)s)) - \frac{s}{(\alpha+1)}\exp(-(\alpha+1)s)$$

if $\alpha_1 = \alpha_2 = \alpha$ or

$$A = \frac{1}{\alpha_1-\alpha_2}[\frac{1}{\alpha_2}(1-\exp(-\alpha_2 s)) - \frac{1}{\alpha_1}(1-\exp(-\alpha_1 s))]$$

and

$$D = \frac{1}{\alpha_1-\alpha_2}[\frac{1}{\alpha_2+1}(1-\exp(-(\alpha_2+1)s) - \frac{1}{\alpha_1+1}(1-\exp(-(\alpha_1+1)s))]$$

if $\alpha_1 \neq \alpha_2$. FurthermoreΓ

$$B = \frac{s}{\alpha_1}\exp(-\alpha_1 s) - \frac{1}{\alpha_1^2}(1-exp(-\alpha_1 s))$$

and

$$C = \frac{1}{\alpha_1-\alpha_2+1}[\frac{1}{\alpha_1+1}(1-exp(-(\alpha_1+1)s)) - \frac{1}{\alpha_2}(1-exp(-\alpha_2 s))]$$

if $\alpha_1 - \alpha_2 = 1$ or

$$B = \frac{1}{\alpha_1-\alpha_2-1}[\frac{1}{\alpha_1}(1-(exp(-\alpha_1 s))) - \frac{1}{\alpha_2+1}(1-exp(-(\alpha_2+1)s))]$$

and

$$C = \frac{s}{\alpha_1+1}(\exp(-(\alpha_1+1)s)) - \frac{1}{(\alpha_1+1)^2)}(1-exp(-(\alpha_1+1)s))$$

if $\alpha_1 - \alpha_2 = -1$ or

$$B = \frac{1}{\alpha_1-\alpha_2-1}[\frac{1}{\alpha_1}(1-exp(-\alpha_1 s)) - \frac{1}{\alpha_2+1}(1-exp(-(\alpha_2+1)s))]$$

and

$$C = \frac{1}{\alpha_1-\alpha_2+1}[\frac{1}{\alpha_2}(1-(exp(-\alpha_2 s)) - \frac{1}{\alpha_1+1}(1-exp(-(\alpha_1+1)s))],$$

otherwise.

Example 4: This example considers the convolution of $y_1 = \ln x_1$ and $y_2 = \ln x_2$ where x_1 has a normal distribution $N(\mu, \sigma^2)$ and x_2 has a gamma distribution $\Gamma(\alpha, \beta)$. One can show $K_{S_2}(t) = -\alpha \ln(1 - \beta t) + \mu t + \sigma^2 t^2/2$. The saddlepoint solution is obtained by solving the saddlepoint equation $K'_{S_2}(t) = \frac{\alpha\beta}{1-\beta t} + \mu + \sigma^2 t = s_2$ for $t < 1/\beta$. The saddlepoint solution $\hat{t}(s_2)$ is obtained as the smaller root of the quadratic equation $\beta\sigma^2 t^2 - (\sigma^2 - \beta\mu + \beta s_2)t - (\alpha\beta + \mu - s_2) = 0$. The mean and variance of S_2 are $\theta = \alpha\beta + \mu$ and $\delta^2 = \alpha\beta^2 + \sigma^2\Gamma$respectively. Its r-th cumulant $r > 2$ is $\Gamma(r)\alpha\beta^r$. The exact distribution of S_2 is based on a million simulated values. We take the percentage points of the simulated distribution as the percentile at which approximations are evaluated. The normal approximation of the distribution function of S_2 is $\Phi(s_2{}^*)$ where $s_2^* = (s_2 - \theta/)\delta$. The Edgeworth approximation is given by

$$F_{S_2^*}(s_2^*) \approx \Phi(s_2^*) - \phi(s_2^*)\Big[\frac{1}{6}C_3 H_2(s_2^*) + \frac{1}{24}C_4 H_3(s_2^*) + \frac{1}{72}C_3^2 H_5(s_2^*)\Big].$$

For the saddlepoint approximation to the c.d.f. of $s_2\Gamma$we use $F_{s_2}(s_2) \approx \Phi(r) + \phi(r)[\frac{1}{r} - \frac{1}{q}]$ where r and q are obtained from (8). Figure 4a compares the distributions when $(\alpha, \beta) = (1, 1)$ and $(\mu, \sigma^2) = (1, 0.1)$. Figure 4b displays the result for $(\alpha, \beta) = (0.5, 10)$ and $(\mu, \sigma^2) = (0, 1)$.

Example 5: This example considers approximations to the distribution of the risk function $R = x_1\ x_2 x_3^{-1}$ where $\ln(x_1)$ has a normal distribution $N(\mu, \sigma^2)\Gamma \ln(x_2)$ has a gamma distribution $\Gamma(\alpha, \beta)$ and $\ln(x_3)$ has a beta distribution $beta(\alpha^*, \beta^*)$. Let $S_3 = \ln(x_1) + \ln(x_2) - \ln(x_3) = \sum_{i=1^3} y_i$. One can show $K_{S_3}(t) = -\alpha \ln(1 - \beta t) + \mu t + \sigma^2 t^2/2 + K_{y_3}(t)$ where

$$K_{y_3} = \ln(\frac{\Gamma(\alpha^* + \beta^*)}{\Gamma(\alpha^*)}) - \ln(\frac{\Gamma(\alpha^* + \beta^* - t)}{\Gamma(\alpha^* - t)}).$$

Let $\beta^* = 1$. The saddlepoint solution is obtained by solving the saddlepoint equation $K'_{S_3}(t) = \frac{\alpha\beta}{1-\beta t} + \mu + \sigma^2 t + \frac{1}{\alpha^* - 1} = s_3$ for $t < min(1/beta, \alpha^*)$. The saddlepoint solution $\hat{t}(s_3)$ is obtained as the smaller real root of the cubic equation $a_3 t^3 + a_2 t^2 + a_1 t + a_0$ where $a_3 = \beta\sigma^2\Gamma a_2 = \mu\beta - \beta\alpha^*\sigma^2 - \sigma^2 - s_3\beta\Gamma$ $a_1 = \alpha^*\sigma^2 - \alpha\beta - \beta\alpha^*\mu - \mu - \beta + s_3\beta\alpha^* + s_3$ and $a_0 = \alpha\alpha^*\beta + \mu\alpha^* + 1 - s_3\alpha^*\Gamma$

The mean and variance of S_3 are obtained from the sum of the first two cumulants of y_i. The exact distribution of S_3 is based on a million simulated values. We take the percentage points of the simulated distribution as the percentile at which approximations are evaluated. Figure 5a compares the distributions when $(\mu, \sigma^2, \alpha, \beta, \alpha^*) = (1, 1, 0.5, 10, 1)$. Figures 5b displays the result for $(\mu, \sigma^2, \alpha, \beta, \alpha^*) = (1, 0.1, 0.5, 1, 0.1)$. In both cases normal and Edgeworth approximations give poor results in the lower and upper tails.

Example 6: This example considers the distribution of the risk function

$$R = \frac{x_3 x_5}{x_1 x_2 x_4}.$$

This function has the same form as ADDΓwhich was defined in the introduction. Let $S_p = -\ln(x_1) - \ln(x_2) + \ln(x_3) - \ln(x) + \ln(x_5) = \sum_{i=1}^{5} y_i$. HereΓ we assume that $y_1 = -\ln(x_1)$ has an exponential distribution with mean $\eta = 1\Gamma y2 = -\ln(x_2) \sim \beta(\alpha_2, \beta_2)\Gamma$and $y_3 = \ln(x_3) \sim \text{Normal}(\mu, \sigma^2)$. We also assume that $y4 = \ln(x_4)$ has a triangular distribution with minimum $a\Gamma$ mode b and maximum $c\Gamma$and that $y5 = \ln(x_5)\Gamma(\alpha_5, \beta_5)$. The rth cumulant of y_1 is $\kappa_{r,1} = (r-1)!\Gamma$and for y_2 is $\kappa_{r,2} = (r-1)! \sum_{j=0}^{\beta_2 - 1} (\alpha_2 + j)^{-r}$ if β_2 is an integer. We will fix the scale parameter β_2 of x_2 to one and consider a variety of shapes for x_2 through the shape parameter α_2. To simplify we will consider two special cases for x_4. Case I assumes $a = 0$ and $b = c = 1$; i.e. $y_4 \sim \beta(\alpha_4 = 2, \beta_4 = 1)$ with $\kappa_{r,4} = (r-1)!/2^r$ and case II assumes $a = b = 0$ and $c = 1$; $y_4 \sim \beta(\alpha_4 = 1, \beta_4 = 2)$ with $\kappa_{r,4} = (r-1)!(1 + 1/2^r)$. The first two cumulants of y_3 are μ and $\sigma^2\Gamma$respectively. Its remaining cumulants are zero. For x_5 we have $\kappa_{r,5} = (r-1)!\alpha_5 \beta_5^r$.

The c.g.f. of $y_1, \ldots y_5$ are $K_{y_1}(t) = -\ln(1-t)$ for $t < 1\Gamma\, K_{y_2}(t) = \log \alpha_2/(\alpha_2 - t)$ for $t < \alpha_2\Gamma\, K_{y_3}(t) = \mu t + \frac{1}{2}\sigma^2 t^2 \Gamma\, K_{y_{4I}}(t) = \log 2/(2-t)$ for $t < 2$ when $a = 0$ and $b = c = 1\Gamma\, K_{y_{4II}}(t) = \log 2/(1-t)(2-t)$ for $t < 1$ when $a = b = 0$ and $c = 1\Gamma$and $K_{y_5}(t) = -\alpha^* \log(1 - \beta^* t)$ for $t < 1\beta^*\Gamma$respectively. Since $\kappa_{r,S_p} = \sum_{i=1}^{5} \kappa_{r,y_i}$ the mean and variance of S_p are determined from $\mu_{S_p} = \kappa_{1,S_p}$ and $\sigma^2_{S_p} = \kappa_{2,S_p}\Gamma$respectively.

The exact distribution of S_p is based on a million simulated values. We take the percentage points of the simulated distribution as the percentile at which approximations are evaluated.

The normal approximation of the distribution function of S_p is $\Phi({s_p}^*)$ and its density is $\phi(s_p^*)$ where $s_p^* = (w - \mu_{S_p})/\sigma_{S_p}$. The Edgeworth approximation is given by

$$F_{S_p^*}(s_p^*) \approx \Phi(s_p^*) - \phi(s_p^*)\Big[\frac{1}{6}C_3 H_2(s_p^*) + \frac{1}{24}C_4 H_3(s_p^*) + \frac{1}{72}C_3^2 H_5(s_p^*)\Big]$$

where C'c are determined by the cumulants. The saddlepoint solution is obtained by solving the saddlepoint equation $K'_{S_p}(t) = s_p$ for $t < min(1, \alpha_2, 1/\beta^*)$. The saddlepoint solution $\hat{t}(s_p)$ is obtained as the smallest real root of a fourth-degree polynomial in each case. ThusΓwe obtain an approximation to the c.d.f. of S_p we use $F_{S_p}(s_p) \approx \Phi(r) + \phi(r)[\frac{1}{r} - \frac{1}{q}]$ where r and q are obtained from (8). The exact distribution of S_5 is based on a million simulated values. We take the percentage points of the simulated distribution as the percentile at which approximations are evaluated. Figure 6a compares the distribution of S_5 under case I where

$$(\eta = 1, \alpha_2 = .1, \beta_2 = 1, \mu = 0, \sigma^2 = 1, a = 0, b = 1, c = 1, \alpha^* = 1, \beta^* = 1)$$

Figure 6b compares the distribution of S_5 under case II where

$$(\eta = 1, \alpha_2 = .1, \beta_2 = 1, \mu = 0, \sigma^2 = 1, a = 0, b = 0, c = 1, \alpha^* = 1, \beta^* = 1)$$

5. Discussion

Often times one may want to obtain an initial or screening estimate of risk R or its distribution. HoweverΓmany times a more elaborate analysis of the distribution of R is required. The National Academy of Sciences (NRCΓ1994) and USEPA (1997) have stressed the need to distinguish between variability and uncertainty in the analysis of risk. A two-dimensional Monte Carlo strategy has been advocated (Hoffman and HammondsΓ1994; Burmaster and WilsonΓ1996) and mixture distributions have been used to justify this approach. Note that Nayak and Kundu (2001) argue that the analysis is only relevant if the results are interpreted in a Bayesian context.

The central idea is to generate a set of values for θ in the outer loop of the simulation. The inner loop produces B_1 realizations of $\vec{X}$ based on the observed value of θ. The process is repeated B_2 timesΓleading to B_2 empirical distributions for risk. For exampleΓconsider the case where we are interested in the effects of variability and uncertainty on the upper tail estimates. Frey and Burmaster (1999) consider four million simulations ($B_1 = B_2 = 2000$) in order to estimate the upper tail of the risk. A simultaneous plot of all such empirical functions displays the overall effects of variability (as measured by the generated values of θ) and uncertainty (as measured by the generated value of R). The process can be extremely time consuming. To speed up computations it is desired to remove the inner loop of this process. Given a value for θ one can replace the result of the inner loop by an asymptotic approximation.

The normal approximation is of $O(p^{-1/2})$ in the i.i.d. case. It provides an initial estimate of the distribution of R. Edgeworth expansion offers an improvement to the Central Limit Theorem. It uses higher order terms in the expansion of the characteristic function and provides correction terms to the normal approximation. In order to use this type of expansion one needs to assume that the moments of the distributions are known. The first correction term of the Edgeworth expansion involves an error of order p^{-1}. Barndorff-Nielsen and CoxΓ(1989) point out that this approximation is useful if the main aspect of non-normality with which we are concerned with is skewness. The Edgeworth expansion gives a good approximation in the center of the density but usually performs poorly in the tailsΓwhere it may lead to negative values. One would expect slow convergence at the tails where the term involving skewness in (5)is large.

It is noted that when the supports of the exact and approximating distributions are not the same there is poor performance in the lower tail of normal and Edgeworth approximations. Normal approximation underestimates the risk in the central region of the distribution within the interquartile range. Edgeworth approximations perform better than normal in the interquartile range. HoweverΓthey underestimate or overestimate R in the upper tail.

One can improve the approximation by eliminating the term involving skewness in (5). The saddlepoint or tilted Edgeworth approximation involves error terms that can decrease at a rate of $p^{-3/2}$ through renormalization of the approximations so that it integrates to one (KolassaΓ1994). Saddlepoint is a technique of asymptotic analysis and Daniels (1954) introduced the technique to Statistics in a seminal paper. The type of approximation is usually very accurate. In the case of approximating the distribution of the mean of a random sampleΓit offers a relative error which is uniformly bounded and is $O(p^{-3/2})$ (KolassaΓ1994). ThusΓit provides an accurate approximation even in the tail of the distribution. Saddlepoint approximations are generally more accurate than other approximations such as normalΓone-term or two-term Edgeworth expansion. MoreoverΓ Edgeworth expansion provides an absolute error. Since interest centers on accurate estimation of the upper or lower quantiles of the risk function we look for approximations with a small relative error. Saddlepoint approximation will always produce a positive approximation over the range of the sample mean. For exampleΓconsider

Figure 1a where we are interested in approximating the distribution function of $\Gamma(0.5, 1)$ The normal and Edgeworth approximations are very inaccurateΓ especially in the lower tail.

In most situations Monte Carlo simulation provides a good solution to the problem. In some cases as illustrated in the introductionΓone needs to proceed with caution and be willing to performs huge number of simulations. Saddlepoint approximation is re commended as a good surrogate in such instances. In most cases the application of this technique will also require a computer program to find the saddlepoint solution. HoweverΓsuch root finding routines are not computer intensive. The saddlepoint approximation performs as well as approximations based on the exact or Monte Carlo methods in all examples considered.

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Basic Information

Title:	Water Environment Studies in Schools Training Program (Teacher Education)
Project Number:	00-16
Start Date:	3/1/2000
End Date:	2/28/2001
Research Category:	Water Quality
Focus Category:	Education, None, None
Descriptors:	water science; environmental studies
Lead Institute:	D.C. Water Resource Research Center
Principal Investigators:	Jo Anne M. Favors

Publication

The Water Environment Studies In Schools (WESS) Teaching Training Institute is designed as a pilot project to engage teachers in ten-days of extensive training in water quality assessment and conservation. Teachers will implement the program in school during the academic year.

The WESS program is designed to respond to the need for 1) environmental education in the schools, 2) teachers proficient in the writing of curriculum around the newly designed performance standards, and 3) innovative practices to improve math and science teaching and learning of teachers and students as expressed by DCPS administrators and teachers. The WESS program focus is the Anacostia River Watershed in which the students and teachers are residents.

The WESS Teacher Training Institute provides teachers with:

1. A critical overview of the need for a citzenry knowledgeable of their environment and the causes and effects of their own actions. Specifically, using the Anacostia River as the model in this case.

2. Knowledge and skills in the scientific testing, measurement and assessment and remote sensing of rivers, particularly the Anacostia River.

3. Curriculum development skills that integrate the Anacostia River scientific, social/political, and cultural aspects with the school s performance standards.

4. Planning Methods and Strategies for implementing a Water Studies Program that:

- Utilizes the research outcomes of the Agricultural Experiment Station and WRRC, provides experiences, data gathering skills, and increased academic achievement for students;

- Provides resources and skills for independent searching for appropriate materials and equipment; and

- Uses the Metropolitan Area as a bank of people, places, and things that serve as viable elements of a hands-on curriculum.

5. The ability to design and implement a plan and process for restoring the River to promote its popularity to the general public as well as to the students.

In brief, the WESS Teacher Training Institute workshops include the following:

- The Importance of Water and Properties of Water
- Assessment and Calculations and Projections of Water Quality
- Remote Satellite Sensing
- Analysis and Demonstrations
- Computer Search
- Computer Analysis and Graphing
- Development of Interactive and Hands-on Activity Among Teacher Trainees

- Design and Scheduling of In-School Activities
-Field Trip(s)

The first Teacher Training Institute was a tremendous success. In sum, benefits gained can be summarized as follows:

- The teachers who attended were overwhelmed with the water science knowledge they received. The many activities they can engage their students in were more than they expected.

- The combination of trainers to include the Anacostia River Institute for Remote Sensing (AIRS) UDC professors and the DC Public School Junior High School science teacher and curriculum writer proved to be a winning combination. The teacher trainees have learned the science and measurement techniques of the assignment - The (Anacostia) River Environmental Studies - and how to translate that into Middle and Junior High School language.

- Information regarding sources of materials and supplies. Agencies, associations and the web have tremendous stores of materials that teachers can use in their schools. Most materials are free or very low in cost.

- The trainers provided information on grants available that can benefit the home schools.

The teachers are interested in continuing this work together. They want to see:

- Future meetings together to review what they are doing with the information they received in the Institute.

- More institutes to build on this first one. And, include more teachers and schools.

- The opportunity to bring their students out to the UDC labs for study.

Information Transfer Program

Basic Information

Title:	Information Transfer Technology
Start Date:	3/1/2000
End Date:	2/28/2001
Descriptors:	Information transfer
Lead Institute:	D.C. Water Resource Research Center
Principal Investigators:	Gloria Wyche-Moore

Publication

Information Transfer Activities

The transfer of technology and technical information is a function of the WRRC of equal importance to its function as an initiator and supporter of research. It is imperative that WRRC is responsive to community needs by providing the best available empowering information fairly to all segments of the community. Due to its urban nature, the District of Columbia has a special inner city population that must be reached to promote increased awareness of water and related environmental problems and issues. Thus, WRRC will work to develop contacts with public libraries, public schools, and churches to provide helpful and insightful information to this segment of our stakeholders. Further, WRRC will continue to publish newsletters, fact sheets, brochures, and information documents for stakeholders who include the general public, including high school students, undergraduate and graduate students; UDC administrators, faculty, and staff, local and regional government administrators, and other experts. A web page has been established for DC WRRC accessible through the University s website. This web page provides easy access to those who seek information and/or assistance from WRRC.

USGS Summer Intern Program

Student Support

None

Notable Awards and Achievements

None

Publications from Prior Projects