D.C. Water Resource Research Center
Annual Technical Report
FY 2001

Introduction

This report summarizes the activities of the DC water Resources Research Institute (WRRI) for the period of March 1, 2001 through February 28, 2002. WRRI is in full operation and progressing toward strengthening a credible program. The Institute is updating its directory of water resources experts in the District as well as upgrading its webpage to better serve its stakeholders. Principal Investigators for the FY 2001 research projects included two (2) investigators from the University of the District of Columbia (UDC) and two (2) investigators within the consortium of DC universities.

The District of Columbia continues to encounter environmental problems related to the Anacostia River. Non-point source pollution, storm water problems, toxic contamination of sediments, and loss of natural fish habitat remain the fundamental environmental issues. In support of research on these water resources problems in the District, WRRI awarded seed grant to researchers within the consortium of DC universities. Funds were provided to determine the sources of bioavailable toxic pollutants in the Anacostia River, evaluate the speciation of tributyltin and triphenyltin compounds in clays from sediments using mossbauer spectroscopy, analyze transformed environmental data with detection limits, and train DC public school teachers and students in technology of water environmental education.

WRRI continues to disseminate the results of its research to its stakeholders which include the residents of the District of Columbia, administrators, faculty, students, and staff of UDC, and public and private agencies via fact sheets, brochures, and its webpage.

Research Program

Environmental quality of the Anacostia River continues to be the most pressing and urgent water resources issue in the District. The Anacostia Watershed still suffers from severe problems of non-point source pollution (NPS) from urban run-off, combined sewer overflows, and sediments made toxic by past dumping and industrial activities. The destruction of wetlands and marshes has resulted in the loss of the watershed buffering or filtration capacity. This continued degradation of a once beautiful river has incited the involvement of several concerned stakeholders to form clean-up and monitoring groups such as the Anacostia Watershed Toxic Alliance (AWTA), the Anacostia Watershed Society (AWS), and the Anacostia Watershed Restoration Committee (AWRC). These groups are pooling knowledge, expertise, and resources to make the river swimmable and fishable once more.

The demand for urban river restoration projects has been initiated by the excessive amount of pollution endured by the river over a considerable length of time. The river sediment has high concentrations of polychlorinated biphenyls (PCBs), polynuclear aromatic hydrocarbons (PAHs), pesticides, lead and other trace elements. This has contributed significantly to serious health problems affecting the local population and aquatic organisms.

The DC Water Resources Research Institute continues to provide the District with inter-disciplinary research support to both identify and contribute to the solution of DC water resources problems. Six proposals were submitted and approved for funding during the 2001 fiscal year, however, due to insufficient non-federal match, only four were funded. Dr. Favors developed a program and trained DC public school teachers and students through the Water Environment Studies in Schools: In-Schools Program. Dr. Harriette Phelps determined the Sources of Bioavailable Toxic Pollutants in the Anacostia. At George Washington University, Dr. Reza Modarres evaluated the Analysis of Transformed Environmental Data with Detection Limits. Dr. Leopold May at Catholic University got ill during the grant period and requested an extension to August 2003. This extension was granted and he provided a progress report on the Speciation of Tributyltin and Triphenyltin Compounds in Clays from Sediments Using Mossbauer Spectroscopy. These research findings will be presented to our stakeholders for effective utilization which we anticipate will provide enhancement to the quality of life of all DC residents.

Sources of Bioavailable Toxic Pollutants in the Anacostia

Basic Information

Title:	Sources of Bioavailable Toxic Pollutants in the Anacostia
Project Number:	2001DC3801B
Start Date:	3/1/2001
End Date:	2/28/2002
Funding Source:	104B
Congressional District:	DC
Research Category:	Not Applicable
Focus Category:	Toxic Substances, None, None
Descriptors:	sediment, urban, biomonitoring, molluscs,PCB’s
Principal Investigators:	Harriette Phelps

Publication

Sources of Bioavailable Toxic Pollutants in the Anacostia

Final Report to the DC Water Resources Research Center

Dr. Harriette L. Phelps

May 30, 2002

Abstract:

The polluted urban Anacostia River estuary and four of its major tributaries were monitored in summer 2001 for bioavailable EPA Priority Pollutants (PCBS, PAHS, Aroclors, pesticides and five metals) using the locally available Asiatic Clam, *Corbicula fluminea*. Total metal levels in clams at all sites were not significantly different from clams from the nearby control site on the Potomac at Fort Foote. PCB congenors (especially 2 - 5 Cl) and Aroclor totals were significantly greater than controls at Lower Beaverdam Creek (MD). Total pesticides (especially chlordane) were significently greater at the Northeast Branch. Total accumulated PAHs significantly exceeded controls at the Northeast Branch and Lower Beaverdam Creek tributaries, and also at upper and lower Anacostia estuary sites (Bladensburg Marina, Washington Gas Light and the Navy Yard). Clams placed in the Northwest Branch (MD) and Hickey Run (DC) tributaries had total pollutant levels no greater than controls. Clams placed at Hickey Run (DC) before it entered the National Arboretum grounds had only 6% survival, but when placed at the exit from the lake had 92% survival, and contaminant levels were lower than controls. Contaminants in clams at the control site suggest pollutants from the Anacostia estuary are influencing the Potomac estuary.

Introduction:

The Anacostia River estuary is the DC urban river with plans for improving public access and fishing. The poor biological condition of the Anacostia River estuary is receiving increasing public attention as it has a fishing advisory and depauperate benthic life (Phelps 1985), especially as it is a branch of the nearby Potomac estuary which is considered a recovery success of the Chesapeake Bay. The biological problems of the Anacostia have been known for years (Freudberg et al.1989, Cummins et al. 1991) and there have been many studies of its water and sediment chemical contaminants (Velinsky et al. 1992, Velinsky and Cummins 1994, Velinsky et al. 1994, Wade et al 1994, Syracuse Research Corporation 2000). Some studies have been done on the tributary origins of Anacostia pollutants (Warner et al. 1997, Coffin et al. 1999) and bioeffects such as sediment toxicity, tumor formation and bioaccumulation (Phelps 1990, Phelps 1991, Phelps 1993, Phelps 1995, Phelps 2001, Pinkney et al. 2000).

The most serious toxic contaminants of the Anacostia from the standpoint of human health are the pesticide chlordane and PCBs which are above FDA action levels in Anacostia fish and have sponsored a fishing advisory (Velinsky and Cummins 1994, Pinkney 2001). PCBs have a number of harmful effects in biota and can come from a variety of sources including old electrical equipment (Ahlborg et al. 1994, Safe 1990, Safe 1994 Fikslin 1995). PCBs and chlordane and other persistant organic pollutants (POPs) can remain buried in sediments for years but become bioavailable through remobilization by dredging (Phelps 2001). The Anacostia Watershed Toxics

Alliance (NOAA/EPA) has recently formed to study and recommend solutions to the toxic problems of the Anacostia and is proposing several remediation actions for toxics in sediments (AWTA 2002).

However, for sediment toxic remediation to be successful it will be necessary to find and control ongoing sources of pollutants to the estuary. Earlier studies (Gruessner et al. 1997, Coffin 1999) suggested the major water sources to the Anacostia estuary, the Northeast and Northwest Branches (MD), contributed significant amounts of PCBs and other pollutants. A recent Anacostia watershed study (Phelps 2001) found chlordane only in sediments and Asiatic clams at the mid to upper end of the Anacostia estuary and the Northeast Branch. The use of clams to monitor these sites detected the bioavailable chlordane and suggested a Northeast Branch source.

Molluscs are used for biomonitoring aquatic health worldwide because they mostly lack a cytochrome P450 system and will accumulate rather than detoxify or modify pollutants. The Asiatic clam, *Corbicula fluminea,* is common, widespread, resistant to toxics and has been recommended for freshwater contaminant bioaccumulation studies by the National Water Quality Assessment Program (Dougherty and Cherry 1988, Crawford and Luoma 1993, Phelps 1997). The Asiatic clam is considered an especially good accumulator of PCBÆs (Peterson et al. 1994). Translocated Asiatic clams have been used to detect organochlorines and pesticides in rivers in several countries (Elder and Mattraw 1985, Hartley and Johnston 1983, Colombo et al.1995, Smith and Ruhl 1996).

Molluscs are important indicators of contaminant bioavailability. Pollutant concentrations in sediment and water are not the same as their bioavailability to living organisms (Elder and Mattraw 1984, Tatem 1986). Complexation of pollutants by organic material or ions can prevent uptake by living tissue (Sunda and Guillard 1976, Long and Morgan 1990, MacDonald et al. 2000). A recent bioavailability study found Asiatic clams did not accumulate contaminants from exposure to contaminated Anacostia sediments in the Potomac (Phelps 2000). However, clams placed on clean sand at Anacostia estuary sites accumulated water contaminants. Filter-feeding molluscs like the Asiatic clam can accumulate contaminants from water and suspended particulates but not from bed sediments (Harrison 1984, Phelps 1979, Phelps 2000). Catfish in contact with polluted Anacostia sediments have a high rate of tumors (Pinkney et al. 2000). The fish and birds of the Anacostia could be affected by bioavailable pollutants that are part of the food chain. Bioavailability information is essential to understanding the dynamics and effects of pollutants in the Anacostia.

The present study uses the locally available Asiatic clam to biomonitor the bioavailable pollutants contributed by tributary subwatersheds to the Anacostia River estuary. _The *A*siatic clam population in the freshwater Potomac River estuary near the Anacostia has been flourishing since this invasive species was first found in 1978 (Dresler and Cory 1980, Cohen et al. 1984, Phelps 1994). The State of Maryland allows biomonitoring with *Corbicula* as it is now considered a naturalized species and has been reported in many Maryland rivers and streams. *Corbicula* in the Anacostia are small and few with no young clams, and probably entering by drift and failing to grow or reproduce (Prezant and Chalermwat 1984, Phelps 1985). Juvenile

Corbicula have been used in biomonitoring toxicity in Anacostia sediment and water (Phelps 1990, Phelps 1993, Phelps and Clark 1988). Adult clams placed in the Anacostia generally survive and can be useful in bioaccumulation studies (Douherty and Cherry 1988, Phelps and Clark 1988, Phelps 2001). To assess the bioavailability of contaminants it is considered necessary to expose molluscs for six to eight weeks for tissue concentrations to reach equilibrium (Roesijadi et al.1984).

Methodology

From 4/5/ to 11/23/2001, two clam biomonitoring studies were carried out in the Anacostia River estuary and tributaries (Table 1, Fig. 1). For studies, Asiatic clams *(Corbicula fluminea)* were collected by sieving the sandy sediment at Fort Foote, MD, on the Potomac estuary at eight km below the opening of the Anacostia estuary. Clams averaged 22 - 26 mm (approximately two years old, Aldridge and McMahon 1978). A Fort Foote control sample was taken. Clams were kept cool and translocated to the biomonitoring sites within 48 hours, where GPS readings were made. At the biomonitoring sites, 80 -110 clams were placed in mesh shellfish bags and fastened or suspended. At some sites the clams were anchored in the stream in weighted plastic boxes with mesh lids. Upon retrieval the clam samples were depurated 24 hours at room temperature with three changes of spring water, frozen, briefly thawed, shucked, and the tissues re-frozen. The frozen tissue samples were hand-carried to Severn-Trent Laboratories (STL) at Sparks, MD within one week for analysis.

Table 1. Study site locations on the Anacostia and Potomac River estuaries and tributaries.

	Site	GPS
Potomac River	Fort Foote	N38^{0}46.460Æ, W77^{0}01.770Æ
Anacostia River		
MD Tributary	Northeast Branch	N38^{0}57.621Æ, W78^{0}55.583Æ
	Northwest Branch	N38^{0}56.741Æ, W76^{0}56.855Æ
	Lower Beaverdam Creek	N38^{0}54.977Æ, W76^{0}55.985Æ
MD Estuary	Bladensburg Marina	N38^{0}56.054Æ, W76^{0}56.361Æ
DC Tributary	Hickey Run (4/5/01)	N38^{0}54.555Æ, W76^{0}57.739Æ
	Hickey Run(7/24/01)	N38^{0}54.586Æ, W76^{0}57.710Æ
DC Estuary	Washington Gas Light	N38^{0}52.413Æ, W76^{0}56.334Æ
	Navy Yard	N38052.304Æ, W76^{0}59.712Æ

Clam tissue samples had 50 to 90 clams each. STL carried out a complete EPA Priority Pollutant analysis of the clam tissues, including 21 pesticides, 28 PCB congenors, 18 PAHs, five metals, and lipid, and made the data available in electronic format within five weeks. STL analysis of EPA Priority Pollutants was: PBC congenors by gas chromatography (method SW 8082), chlorinated pesticides by gas chromatography (method SW 8082), PAHÆs by high performance liquid chromatography (method SW 8310), and total copper, zinc, iron, cadmium and chromium by inductively coupled plasma (methods SW 6000, 7000).

For the first biomonitoring study clams were collected at Fort Foote on 4/5/01. Four Anacostia tributary sites near the estuary but above tidal influence were selected for biomonitoring. Two were the same Northeast Branch (MD) and Northwest Branch (MD) tributary sites as in an earlier study (Pinkney, 2001); one at the Bladensburg Marina estuary near another study site (Phelps 2001), one at Lower Beaverdam Creek (MD), and one at Hickey Run (DC) where it enters the National Arboretum (Table 1).

The first group of clams were collected from the biomonitoring sites on 7/15/01 (14 weeks exposure). Clam boxes were missing at Northwest Branch due to high water flow and Bladensburg Marina due to construction. At Hickey Run the clam mortality was high (94%) and there was insufficient tissue for analysis. Clam mortality at Northeast Branch (8%) and Lower Beaverdam Creek (16%) sites was acceptable for adequate tissue samples.

A control sample of clams was collected at Fort Foote on 7/24/01.

The second biomonitoring study on 9/29/01 had biomonitoring placement on 9/29 and 9/31. Bags or boxes of clams were placed at the Navy Yard, and Washington Gas Light facility sites in the lower Anacostia estuary, Bladensburg Marina (MD) at the new dock, the earlier Northwest Branch site, and a different site on Hickey Run where it leaves National Arboretum grounds (Table 1). TidbiT temperature monitors were attached to clam bags at the Northeast Branch tributary and the Washington Gas estuary sites.

On 10/15/01 clams were collected at the Potomac Fort Foote control site and the tissues divided into six subsamples, which were analyzed by STL for nine PAHs to determine analytical variability. Statistical analysis was carried out by Excel.

The second group of clam biomonitors was recovered on 11/21 and 11/23/01 (eight weeks) as the average daily water temperature had dropped to 10 deg. C, when the Asiatic clam becomes inactive (pers. obs). Mortality at all sites was low (0 - 8%). The clams were handled and the frozen clam tissue samples hand-carried to STL for analysis as before.

Results:

Analytical variability of the nine PAHs in the six control tissue subsamples had a coefficient of variation of 9 -18%. The relationship of standard deviation (SD) to mean was linear: SD = 0.175 MEAN - 1.12 ($R^2 = 0.94$). This equation was used to estimate the analytical SD of all contaminant totals and to calculate significent differences. Due to the large number of clams per sample the analytical variability is assumed to be the largest source of error.

Total PCB, PAH, metal and pesticide concentrations of tissue samples at biomonitored sites were statistically compared with the largest values from the three control samples taken on 4/05/01, 7/24/01 and 9/29/01. Concentrations that did not exceed analytical thresholds were entered as zero. Statistically significent increased total contaminant levels were taken as those exceeding twice the combined estimated analytical standard deviation of the (largest) control and the biomonitoring sample (Table 2).

Table 2. Total concentrations of EPA Priority Pollutant pesticides: t tPAH, tPCB, tAroclors, and tmetals (Cu + Cd + Fe + Zn +Cr) in Potomac and Anacostia clam tissues.

(ug/Kg)	tMetals (x .01)	tPCB	tAroclors	tPAH	tPesticides
CONTROL SITE					
Potomac FF 5/16/99	490	46		421	25 (Phelps 2000)
Potomac FF 4/05/01	945	173	131	384	425
Potomac FF 7/15/01	745	131	91	457	270
Potomac FF 9/29/01	709	97	57	354	53
TRIBUTARIES					
Northwest Branch	660	83	82	637	77
NortheastBranch	73	187	196	1442*	740*
Lower Beav.Creek	1189	666*	1250*	855	295
Hickey Run	498	97	95	785	42
ESTUARY					
Bladensburg Marina	788	239	361	2350*	94
Wash. Gas Light	905	212	310	1502*	128
Navy Yard	753	186	194	1366*	102

* Statistically significently greater than highest control ($p < .05$)
FF = Fort Foote site

Table 3. EPA Priority Pollutant concentrations in clam tissue samples.

METALS (ug/Kg x 0.01)

	P 4/05	P 7/24	P 9/29	NWB	NEB	LBC	HRN	BM	GL	NY
Cadmium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chromium	0.0	0.0	1.6	1.0	0.0	0.0	0.6	1.2	0.7	1.0
Copper	8.6	9.0	7.6	6.1	7.9	14.2	4.8	7.1	9.5	9.1
Iron	64.3	40.6	38.9	38.2	45.6	82.5	32.4	52.3	59.8	43.3
Zinc	21.6	24.9	22.8	20.7	19.1	22.2	12.0	18.2	20.5	21.9

PCB CONGENORS (ug/Kg)

	P 4/05	P 7/24	P 9/29	NWB	NEB	LBC	HRN	BM	WGL	NY
BZ#18	3.5	2.4	2.4	1.7	2.3	47.0	1.8	2.7	10.0	8.4
BZ#28	1.6	2.1	1.4	2.1	2.6	71.0	1.2	2.5	11.0	9.4
BZ#44	7.1	4.0	4.9	3.1	7.1	74.0	4.3	6.5	15.0	14.0
BZ#49	2.8	2.8	2.2	1.2	2.1	64.0	1.7	2.8	11.0	9.2
BZ#52	4.2	4.1	3.5	2.4	6.0	87.0	4.0	7.7	16.0	13.0
BZ#87	26.0	22.0	16.0	16.0	2.1	42.0	16.0	23.0	43.0	37.0

BZ#101	14.0	11.0	10.0	8.2	17.0	44.0	9.2	29.0	21.0	19.0
BZ#105	4.9	2.9	1.6	2.5	3.0	21.0	3.4	14.0	6.7	3.4
BZ#118	9.3	6.8	6.4	5.5	12.0	36.0	7.1	12.0	10.0	9.4
BZ#128	1.8	2.0	1.4	1.1	3.4	9.3	1.4	4.2	3.0	3.0
BZ#138	16.0	13.0	12.0	9.9	29.0	40.0	13.0	38.0	16.0	15.0
BZ#153	35.0	20.0	22.0	16.0	42.0	61.0	22.0	50.0	25.0	23.0
BZ#156	1.2	0.0	0.0	0.0	1.1	3.2	0.0	1.4	1.2	1.0
BZ#170	1.6	0.0	0.0	0.0	2.1	0.0	0.0	4.8	1.3	1.4
BZ#180	3.9	1.3	3.2	2.5	6.3	5.1	2.3	9.5	3.8	3.8
BZ#183	3.0	2.5	1.3	1.1	4.2	5.2	1.1	6.0	1.9	1.8
BZ#184	4.5	5.0	3.2	5.6	10.0	22.0	3.6	7.3	9.6	8.0
BZ#187	8.1	6.2	5.3	3.8	12.0	13.0	4.6	16.0	6.4	6.1
BZ#198	24.0	23.0	0.0	0.0	23.0	21.0	0.0	1.3	0.0	0.0

AROCLORS (ug/Kg)

	P 4/05	P 7/24	P 9/29	NWB	NEB	LBC	HR	BM	WGL	NY
Aroclor-1242	0	52	0	0	59	810	0	0	0	0
Aroclor-1248	0	0	27	38	0	0	39	81	190	100
Aroclor-1254	98	39	30	44	89	440	56	150	120	70
Aroclor-1260	33	0	0	0	48	0	0	130	0	24

PAHs (ug/Kg)

	P 4/05	P 7/24	P 9/29	NWB	NEB	LBC	HRN	BM	GL	NY
Naphthalene	19	51	22	9	31	21	0	0	15	13
2-Methylnaphthalene	14	9	0	0	10	12	0	0	8	0
1-Methylnaphthalene	0	0	0	0	0	0	0	0	9	0
Acenaphthylene	0	0	0	0	0	0	0	0	0	0
Acenaphthene	0	0	0	0	0	12	0	0	14	0
Fluorene	0	0	0	0	0	32	0	33	15	9
Phenanthrene	19	17	0	23	60	0	36	200	68	34
Anthracene	0	0	0	0	18	19	0	26	20	11
Fluoranthene	59	58	27	120	310	0	140	470	220	170
Pyrene	59	57	30	110	240	0	220	360	200	140
Benzo(a)anthracene	0	0	0	13	88	72	22	87	130	120
Chrysene	36	44	20	100	280	270	85	280	350	340
Benzo(b)fluoranthene	0	11	0	34	94	91	31	180	180	160
Benzo(k)fluoranthene	0	0	0	0	69	48	17	0	0	0
Benzo(a)pyrene	0	0	0	0	22	26	12	36	30	28
Indeno(1,2,3-cd)pyrene	0	0	0	0	21	17	13	0	11	8
Dibenz(a,h)anthracene	0	0	0	0	12	14	12	0	0	0
Benzo(g,h,i)perylene	0	0	28	0	40	38	18	520	19	94
Naphthalene-d8(SS)	38	43	47	52	29	37	35	35	46	54
Acenaphthene-d10(SS)	37	44	46	46	29	39	35	29	42	49
Phenanthrene-d10(SS)	35	42	52	50	30	39	42	31	48	53
Chrysene-d12(SS)	36	40	37	39	30	36	31	27	34	37

Perylene-d12(SS)	32	41	45	41	29	32	36	36	43	46

PESTICIDES (ug/Kg)

	P 4/05	P 7/24	P 9/29	NWB	NEB	LBC	HRN	BM	GL	NY
alpha-BHC	0	0	0	0	0	0	0	0	0	0
beta-BHC	0	0	0	0	0	7	0	0	4	0
delta-BHC	0	0	0	0	0	0	0	0	0	0
gamma-BHC (Lindane)	0	0	0	0	0	0	0	0	0	0
Heptachlor	0	0	0	0	0	0	0	0	0	0
Aldrin	0	0	0	0	0	0	0	0	0	0
Heptachlor epoxide	20	0	0	6	90	0	0	6	0	0
Endosulfan I	0	0	0	0	0	0	0	0	0	0
Dieldrin	42	0	0	12	0	15	0	16	0	0
4,4'-DDE	48	51	10	8	0	56	8	14	27	25
Endrin	0	0	0	0	0	0	0	0	0	0
Endosulfan II	0	0	0	0	0	0	0	0	0	0
4,4'-DDD	31	20	0	0	0	20	5	0	16	12
Endosulfan sulfate	0	0	0	0	0	0	0	0	0	0
4,4'-DDT	67	29	8	0	0	26	0	0	12	0
Methoxychlor	0	0	0	0	0	0	0	0	0	0
Endrin ketone	0	0	0	0	0	0	0	0	0	0
Endrin aldehyde	0	0	0	0	0	0	0	0	0	0
Toxaphene	0	0	0	0	0	0	0	0	0	0
gamma-Chlordane	26	30	7	7	240	28	3	7	15	14
alpha-Chlordane	84	40	8	23	410	38	8	30	35	33
Tetrachloro-m-xylene	53	50	10	11	0	57	8	11	9	9
Decachlorobiphenyl	54	50	11	10	0	48	10	10	10	9

KEY:
P 4/05 Potomac Fort Foote (MD) 4/05/01 control site
P 7/24 Potomac Fort Foote (MD) 7/15/01 control site
P 9/29 Potomac Fort Foote (MD) 9/29/01 control site
NWB Northeast Branch (MD) tributary site
NEB Northeast Branch (MD) tributary site
LBC Lower Beaverdam Creek (MD) tributary site
HRN Hickey Run (DC) tributary site
BM Bladensburg Marina (MD) estuary site
GL Washington Gas Light facility (DC) estuary site
NY Navy Yard (DC) estuary site

Metal totals (Cu + Fe + Zn + Cd + Cr) in clams at biomonitored sites were not significently increased over controls (Table 2, Table 3).

Total PCB congenors in clam tissues significently exceeded controls only at the Lower Beaverdam Creek tributary site (Table 2). The PCB congenor profile for Lower Beaverdam

Creek had elevated levels of the 2 - 5 Cl PCB congenors (Table 3). Other sites had higher levels of the 6-9 Cl PCB congenors.

Total Aroclors significently exceeded the highest control value only at Lower Beaverdam Creek where the principal Aroclors were 1242 and 1254 (Table 3).

Total PAHs in clams were significently greater than controls at the Northeast Branch and Lower Beaverdam Creek tributary sites, and at all the estuary sites (Bladensburg Marina, Washington Gas and Navy Yard) (Table 2). Bladensburg Marina had the highest total PAH.

Total pesticides in clam tissues were signficently greater than control at the Northeast Branch and Lower Beaverdam Creek tributary sites (Table 2). The Northeast Branch clam tissues had highest total clordane (alpha + gamma). The highest DDT/DDD/DDE totals were in clams at the Lower Beaverdam Creek tributary and the Washington Gas estuary sites (Table 3).

Discussion and Conclusions:

Site Summary:

The tissue analytical variability indicated that biomonitoring of suspended and dissolved pollutants with *Corbicula* is probably limited to monitoring high-level sources. The present study identified two tributaries (Northeast Branch and Lower Beaverdam Creek) as high-level sources of specific pollutants. Other tributaries (Northwest Branch and Hickey Run) had no clam pollutants over control levels. The tributaries will be discussed in order, North to South.

The Northwest Branch (MD) subwatershed of the Anacostia River estuary had total contaminant levels in clams no greater than control, and probably is not contributing significently to Anacostia estuary pollution (Table 2). The Northwest Branch provides about 32% of the input flow with a total acreage of 41.9 square miles and an average imperviousness of 17% (Warner et al. 1997). The Northwest Branch is semi-rural and primarily residential (54%) and forested (22%) and considered to have a relatively high quality aquatic habitat for fish and invertebrates.

The Northeast Branch (MD) subwatershed clams had significently greater concentrations of total PAHs and pesticides, with total clordane (alpha + gamma) the greatest of any biomonitored site (Table 2). The Northeast Branch provides about 45% of the Anacostia water input, with an average imperviousness of 26%, and 85% of the mainstream channeled (Warner et al. 1997). It is highly urbanized and dominated by residential land use and includes the Beltsville Agricultural Research Center which has a CERCLA National Priority List site. The fish and invertebrate populations are considered slightly impaired. Future biomonitoring studies should be made on the Northeast Branch tributaries to identify those with greatest contaminant contribution to the Anacostia estuary.

Lower Beaverdam Creek, mostly in Maryland, had clams with significently higher concentrations of PCBs, Aroclors and PAHs. Total DDT (DDT+DDE+DDD) accumulation was highest in this tributary. The Lower Beaverdam Creek subwatershed provides about 12% of the Anacostia water flow (Warner et al. 1997). It is called one of the most intensely developed subwatersheds of the Anacostia and has 17% industrial land with the largest industrial acreage of any Anacostia tributary. Fish and macroinvertebrate populations are considered the most impaired of all the Anacostia tributaries.

Hickey Run (DC) is a small watershed but has 30% industrial land use and is considered a major problem stream in DC. All its pollutant load is non-point and there are no combined sewer overflow outlets but there is chronic petroleum hydrocarbon release. The two biomonitoring attempts at Hickey Run (4/05 and 9/29) were at different sites with differing results. On 4/05 the clams were placed where Hickey Run exits Route 50 and enters the National Arboretum grounds (Table 1). The water appeared heavily polluted and 94% of the clams died. On 9/29, clams were placed one km away where Hickey Run leaves the Arboretum and after it passes through a lake (Table 1). Clam mortality there was only 8% and all the tissue pollutant levels were lower than controls. It appeared that the Hickey Run bioavailable pollutants had been removed by passage through the lake. This finding is a good argument for wastewater pond remediation of tributary pollutants.

All the Anacostia estuary sites, Bladensburg Marina at the upper end, and Washington Gas Light and nearby Navy Yard sites near the lower end, had significently higher levels of total PAHs in clams than control. No other contaminants were significently increased over control levels.

Contaminant summary:

The finding of no significent difference among metal concentrations in clams at Anacostia sites and the control site suggests that metal contamination is not a problem for Anacostia benthos.

The increase in 2 - 5 Cl PCB congenors in Lower Beaverdam Creek clams is similar to that found earlier in lower Anacostia estuary clams and sediments (Phelps 2001). Along with the high Aroclor level it indicates severe ongoing contamination. Future clam biomonitoring studies should be made on the Lower Beaverdam Creek tributaries to identify possible point sources of PCBs. Remediation of point sources is necessary for adequate PCB control in the Anacostia. PCB levels in other Anacostia tributaries were not significently greater than controls and their high 6-7 Cl congenor level suggests they are weathered and attached primarily to sediment.

Significent PAH contamination appeared widespread in the Anacostia estuary. The only major tributary sources of PAHs to the estuary were the Northeast Branch and Lower Beaverdam Creek. However, since PAH levels were high at all estuary sites there may be other sources in the Anacostia watershed. The pattern of PAH contamination at Bladensburg Marina with high clam tissue levels of phenanthrene, pyrene, fluoranthene and benzo(g,h,i)perylene (Table 3) was not seen in the Northwest and Northeast Branches which form the Anacostia estuary there. Although the new wood bulkheaded marina at Bladensburg was not creosoted, those PAHs may have had another source relating to the recent construction activity.

The pesticide clordane was a significent clam contaminant only in the Northeast Branch. Followup studies need to be made on Northeast Branch tributaries to identify the areas of possible remediation. As clordane has been banned for 20 years and Asiatic clams biomonitor both dissolved and particulate pollutants, it is likely the chlordane is old contamination bound to particulates. The pesticide DDT was detected in clams at the Lower Beaverdam Creek tributary and the Washington Gas Light estuary location. Agee (1986) suggested the ratio of DDT to its sum with breakdown products (f DDT = DDT + DDE + DDD) can indicate recent transport from land to water, since DDT degrades rapidly in water. He proposed a ratio of above 10% to indicate a fresh source. This ratio was 24% at Lower Beaverdam Creek and 21% at the Washington Gas Light downstream estuary site. The f DDT at the WGL facility could be a fresh source or due to transport from the upstream Lower Beaverdam Creek.

The levels of total metals, PCBs and pesticides (but not PAHs) in the downstream Potomac estuary clams at Fort Foote are slowly returning to pre-dredging levels two years after the extensive COE Anacostia dredging project (8/99 - 4/00) (Phelps 2001) (Table 2). Aerial photographs of the Anacostia mouth always show a turbid plume entering the relatively clear Potomac. Many pesticides and PCBs are transported by association with suspended sediment particles (Coffin et al. 1999, Bergamaschi et al. 2001). However, the levels of contaminants in the Potomac Fort Foote clams did not affect normal *Corbicula* growth and reproduction (Boltovskoy et al. 1997, pers. obs.), and can be considered contaminant bioaccumulation benchmarks that are compatible with a healthy ecosystem. Although the Potomac estuary near DC is considered healthy, the contamination of its fish (Pinkney 2001) and benthos may continue until toxic Anacostia sources of pollutants are cleaned up. The recent AWTA draft document summarizing Anacostia sediment remediation plans does not specifically address the problem of contaminant transport into the Potomac, but does state. It is premature to proceed with a detailed final evaluation of specific remedial actions until a refined conceptual model of the river is developed to provide a better understanding of contaminant inputs, in-river processes and exposure and risk to ecological and human healthö (AWTA 2002). Bioaccumulation studies with the Asiatic clam can be used to locate and monitor the location and remediation of high-level sources in of pollution to the Anacostia River estuary and its tributarries.

LITERATURE CITED:

Agee BA. 1986. DDT in the Salinas Valley. Water Quality Monitoring Report 86-2-WQ. California Water Resources Control Board, Sacramento, CA.

Aldridge DW, McMahon RW 1978. Growth, fecundity, and bioenergetics in a natural population of the Asiatic freshwater clam, *Corbicula manilensis* Philippi, from North Central Texas. Journal of molluscan Studies 44:49-70.

Anacostia Watershed Toxics Alliance. 2002. Charting a Course Toward Restoration: A Contaminated Sediment Management Plan. Draft document.

Ahlborg, U., G. Becking, L. Birnbaum, A. Brower, H. Derks, M. Feeley, G. Golor, A. Hanberg, J. Larsen, A. Liem, S. Safe, C. Schlatter, F. Waern, M. Younes and E. Yrjanheikki. 1994. Toxicity equivalency factors for dioxin-like PCBs. *Chemosphere* 28(6): 1049-1067.

Bergamaschi BA, Kuivila KM, Fram MS. 2001. Pesticides associated with suspended sediment entering San Francisco Bay following the first major storm of water Year 1996. *Estuaries* 24(6): 365-380.

Boltovskoy D; Correa N; Cataldo D; Stripeikis J; Tudino M. 1997. Environmental stress on *Corbicula fluminea* (Bivalvia) in the Parana River delta (Argentina): complex pollution-related disruption of population structures. *Arch. Hydrobiol.* 138:483-507

Coffin, RB, JW Pohlman and CS Mitchell. 1999. Fate and Transportation of PAH and Metal

Contaminants in the Anacostia River Tidal Region. NRL/MR/6110-99-8327. Naval Research Laboratory, Wash., DC

Cohen, R.R.H., P.V. Dresler, E.J.P. Phillips and R.L. Cory. 1984. The effect of the Asiatic clam, ______________*Corbicula fluminea,* on the phytoplankton of the Potomac River, Maryland. *Limn. and Ocean*. 29:170-180.

Colombo, J.C., C. Bilos, M. Campanaro, M.J. Rodriguez-Presa and J.A. Catoggio. 1995. Bioaccumulation of polychlorinated biphenyls and chlorinated pesticides by the Asiatic clam *Corbicula fluminea:* Its use as a sentinel organism in the Rio de La Plata Estuary, Argentina. *Env. Sci. and Tech.* 29(4):914-927.

Crawford, JK and SN Luoma. 1993. Guidelines for studies of contaminants in biological tissues for the National Water Quality Assessment Program. U.S. Geological Survey Open-FileReport 92-494.

Cummins, J.D., J.B. Stribling and P.D. Thaler. 1991. 1990 MD Anacostia River Basin Study, Part 1. Habitat, Macrobenthic Invertebrate Communities, and Water Quality Assessment. Interstate Commission on the Potomac River Basin Report #91-02. Rockville, MD.

Douherty FS And DS Cherry. 1988. Tolerance of the Asiatic clam *Corbicula* spp. to lethal levels of toxic stressors - A review." *Environ Poll* 51:269-313

Dresler, P.V. and R.L. Cory. 1980. The Asiatic clam, *Corbicula fluminea* (Muller), in the tidal Potomac River, Maryland. *Estuaries* 3:150-151.

Elder, J.F. And H.C. Mattraw, Jr. 1984. Accumulation of trace elments, pesticides and polychlorinated biphenyls in sediments and the clam *Corbicula manilensis* of the Apalachicola River, Florida. Arch. Environ. Contam. Toxicol. 13:453-469

Fikslin, T.J. 1998. Study of the Loadings of Polychlorinated Biphenyls from Tributaries and Point Sources Discharging to the Tidal Delaware River. Delaware River Basin Commission, West Trenton, NJ.

Gruessner, B, DJ Velinsky, GD Foster, J Scudlark and R Mason. 1997. Final Report – Dissolved and Particulate Transport of Chemical Contaminants in the Northeast and Northwest Branches of the Anacostia River. Prepared for the Department of Consumer and Regulatory Affairs, Environmental Regulation Administration, Washington, DC. ICPRB Report #97-10

Freudberg S, Schueler T, Herson L.M. 1989. The state of the Anacostia: 1988 status report. Metropolitan Washington Council of Governments, Washington, DC.

Harrison, G. 1984. A survey of the trace-metal content of *Corbicula fluminea* and associated sediments in the tidal Potomac River. U.S. Geological Survey Open-File Report 84-558.

Hartley, DM and JB Johnston. 1983. Use of the freshwater clam *Corbicula manilensis* as a monitor for organochlorine pesticides. *Bull. Env. Contam. Toxicol.* 31:33-40

Long, E.R.and L.G. Morgan. 1990. The potential for biological effects of sediment-sorbed contaminants in Seattle, WA: National Ocean and Atmospheric Administration, NOAA National Status and Trends Program. Technical Memorandum NOS OMA 52.

MacDonald DD, Dipinto LM , Field J, Ingersoll CG, Long ER, Swartz RC. 2000. Development and evaluation of consensus-based sediment effect concentrations for polychlorinated biphenyls. Env. Tox. Chem. 19(5):1403.

Peterson, MJ, GR Southworth and KD Ham. 1994. Effect of sublethal chlorinated discharges on PCB accumulation in transplanted Asiatic clams (*Corbicula fluminea*). *Water, Air and Soil Pollution.* 73:169.

Phelps, HL. 1979. Cadmium sorption in estuarine mud-type sediment and cadmium accumulation in the soft-shell clam, *Mya arenaria*. *Estuaries* 2(1):40-44.

Phelps, HL.1985. Summer 1984 Survey of Mollusc Populations of the Potomac and Anacostia Rivers near Washington, D.C. Report to D.C. Environmental Services. 67p.

Phelps HL. 1990. Anacostia river sediment toxicity: Localization and characterization using a ______________*Corbicula* larva bioassay. D.C. Water Resources Research Center, Washington, D.C. 31 p

Phelps HL. 1991. A preliminary study for identification of sediment toxics in the tidal freshwater Anacostia river. D.C. Water Resources Research Center, Washington, D.C. 11pp.

Phelps, HL. 1993. Sediment toxicity of the Anacostia River estuary Washington, DC. *Bull. Environ. Contam. Toxicol*. 51:582-587.

Phelps, HL. 1994. The Asiatic clam *(Corbicula fluminea)* invasion and system-level ecological change in the Potomac River estuary near Washington, D.C. *Estuaries* 17(3):614-621.

Phelps, HL. 1995. Studies on sediment toxicity in the Anacostia estuary and DC's Kenilworth Marsh. p.183-187. In: Hill and Nelson, eds. Towards a Sustainable Coastal Watershed: The Chesapeake Experiment. 1994 Chesapeake Research Conference. Chesapeake Research Consortium, Inc. Edgewater, MD. 723 p.

Phelps, HL. 1997. Life History Data for the Asiatic Clam (*Corbicula fluminea*).Delaware River *Corbicula* Bivalve Project for the Delaware River Basin Commission (DRBC-F98D-1/2).

Phelps, HL. 2000. DC AES Contaminated Anacostia Estuary Sediments: A Biomonitoring Approach. Report, DC Water Resources Research Center, Washington, DC.

Phelps HL. 2001. Biomonitoring Anacostia River Estuary Pollutants with the Asiatic Clam *(Corbicula fluminea*): Possible Effects of Dredging. Report, DC Water Resources Research Center, Washington, DC. 10p

Phelps, HL and K Clark. 1988. Clam Assay for Toxic Sediment at Kenilworth Marsh. Center for Urban Ecology Report, U.S. Park Service, Washington, D.C. 21pp.

Pinkney, AE, JC Harshbarger, EB May and MJ Melancon. 2000. Tumor revalence and biomarkers of exposure in Brown Bullheads (*Ameiurus nebulosus*) from the Tidal Potomac River Watershed. *Environ Tox and Chem* 20:1196-1205.

Pinkney, AE. 2001. Analysis of Contaminant Concentrations in Fish Tissue Collected from the Waters of the District of Columbia. USFWS, Annapolis, MD

Pinkney, AE and HL Phelps. Use of Caged *Corbicula fluminea* and Semi-Permeable Membrane Devices to Investigate Contaminant Bioavailability in the Anacostia River. (In prep)

Prezant, R.S. and K. Chalermwat. 1984. Flotation of the bivalve *Corbicula fluminea* as a means of dispersal. Science 225:1491-3.

Roesijadi, G., J.S. Young, A.S. Drum and J.M. Gurtisen. 1984. Behavior of trace metals in ______________*Mytilus edulis* during a reciprocal transplant field experiment. *Mar. Ecol. Prog. Ser.*18:155-170.

Safe, S. 1990. Polychlorinated biphenyls (PBCBs), dibenzo-p-dioxins (PCDDs), dibenzofurans (PCDFs) and related compounds: Environmental and mechanistic considerations which support the development of Toxic Equivalency Factors (TEFs). *Crit. Rev.Toxicol.* 21(1):51-58.

Safe, S. 1994. Polychlorinated biphenyls (PCBs): Environmental impact: biochemical and toxic responses, and implications for risk assessment. *Crit. Rev. Toxicol.* 24(2):87-149.

Smith, KE and PM Ruhl. 1996. Water Quality Assessment of the Albemarle-Pamlico Drainage Basin, North Carolina and Virginia--Organochlorine compounds in the Asiatic clam (*Corbicula fluminea*) and whole redbreast sunfish (*Lepomis auritus)* 1992-93. U.S.

Geological Survey Open-File Report 96-201.
Sunda, W and R.R.L. Guillard. 1976. The relationship between cupric ion activity and the toxicity of copper to phytoplankton. *J. Mar. Res.* 34:511-529.
Syracuse Research Corporation and the National Oceanic and Atmospheric Administration 2000. Interpretive Summary of Existing Data Relevant to Potential Contaminants of Concern within the Anacostia River Watershed. Report to the Anacostia Watershed Toxics Alliance. 218 pp + appendices.
Tatem, H.E. 1986. Bioaccumulation of polychlorinated biphenyls and metals from contaminated sediment by freshwater prawns, *Macrobrachium rosenbergii* and clams, *Corbicula fluminea. Arch. Environ Contam. Toxicol.* 15S; 171-183.
Velinsky, DJ, CH Haywood, TL Wade and E Reinharz. 1992. Sediment contamination studies of the Potomac and Anacostia Rivers around the District of Columbia. ICPRB Report #92-2. ICPRB, Rockville, MD.
Velinsky, DJ and JC Cummins. 1994. Distribution of chemical contaminants in wild fish species in the Washington DC area. ICPRB Report #94-1. ICPRB, Rockville, MD
Velinsky, D.J., T. Wade, C.E. Schlekat, B. McGee and B.J. Presley. 1994. Tidal river sediments in the Washington, D.C. Area. I. Distribution and sources of trace metals. *Estuaries* 17(2):305-320.
Wade, T.L., D.J. Velinsky, E. Reinharz and C.E. Schlekat. 1994. Tidal river sediments in the Washington, D.C. Area. II. Distribution and sources of organic contaminants. *Estuaries* 17:304-320.
Warner, A., DL. Shepp, K. Corish and J. Galli. 1997. An Existing Source Assessment of Pollutants to the Anacostia Watershed. DCRA, Washington, DC.

Analysis of Transformed Environmental Data with Detection Limits

Basic Information

Title:	Analysis of Transformed Environmental Data with Detection Limits
Project Number:	2001DC3921B
Start Date:	3/1/2001
End Date:	2/28/2002
Funding Source:	104B
Congressional District:	DC
Research Category:	Not Applicable
Focus Category:	Water Quality, None, None
Descriptors:	Box-Cox Transformation; Mean Concentration; Detection Limits; E-M Algorithm; Bivariate Censored Observations
Principal Investigators:	Reza Modarres

Publication

Properties of the Power-Normal Distribution

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Abstract:

Box-Cox transformation system produces the power normal (PN) family, whose members include normal and log-normal distributions. We study the moments of PN and obtain expressions for its mean and variance. The quantile functions are discussed. The conditional distributions are studied and shown to belong to the PN family. We obtain expressions for the mean, median and modal regressions. Chevyshev-Hermite polynomials are used to obtain an expression for the correlation coefficient and to prove that correlation is smaller in the PN scale than the original scale. We use the Fréchet bounds to obtain expressions for the lower and upper bounds of the correlation coefficient.

Key Words: Box-Cox Transformation, Log-Normal, Uncertainty Analysis.

1. Introduction

When $\{X_i\}$ are independent and positive random variables Galton (1879) showed that the limiting distribution of $\prod_{i=1}^n X_i$ on the log-scale, i.e., $\sum_{i=1}^n \log X_i$, is normal as n approaches infinity. The distribution of this product in the original scale is well approximated with a two-parameter log-normal distribution. The result is exact when the $\{X_i\}$ are log-normal. More generally, one may consider a power transformation, rather than logarithm, of an underlying normal process. Consider the Box-Cox (1964) power transformation: $Y = P_\lambda(X) = (X^\lambda - 1)/\lambda$ when $\lambda \neq 0$ or $Y = \ln(X)$ when $\lambda = 0$. Frequently, Y is approximated with a normal distribution with mean μ and variance σ^2. After a Box-Cox transformation, one is often interested in inference on the original scale; e.g. estimate the mean (Shumway, Azari and Johnson, 1989; Freeman and Modarres, 2002a), requiring a back transformation. This is often difficult as the mean is a non-linear function of μ and σ^2 (Land, 1974). An equivalent strategy is to model the data directly in the original scale in terms of functions of normal variates. Box-Cox transformation has been successful in many applications and the subject of numerous investigations (Sakia, 1992). Whenever Box-Cox transformation is effective, one may argue that the observations in the original scale must be well approximated by powers of normal variates. It is the purpose of this article to study the family of distributions obtained through this system.

The analysis of environmental data frequently centers on positive random variables such as the concentration of pollutants. Such concentrations are usually right skewed with several extreme observations at both low and high levels. A parametric model such as log-normal, gamma, Weibull or Inverse Gaussian (Haas, 1997; Ott, 1995) is often used to model the observations. However, we often do not have adequate knowledge (e.g. sample size) to specify a distributional form; i.e. a clear fit is not obtained through goodness of fit tests. Hence, model uncertainties exist. In such cases transformation to normality, or equivalently, analysis on the PN scale is an appealing alternative. One can study model uncertainties through the transformation parameter of a PN distribution. Frequently, the log-normal model is selected based on chemical, biological, or physical grounds (Ott, 1995) and it has a prominent role in many application areas (Johnson, Kotz, and Balakrishnan, 1994).

Much effort has been exerted to research the Box-Cox transformation. With the exception of the work of Goto and Inoue (1980), relatively little is known about the distribution of the variables in the PN scale. Much of the available results pertain to the log-normal distribution. In the next section, we discuss the PN family, its moments and quantile function. We develop the multivariate PN distribution in section 3, where we study the conditional distributions and show that they are also in the PN family. We also investigate the mean, median and modal re-

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The work of Reza Modarres was supported by a cooperative agreement with the Office of Water of the USEPA. The work of Jade Freeman was supported by a grant from the USGS through the Water Resources Research Institute of the University of District of Columbia.

gressions of this family. Chevyshev-Hermite polynomials are used in section 4 to derive an expression for the correlation coefficient and to prove it is smaller in the PN scale than the original scale. We use the Fréchet bounds to obtain expressions for the lower and upper bounds of the correlation coefficient.

2. Power Normal Distribution

Johnson (1949) considers a transformation system which includes normal, lognormal, $\sinh^{-1}$-normal, and logit-normal. Johnson (1987) uses the system for generating variates for statistical simulation and further develops it to a multivariate system. Here, we discuss the Box-Cox power transformation system and the PN distribution. By applying an inverse transformation to a normal random variable Y, one obtains $BC(\lambda) : X = (\lambda Y + 1)^{1/\lambda}$ for $\lambda \neq 0$ and $X = \exp(Y)$ for $\lambda = 0$. The system produces the PN family of distributions. This family was first noted in Goto and Inoue (1980), where the authors investigate some of its properties. We discuss other aspects of this family in this article and concentrate on $0 \leq \lambda \leq 1$, which includes several well-known transformations such logarithm, square, cube or fourth roots (see Shumway et al, 1989).

Researchers have generally assumed that there is a transformation parameter that produces a normal distribution for all λ. Since the support of X is positive, Y has a truncated normal distribution for $\lambda \neq 0$. Let $Y \sim TN(\mu, \sigma^2, -1/\lambda)$ have a truncated normal density function $g(Y \mid \mu, \sigma^2, -1/\lambda) = \frac{1}{K}\frac{1}{\sqrt{2\pi}\sigma}\exp\left\{-\frac{1}{2\sigma^2}(Y-\mu)^2\right\}$ where $K = \Phi(T)$, 1, or $\Phi(-T)$ when $\lambda > 0$, $\lambda = 0$ or $\lambda < 0$, respectively. Note that $T = (1/(\lambda\sigma) + 1/\kappa)$ where $\kappa = \sigma/\mu$ is the coefficient of variation and K is a normalizing constant that corresponds to the area above or below the point of truncation, $-1/\lambda$. Let $X \sim PN(\lambda, \mu, \sigma^2)$ denote a PN random variable with pdf, for $X > 0$, $f(X \mid \lambda, \mu, \sigma^2) = \frac{1}{K}\frac{1}{\sqrt{2\pi}\sigma}X^{\lambda-1} \cdot \exp[-\frac{1}{2}(\frac{p_\lambda(X)-\mu}{\sigma})^2]$. By differentiating the density function, one can show that the distribution is unimodal in the interval $0 \leq \lambda \leq 1$ as κ approaches zero. Let $\delta = (1+\lambda\mu)^2 + 4\sigma^2\lambda(\lambda-1)$. The density has a mode at

$$Mode(X) = \begin{cases} [0.5(1+\lambda\mu+\sqrt{\delta})]^{1/\lambda}, & \lambda \neq 0, \\ \exp(\mu - \sigma^2), & \lambda = 0. \end{cases} \quad (1)$$

The density is right skewed for $0 \leq \lambda < 1$. For $\lambda > 0$, as $\kappa \to 0$, the standardized point of truncation $T \to \infty$ and the left tail of Y is no longer truncated.

2.1 Moments

One can show that the rth moment in the PN scale is a non-linear function of the means and variances in the transformed scale. When $\lambda > 0$, we have

$$E(X^r) = \int_{-1/\lambda}^{\infty} (\lambda y + 1)^{r/\lambda} \phi\left(\frac{y-\mu}{\sigma}\right)\frac{dy}{d\sigma}. \quad (2)$$

In this section, we obtain several more useful forms for the moments of a PN distribution. For $\lambda = 0$, note that $E(X^r) = E(\exp(rY)) = \exp(r\mu + r^2\sigma^2/2)$ and for $\lambda > 0$, we have $Y \sim TN(\mu, \sigma^2, -1/\lambda)$. Let $S(y) = (\lambda y + 1)^{r/\lambda}$. One can expand $S(y)$ around μ to show $S(y) = \sum_{i=0}^{\infty}\frac{1}{i!}S^{(i)}(\mu)(y-\mu)^i$ where $S^{(i)}(y) = (\lambda y + 1)^{r/\lambda - i}\prod_{j=1}^{i-1}(r - j\lambda)$ and obtain

Lemma 1 : Let $X \sim PN(\lambda, \mu, \sigma^2)$. *If* $Y = (X^\lambda - 1)/\lambda$ *and* $Z = (Y-\mu)/\sigma$. *One has*

$$E(X^r) = \sum_{i=0}^{\infty}\frac{1}{i!}S^{(i)}(y)\sigma^i E(Z^i), \quad (3)$$

for $\lambda > 0$ *and* $E(X^r) = \exp(r\mu + \frac{r^2\sigma^2}{2})$ *for* $\lambda = 0$.

Note that $Z \sim TN(0, 1, T)$ and that $E(Z^i) = \frac{\phi(T)}{1-\Phi(T)}H_{i-1}(T) + R$ where R is a polynomial of degree $i-2$ in Z and H_{i-1} is the $(i-1)th$ Chevyshev-Hermite Polynomial. When Y is approximated with a normal distribution; e.g. for small κ, we have $E(y-\mu)^i = (\sigma^i i!)/(2^{i/2}(i/2)!)$ for even i and 0 for odd i. Therefore,

Lemma 2 : Let $X \sim PN(\lambda, \mu, \sigma^2)$, $\lambda \neq 0$ *and* $Y \sim N(\mu, \sigma^2)$. *Then,*

$$E(X^r) = \sum_{\text{Even } i \geq 0}\frac{\sigma^i i!}{2^{i/2}(i/2)!}S^{(i)}(y). \quad (4)$$

Tables 1 and 2 obtain the form of $E(X)$ and $Var(X)$ for some $0 \leq \lambda \leq 1$. Let $\delta_i = (\lambda\sigma)^i(\lambda\mu + 1)^{(m-i)}$. When $m = r/\lambda$ is an integer, one can show for $\lambda \neq 0$, that $E(X^r)$ is

$$\begin{cases} \sum_{i=0}^{m}\binom{m}{i}\delta_i E(Z^i), \\ \sum_{\text{Even } i=0}^{m}\binom{m}{i}\delta_i i!/(2^{i/2}(i/2)!) \end{cases} \quad (5)$$

where $Y \sim TN(\mu, \sigma^2, -1/\lambda)$ and $Y \sim N(\mu, \sigma^2)$, respectively. For example, when $r = \lambda$, $E(X^\lambda) = \lambda\mu + 1$ and $Var(X^\lambda) = \lambda^2\sigma^2$.

2.2 CDF and the Quantile Functions

One can consider median and other quantiles to avoid difficulties with the mean. CDF and quantile functions can be used as tools in statistical modeling in a number of applications when interest focuses particularly on the extreme observations in the tails of the data (Modarres, Nayak and Gastwirth, 2002). For example, to identify a suitable model, graphs and exploratory analysis of sample observations will give an impression of the basic shape of distribution. Adequacy of fit can be judged from a plot of sample quantiles against the corresponding model quantiles. Let $Z = (p_\lambda(X) - \mu)/\sigma$. The cdf of $PN(\lambda, \mu, \sigma^2)$ is $F(X) = \frac{1}{K} \cdot (\Phi(Z) - \Phi(-T))$ for $\lambda > 0$, and $\frac{1}{K} \cdot \Phi(Z)$ for $\lambda < 0$. When $\lambda = 0$ or $Y \sim N(\mu, \sigma^2)$ one has $F(X) = \Phi(Z)$. For large T, $F(X) = \Phi(p_\lambda(X) - \mu)/\sigma)$. Let $V(p) = 1 - (1-p)\Phi(T)$ for $0 < p < 1$. The quantile function of $PN(\lambda, \mu, \sigma^2)$ is given by $Q_\lambda(p) =$

$$\begin{cases} (\lambda(\sigma\Phi^{-1}(V(p)) + \mu) + 1)^{1/\lambda}, & \lambda > 0, \\ \exp(\mu + \sigma\Phi^{-1}(p)), & \lambda = 0, \\ (\lambda(\sigma\Phi^{-1}(p) + \mu) + 1)^{1/\lambda}, & \lambda < 0. \end{cases} \quad (6)$$

One can obtain a simultaneous quantile plot for different values of λ. Such a plot reveals that the transformation parameter λ has more effects on the upper tail for $0 \le \lambda \le 1$ and that extreme observations may have more influence on estimation of λ. The log-normal quantile function has a longer tail and is clearly separated from other PN quantiles. This explains why likelihood-based methods of model selection perform so well in identifying the lognormal distribution (Shumway et al., 1989). One may obtain a weighted least squares estimator for λ by modifying the least squares estimator of λ. Maximum likelihood estimation of the quantiles is an attractive procedure due to the existing form of (6). One can use the asymptotic normality of MLE's along with their invariance property to show asymptotic normality of $\hat{Q}_\lambda(p)$ using $\hat{\mu}$ and $\hat{\sigma}^2$, which are MLE's of the mean and variance on the transformed scale.

3. Multivariate Power-Normal

Consider the Box-Cox power transformation defined by $p_{\lambda_j}(X_j) = \frac{X_j^{\lambda_j} - 1}{\lambda_j}$ when $\lambda_j \neq 0$ and $p_{\lambda_j}(X_j) = \ln X_j$ when $\lambda_j = 0$ for each variable X_j, $j = 1, ..., p$, that is non-negative. Let $Q = [p_{\vec{\lambda}}(\vec{X}) - \vec{\mu}]'\Sigma^{-1}[p_{\vec{\lambda}}(\vec{X}) - \vec{\mu}]$. The inverse transformations define a p-variate vector $\vec{X} = (X_1, X_2, ..., X_p)$ with a probability distribution $f(\vec{X} \mid \vec{\lambda}, \vec{\mu}, \Sigma) =$

$$\frac{1}{K} \cdot \frac{1}{(2\pi)^{p/2} \mid \Sigma \mid^{1/2}} \prod_{j=1}^{p} X_j^{\lambda_j - 1} \cdot \exp(-\frac{1}{2}Q),$$

where K depends on $T_i = 1/(\lambda_i \sigma_i) + 1/\kappa_i$. Denote the bivariate standard normal pdf and cdf with $\phi_2(z_1, z_2) = \frac{1}{2\pi\sqrt{1-\rho^2}} \exp[-\frac{1}{2(1-\rho^2)}(z_1^2 + z_2^2 - 2\rho z_1 z_2)]$ and $\Phi_2(z_1, z_2) = \int_{-\infty}^{z_1} \int_{-\infty}^{z_2} \phi_2(t_1, t_2) dt_1 dt_2$, respectively. The random vector (X_1, X_2) from $PN(\vec{\lambda}, \vec{\mu}, \Sigma)$ has a pdf $f(X_1, X_2) = \frac{1}{K} \cdot \frac{1}{\sigma_1 \sigma_2} X_1^{\lambda_1 - 1} X_2^{\lambda_2 - 1} \phi_2(Z_1, Z_2)$ for $X_i > 0$, i= 1, 2, where $\vec{\lambda} = (\lambda_1, \lambda_2)$, $\vec{\mu} = (\mu_1, \mu_2)$, $\Sigma = (\sigma_{ij})$. Note that $K = \Phi_2[S(\lambda_i)T_i, S(\lambda_j)T_j]$ for $\lambda_i \neq 0$ and $\lambda_j \neq 0$, and $K = \Phi(S(T_i)T_i)$ for $\lambda_i \neq 0$ and $\lambda_j = 0$ where $S(\lambda_i)$ refers to the sign of the transformation, For the bivariate log-normal distribution, $K = 1$ when $\lambda_i = \lambda_j = 0$.

Assuming that the joint distribution of $\vec{Y} = p_{\vec{\lambda}}(\vec{X})$ is approximately normal, the forms for the covariance of the selected bivariate PN distributions are given in Table 3. The distribution of (Y_1, Y_2) is truncated bivariate normal for $\lambda_i \neq 0$, i=1, 2, and bivariate normal for (λ_1, λ_2)=(0,0). As in the univariate case, (Y_1, Y_2) are approximately bivariate normal for small coefficient of variations κ_1 and κ_2 for $\vec{\lambda} \neq \vec{0}$. Most researchers assume $K \approx 1$ for practical purposes (Johnson and Wichern, 2002; Gnanadesikan, 1977).

As an aid for model selection, a collection of contours and 3-dimensional plots for several values of $\vec{\lambda}$ appear in Freeman and Modarres (2002b). These plots are helpful in the early stages of model selection. Examination of bivariate contour plots along with univariate Q-Q plots help to identify a transformation set. The likelihood function can be maximized over this set to obtain an effective scale on which to analyze the data. It is interesting to note that the bivariate contours change forms as the forms of the margins change and the elliptical shape of the bivariate contours vanish when the margins are not normal even though the joint dependence is through a bivariate normal copula. One can show that if (y_1, y_2) has a bivariate normal distribution, then $F(X_1, X_2) = \Phi_2(Z_1, Z_2)$. The next lemma, which follows from properties of a multivariate normal distribution (Anderson, 1984), states that the conditional distributions derived from joint PN distributions are also PN.

Lemma 3 : Let $\vec{X}$ *be the PN p-variate random vector such that* $\vec{X} = \left(\vec{X}^{(1)}, \vec{X}^{(2)}\right)$ *where* $\vec{X}^{(1)}$ *and* $\vec{X}^{(2)}$ *are q and* $(p-q)$*-variate random vectors with parameter vectors* $\vec{\lambda}^{(1)}$ *and* $\vec{\lambda}^{(2)}$*. Suppose that we partition* $\vec{\mu}$ *and* Σ *similarly.*

- *The marginal distribution of* $\vec{X}^{(1)}$ *is PN*$(\vec{\lambda}^{(1)}, \vec{\mu}^{(1)}, \Sigma_1)$*.*
- *The conditional distribution of* $\vec{X}^{(2)}$ *given* $\vec{X}^{(1)}$=$\vec{x}^{(1)}$ *is a* $(p-q)$*-variate* $PN(\vec{\lambda}^{(2)}, \vec{\mu}^*, \Sigma^*)$ *with* $\vec{\mu}^* = \vec{\mu}^{(2)} + \Sigma_{12}\Sigma_{11}^{-1}(p_{\vec{\lambda}^{(1)}}(\vec{X}^{(1)}) - \vec{\mu}^{(1)})$ *and* $\Sigma^* = \Sigma_{22} - \Sigma_{21}\Sigma_{11}^{-1}\Sigma_{12}$*.*
- $\vec{X}^{(1)}$ *and* $\vec{X}^{(2)}$ *are independent when* $\Sigma_{12} = 0$*.*

Note that the conditional means depend non-linearly and the variances and covariances do not depend on the values of the fixed variates. For example, the conditional distribution of X_2 given $X_1 = x_1$ is $PN(\lambda_2, \mu, \sigma^2)$ where $\mu = \mu_2 + \rho\sigma_2/\sigma_1(p_{\lambda_1}(x_1) - \mu_1)$ and $\sigma^2 = \sigma_2^2(1-\rho^2)$. Mostafa and Mahmoud (1964) study the mean, median and modal regression of the bivariate log-normal distribution. We extend their result to the PN distribution in the following lemma.

Lemma 4 : If (X_1, X_2) *has a bivariate PN distribution, then Median*$(X_2|X_1)$*,* $E(X_2|X_1)$*, and Mode*$(X_2|X_1)$ *are obtained by evaluating (1), (3) and (6), respectively, at* $\mu = \mu_2 + \rho\sigma_2/\sigma_1(p_{\lambda_1}(x_1) - \mu_1)$ *and* $\sigma^2 = \sigma_2^2(1-\rho^2)$ *with* $\lambda = \lambda_2$*.*

4. Correlations

Let ρ_{X_1,X_2} and $\rho = \rho_{Y_1,Y_2}$ denote the coefficient of correlations in the PN and normal scales, respectively. In this section we assume $\vec{Y} \sim (\vec{\mu}, \Sigma)$ and show that $\rho_{X_1,X_2} = f(\rho)$, where the form of the function f depends on the transformation parameter $\vec{\lambda}$ as well as $\vec{\mu}$, and Σ. See (Freeman and Modarres, 2002b) for a more complete discussion. One can show

$$f(\rho) = \frac{\sum_{i=1}^{\infty} b_{1i} b_{2i} \rho^i i!}{\sqrt{(\sum_{i=1}^{\infty} b_{1i}^2 i!)(\sum_{j=1}^{\infty} b_{2j}^2 j!)}}. \qquad (7)$$

It follows from the form of the joint density of (X_1, X_2) and equation (7) that if $\rho = 0$, then $f(\rho) = 0$. Further, ρ is zero when $f(\rho) = 0$ by the transformation property of functions of independent random variables (Karr, 1993). The following lemma whose proof appears in the technical report shows that the coefficient of correlation in the PN scale cannot be greater than that in the normal scale.

Lemma 5 : Let (X_1, X_2) *be distributed with* $PN(\vec{\lambda}, \vec{\mu}, \Sigma)$ *with* $\vec{\mu} = (\mu_1, \mu_2)$*, and covariance* Σ*. Let* $f(\rho)$ *be the correlation of coefficient of* X_1 *and* X_2*. Then,* $\mid f(\rho) \mid \leq \mid \rho \mid$ *.*

For the bivariate log-normal distribution this result is given without proof in Mostafa and Mahmoud (1964). Finally, note that $P_\lambda(X)$ are monotone transformations and the rank measures of correlation remain the same on both scales.

4.1 Extreme Correlations

Even though the minimum and maximum correlation for $\vec{\lambda} = (0,0)$ and $\vec{\lambda} = (1,1)$ are -1 and 1, it may not be the case for other transformations. Specific forms of extreme correlations of selected (λ_1, λ_2) are obtained and appear in Table 3. It is tedious to determine the mathematical forms of extreme correlations. One can, however, use the following computational scheme to calculate them numerically. Let Π be the set of all cdf's $F(X_1, X_2)$ on R^2 having marginal cdf's $F_i(X_i)$, $i = 1, 2$, with finite variances. Fréchet's bounds (Fréchet, 1951) provide $H_0(X_1, X_2) \leq F(X_1, X_2) \leq H_1(X_1, X_2)$ where $H_0(X_1, X_2) = Max(0, F_1(X_1) + F_2(X_2) - 1))$ and $H_1(X_1, X_2) = Min(F_1(X_1), F_2(X_2))$ belong to Π.

To show that the correlations under H_0 and H_1 are the minimum and maximum, respectively, note that $f(\rho) = \frac{1}{\sigma_1\sigma_2}(\int_0^\infty \int_0^\infty F(x_1, x_2) - F_1(x_1)F_2(x_2)dx_1dx_2)$ (Lehmann, 1966). Let ρ_0 and ρ_1 be the coefficient of correlation under H_0 and H_1. It follows that $\rho_0 \leq f(\rho) \leq \rho_1$. Let Q_j be the quantile function of X_j for $j = 1, 2$ and u be a uniform random variable in the intervel $(0, 1)$. One can show (See Whitt, 1976) that $(Q_1(u),\ Q_2(1-u))$ has cdf $H_0(X_1, X_2)$ and $(Q_1(u),\ Q_2(u))$ has cdf $H_1(X_1, X_2)$. It follows that $Corr[(Q_1(u), Q_2(1-u))] \leq f(\rho) \leq Corr(Q_1(u), Q_2(u))$.

To obtain the numerical values for the minimum and maximum correlations of $PN(\vec{\lambda}, \vec{\mu}, \Sigma)$, we generate a vector of independent uniform random variables $\vec{u}_n$; then, the maximum and minimum correlations for $(\lambda_1 > 0, \lambda_2 > 0)$ are computed from $f^{min}(\rho) = Corr(Q_1(u), Q_2(1-u))$ and $f^{max}(\rho) = Corr(Q_1(u), Q_2(u))$ where the quantile function is given by (6). Technical report contains a table of the averages of 100 minimum and maximum correlations computed based on $n = 100,000$, $\vec{\mu}$=(4,4), and $\sigma_1^2 = \sigma_2^2 = 1$ for each selected $\vec{\lambda}$.

References

[1] Anderson, T. W. (1984). An Introduction to Multivariate Analysis. Second Edition. Wiely.

[2] Box, G. E., and Cox, D. R. (1964). An Analysis of Transformed Data. Journal of Royal Statistical Society. B, 39, 211-252.

[3] David, F. N. and Johnson, N. L. (1954). A Test for Skewness with Ordered Variables. Annals of Eugenics. 18, 351-353.

[4] Fréchet, M. (1951). Sur Les Tableaux de Corrélation Dont le Marges sont Données. Ann. Univ: Lyon Sect. A 14, 53-77.

[5] Freeman, J., and Modarres, R. (2002a). Analysis of Censored Environmental Data with Box-Cox Transformations. Technical Report. Department of Statistics. George Washington University.

[6] Freeman, J., and Modarres, R. (2002b). Properties of the Power Normal Distribution. Technical Report. Department of Statistics. George Washington University.

[7] Galton, F. (1879). The Geometric Mean in Vital and Social Statistics. Proceedings of the Royal Statistical Society of London. Volume 29, 365-367.

[8] Gnanadesikan, R. (1977). Methods for Statistical Analysis of Multivariate Observations. John Wiley & Sons. New York.

[9] Goto, M. and Inoue, T. (1980). Some Properties of Power Normal Distribution. Bulletin of the Biometric Society of Japan, 1, 28-54.

[10] Haas, C. N. (1997). Importance of Distributional Form in Characterizing Inputs to Monte Carlo Risk Assessment. Risk Analysis. Volume 17, No. 1, 107-113.

[11] Johnson, M. E. (1987). Multivariate Statistical Simulation, New York.

[12] Johnson, N. L. (1949). Systems of Frequency Curves Generated by Methods of Translation. Biometrika, Vol. 36, No. 1/2, 149-176.

[13] Johnson, R. A., and Wichern, D. W. (2002). Applied Multivariate Analysis. Fifth Edition, Prentice Hall.

[14] Johnson, N. L., Kotz, S. and Balakrishnan, N. (1994). Continuous Univariate distributions. Volumes I. John Wiley & Sons, 2nd ed.

[15] Karr, A. F. (1993). Probability. Springer, New York.

[16] Land, C. E. (1974). Confidence Interval Estimation for Means After Data Transformations to Normality. Journal of the American Statistical Association, Vol. 69, No. 347, 795-802.

[17] Lehmann, E. L. (1966). Some Concept of Dependence. Annals of Mathematical Statistics. 37, 1137-1153.

[18] Modarres, R., Nayak, T. K. and Gastwirth, J. L. (2002). Estimation of Upper Quantiles under Model and Parameter Uncertainty. Computational Statistics and Data Analysis, 39, 529-554.

[19] Mostafa, M. D. and Mahmoud, M. W. (1964). On the Problem of Estimation for the Bivariate Lognormal Distribution. Biometrika, Vol. 51, No. 3/4. 522-527.

[20] Ott, W. R. (1995). Environmental Statistics and Data Analysis. Lewis Publishers.

[21] Sakia, R. M. (1992). Box-Cox Transformation Technique: A Review. The Statistician. 42, 169-178.

[22] Shumway, R. H., Azari, A.S., and Johnson, P. (1989). Transformation for Environmental Data with Detection Limits. Technometrics. Volume 31, No. 3, 347-356.

[23] Whitt, W. (1976). Bivariate Distributions with Given Marginals. Annals of Statistics. 4, 6, 1280-1289.

Table 1: Means of Power-Normal Distribution

λ	E(X)
0	$\exp(\mu + \frac{1}{2}\sigma^2$
$\frac{1}{4}$	$\frac{1}{4}\mu + 1)^4 + \frac{3}{8}\sigma^2(\frac{1}{4}\mu + 1)^2 + \frac{3}{256}\sigma^4$
$\frac{1}{3}$	$\left(\frac{1}{3}\mu + 1\right)^3 + \frac{1}{3}\sigma^2 \left(\frac{1}{3}\mu + 1\right)$
$\frac{1}{2}$	$\frac{1}{2}\mu + 1)^2 + \frac{1}{4}\sigma^2$
1	$\mu + 1$

Table 2: Variances of Power-Normal Distribution

λ	Var(X)
0	$\exp(2\mu + \sigma^2)(\exp(\sigma^2) - 1)$
$\frac{1}{4}$	$\frac{8}{2048}\sigma^8 + (\frac{1}{4}\mu + 1)^2\sigma^2(\frac{3}{32}\sigma^4 + \frac{21}{32}\sigma^2 \left(\frac{1}{4}\mu + 1\right)^2 + \left(\frac{1}{4}\mu + 1\right)^4)$
$\frac{1}{3}$	$\frac{5}{243}\sigma^6 + \frac{4}{9}\sigma^4 \left(\frac{1}{3}\mu + 1\right)^2 + \sigma^2 \left(\frac{1}{3}\mu + 1\right)^4$
$\frac{1}{2}$	$\frac{1}{8}\sigma^4 + \sigma^2 \left(\frac{1}{2}\mu + 1\right)^2$
1	σ^2

Table 3: Covariances of Bivariate Power-Normal Distribution

(λ_1, λ_2)	$\mathrm{Cov}(X_1, X_2)$
$(0, 0)$	$\exp(\mu_1 + \mu_2 + \frac{1}{2}\sigma_1^2 + \frac{1}{2}\sigma_2^2)(\exp(\rho\sigma_1\sigma_2) - 1)$
(0,1/2)	$\rho\sigma_1\sigma_2 \exp(\mu_1 + \frac{1}{2}\sigma_1^2)(\frac{1}{4}\rho\sigma_1\sigma_2 + \frac{1}{2}\mu_2 + 1)$
(0,1)	$\rho\sigma_1\sigma_2 \exp(\mu_1 + \frac{1}{2}\sigma_1^2)$
(1/2,1/2)	$\frac{1}{8}(\rho\sigma_1\sigma_2)^2 + \rho\sigma_1\sigma_2\frac{1}{2}(\frac{1}{2}\mu_1\mu_2 + \mu_1\mu_2 + 2)$
(1/2,1)	$\rho\sigma_1\sigma_2(\frac{1}{2}\mu_1 + 1)$
(1,1)	$\rho\sigma_1\sigma_2$

Teacher Education: Technology of Water Environmental Education

Basic Information

Title:	Teacher Education: Technology of Water Environmental Education
Project Number:	2001DC4021B
Start Date:	3/1/2001
End Date:	2/28/2002
Funding Source:	104B
Congressional District:	DC
Research Category:	Not Applicable
Focus Category:	Education, None, None
Descriptors:	Environment, Water Science, Environmental Studies, Middle School/Junior High Schools Science Curriculum Mathematics, Science Environment Performance Objectives
Principal Investigators:	joanne.m.favors.1

Publication

WATER ENVIRONMENT STUDIES IN SCHOOLS
IN-SCHOOLS PROGRAM

OF

THE UNIVERSITY OF THE DISTRICT OF COLUMBIA
AGRICULTURAL EXPERIMENT STATION

PROGRAM SUMMARY

INTRODUCTION

The University of the District of Columbia (“UDC”) Agricultural Experimental Station (“AES”) and Water Resource Research Center (WRRC), in collaboration with Browne Junior High School, Terrell Jr High School and P.R. Harris Educational Center proposed the **Water Environment Studies In Schools (“WESS”)** to engage students in the exploration, analysis and restoration of selected areas of the Anacostia River Watershed. Teachers from these Institutes engaged in ten-days of extensive training in water quality assessment and conservation during the summer. A ten-day follow-up summer program practicum was completed with students. Teachers implemented the program in school during the academic year.

Program Overview

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’s focus is the Anacostia River Watershed in which the students and teachers are residents. The goals of **WESS** provide for 1) training for the schools' teachers in math, science, technology, art and humanities within water environmental studies; 2) involvement of students in the same discipline areas as required for the restoration and conservation of the Anacostia River and its flora and fauna; and 3) the development of a plan that engages the total community in the conservation of the Anacostia Watershed.

Student Program Activity

The **WESS Teacher Training Institute** is designed to empower teachers with the skills to introduce inner city students to environmental monitoring, assessment of land and water, data analyses including background rationale, scientific terminology, laboratory exercises, research projects, mathematical calculations and some specific laboratory and field techniques. The program provides a unique “hands-on” educational approach that engages university professors, public school teachers, student mentors, and middle/junior high school students in the development of critical thinking and problem solving skills. To support this line of study, field laboratory stations for environmental land and water quality monitoring of the Anacostia River Watershed have been established. Locations for activities include the participating schools, UDC laboratories and the Anacostia River.

Through the implementation of the program, teachers will be able to guide their students to experience a variety of science, mathematics, art and humanities projects that promote improving water quality and water conservation for the Anacostia Watershed. The program agenda also includes community organization activities and the constant inclusion of cultural connections.

Program Goals *for Student Activity*

1. To establish a core group of teachers trained in the knowledge and technology to integrate environmental education into the total junior high school and middle school curriculum.

2. To provide teachers with the expertise to write curriculum that integrates the current performance standards and allows for their application and reinforcement in mathematics, science, arts and humanities through environmental education.

3. To provide teachers with the skills to help students to achieve and maintain the academic standards necessary to bridge the transition from high school to college in science, mathematics and technology.

4. To increase the participation of minority youth in environmental issues and enhance their perspective of the effect they have on the environment through project focus on the Anacostia River.

5. To create a community movement to benefit the local environment issue which, in this case, is the Anacostia River.

Program Objectives

1. To engage teachers in the **WESS** Teacher Training Institute for a ten-day training session on the information and technology for implementing water environment studies programs with students.

2. To engage students in environmental studies that can reinforce skills and performance standards in math, science and computer technology, primarily; and arts and humanities in the process of learning the tasks necessary for the restoration and preservation of the Anacostia River Watershed.

3. To design a plan to improve the ecological integrity and aquatic diversity of the Anacostia River Watershed that includes strategies for reducing pollutant loads to improve water quality.

4. To establish collaborative and working partnerships with community residents and watershed restoration groups that can increase public awareness and participation in the clean up and restoration of the Anacostia River Watershed.

5. To familiarize youth and teachers with the unique careers in environmental and water quality management.

WATER ENVIRONMENT STUDIES IN SCHOOLS *IN-SCHOOLS PROGRAM* EFFECTIVENESS EVALUATION

Introduction

This report provides formative and summative findings for the Water Environment Studies in Schools (**WESS**) *In-School* Program. The evaluation measures the effectiveness of the goals and objectives of the program and addresses the program's strengths and areas for improvement. The assessment was based upon data collected, including the proposal plans submitted by each school, the activities observed, the documentation of student experiences, and the submission and evaluation of the final projects.

Methodology

Data was collected throughout the project and was compiled at the end of the project. These methods were used to collect the data from the participants:

- An outline of the proposed project was submitted for each school.
- Observation Forms of classroom performances were completed by the Monitor.
- Informal observations were conducted by the monitor.
- Documentation of student experiences was provided.
- Documentation of each schools final project was submitted.

Overview

The **Water Environment Studies in Schools ("WESS")** ***In-Schools*** Program of the Agricultural Experiment Station (AES) and Water Resources Research Center (WRRC) of University of the District of Columbia (UDC) is a project that focuses on the Anacostia River Watershed. Designed to enhance children's awareness, as well as, the community's awareness of water environmental education, the program was conducted in three District of Columbia Public Schools. The three schools represented three quadrants of the city. The participating schools are Browne Junior High School located at 850 26th Street, NE; P.R. Harris Educational Center located at 4600 Livingston Road, SE; and R.E. Terrell Junior High School located at 100 Pierce Street, NW. Seventh and eighth grade along with the inclusion of special needs students represented the populations at Browne and R.E. Terrell Junior High Schools. Non-graded students ranging in age from

10 to 12, but functioning at second to third grade level represented the population at P.R. Harris Educational Center.

Program Mission

The mission for the program is to engage students in the exploration, analysis and restoration of selected areas of the Anacostia River Watershed. With this mission as a guide, the following school projects were designed and conducted.

Browne Junior High School

Focus

The focus of the project at Browne Junior High School was to engage students in hands-on water related experimentation activities exploring how water is purified and researching the history of the Anacostia River. In addition, the focus was to incorporate the water related activities with the on-going school program – "Connect" – Project-based Learning Environment. (This school-wide program promotes students' making connections in their learning as they explore projects based on multiple disciplines, common themes, and related concepts in an engaging learning environment.) Thus all of the WESS activities were incorporated into projects related to regular classroom instruction at Browne JHS.

Efforts Addressed through Standards-Based Curriculum

The following concepts and performances were addressed through the curriculum.

- Gaining an understanding of water purity;
- Designing flow charts to illustrate water purification;
- Using technology to increase students' awareness of the history of the Anacostia River and other water studies;
- Gaining an understanding of natural resource management; and
- Using creative writing skills to recapture historical events about the Anacostia River and to share information about water studies.

Classroom and Field Lab Activities

The participants engaged in the following classroom and field lab activities:

- Accessing information through the Internet and other sources of media to compose a research report depicting issues concerning the Anacostia River;
- Creating and photocopying a Newsletter for dissemination to the BJHS Community to arouse the awareness of the Anacostia River and its problems;
- Organizing and inviting the area residents to participate in a Non-point Sources Cleanup Day at Browne JHS; and
- Experimenting with water activities, conducting research for an anthology project, preparing photograph portfolios, exploring creative writing and other projects related to the Anacostia River project.

Culminating Performances

The following activities are a listing of the culminating performances. The students:

- Designed and prepared a computer generated Newsletter that showcased articles that depicted activities of the group and that promoted the need for the community to make an effort to help save the Anacostia River.
- Prepared and presented an anthology on the Anacostia River for BJHS students, the WESS monitor and others.
- Designed and prepared computer generated fliers to inform the school's student body and the neighboring community members about the Anacostia River, water conservation, and protecting the environment against pollution.
- Participated in a Non-point Sources Cleanup Day which included the immediate area at Browne JHS and the neighboring area.

R.E. Terrell Junior High School

Focus

The WESS Program at R.E. Terrell Junior High School was to engage students in standards-based activities as a means to stimulate their desire to learn about the importance of water and how it contributes to the sciences and to our environment. Experiences to support these activities include field lab investigations at selected water sites where experiments were conducted.

Efforts Addressed through Standards-Based Curriculum

The following concepts and performances were addressed through the curriculum.

- Creating an awareness of water purity;
- Testing water purity by investigating water samples from Anacostia River;
- Using technology to increase student's awareness of water studies;
- Increasing students' awareness of environmental scientists and the various water conservation methods that they employ; and
- Exploring various areas of study in water research.

Classroom and Field Lab Activities

The participants engaged in the following classroom and field lab activities:

- Surfing the Internet to collect information on facts about water (its uses, where its found, its varying conditions, and its importance);
- Exploring technology skills to develop Power Point Presentations;
- Interacting with guest speakers from organizations affiliated with the water environmental community and addressing issues related to the Anacostia River as well as careers related to water studies;
- Viewing videos on water biomes and water purification and viewing slide presentations about the Anacostia River and the Anacostia Watershed;
- Touring water sites including the National Aquarium, the Anacostia River and the Bladensburg Waterfront to gain an understanding of the importance of water and some of it' many uses; and

- Conducting test on water samples taken from the Anacostia River to determine the quality of the river water.

Culminating Performances

The following activities are a listing of the culminating performances. The students:

- Completed a survey to determine the effectiveness of the WESS project.
- Prepared a Power Point presentation on the study of water including the water cycle, an explanation of terms related to water and historical events about the Anacostia River.
- Analyzed and summarized data collected, based upon the test results of water samples from the Anacostia River (Bladensburg Water front Center).
- Designed and prepared computer generated Newsletter to share information gained throughout the study of water.

P.R. Harris Educational Center

Focus

The focus of the WESS Program at P.R. Harris was to introduce students to the study of water, water quality and pollution.

Efforts Addressed through Standards-Based Curriculum

The following concepts and performances were addressed through the curriculum.

- Gaining an understanding that water on earth moves in a continuous cycle,
- Naming and explaining the stages of the water cycle.
- Using Internet data to access information about the water cycle on the Anacostia River.

Classroom and Field Lab Activities

The students engaged in the following classroom and field lab activities:

- Exploring the study of water by focusing on the forms of water, where water is found, how pollution affects the use of water;
- Viewing videos and slide presentations about the Anacostia River and the Anacostia Watershed to make connections between the forms of water and the water cycle;
- Interacting with guest speakers from organizations affiliated with the water environmental community and addressing issues related to the Anacostia River and the water cycle;
- Conducting test on water samples taken from the Anacostia River to observe how pollution affects the quality of the river water; and
- Participating in Earth Day Cleanup and Celebration on Anacostia River as a means to help restore the river.

Culminating Performances

The following activities are a listing of the culminating performances. The students:

- Completed a survey to determine their understanding of the water cycle.

- Created drawings to illustrate their ability to describe the water cycle.
- Created drawings of pictures that represented their environment (community) including the water cycle.
- Conducted test on water samples taken from the Anacostia River.
- Participated in the Earth Day Cleanup and Celebration on Anacostia River.

Summary of Findings

Students from the three participating schools and community members from the surrounding neighborhoods benefited from the overall experience with the **WESS** *In-Schools* Program. In each of the schools the program's primary focus was addressed through science, mathematics and technology with a direct relation to the standards. One school included in their study an emphasis on research and creative writing skills. Again, the standards relating to those disciplines were addressed. All schools engaged in activities that focused on the Anacostia River. These activities ranged from writing an anthology on the history of the river, to testing and analyzing water samples taken from the river, to participating in the Anacostia River Cleanup Day. Students from the schools sort and received community support with their cleanup efforts. Members of the community as well as members from environmental groups offered their support to help with the effort of restoring the Anacostia River. In addition to these individuals providing assistance and information about restoring the river, they also provided information about careers in environmental science and water quality management. As a part of each schools project, they discussed restoration efforts for the river and initiated a plan to help increase public awareness and participation in the continuing cleanup of the Anacostia River.

It was a learning experience for all that were involved, directly and indirectly. Participation in the program promoted a list of positive outcomes and raised a number of issues that support the need and continuation of such environmental studies. The major benefits and areas of improvement are identified below:

Major Benefits to the Students:

- Gained a deeper understanding of water (ie., its uses, where it is found, the forms, water purification, etc);
- Gained an appreciation for the value of water and the value of a clean Anacostia River;
- Gained experience by working in teams and collaborating to solve problems;
- Gained experience in using the technology tools to gather, analyze and present data;
- Gained experience in writing efforts to inform the public about water – and in particular the Anacostia River;
- Gained an opportunity to view first hand, the positive and negative effects of what can happen to water in various situations; and
- Gained information regarding careers related to environmental studies.

Major Benefits to Community:

- Gained information about the value of protecting the water ways in the community;
- Gained information regarding the impact of pollution on the environment as a whole and in particular the impact of pollution on the Anacostia River;
- Gained an awareness of the many organizations available to help support the cleanup effort for the Anacostia River;
- Gained information about the pool of resources that environmental organizations have to share with the community; and
- Gained the efforts of student participants who are carrying the message to the community "Care for our water."

Strengths of the WESS *In-Schools* Program:

Based upon the evaluation of the program the following strengths are documented:

- Promotes environmental awareness;
- Promotes standards-based curriculum;
- Promotes the integration of the disciplines (science, mathematics, art, language arts/literature) ;
- Promotes the use of the computer and Internet accessibility to enhance the acquisition of information;
- Promotes collaboration and teaming efforts among students; and
- Promotes community involvement.

Areas of Improvement for WESS *In-School*s Program:

- Field trips to water sites should be encouraged for all schools.
- Broader scopes of inclusion of the WESS Project should be encouraged for all schools.

Recommendations for WESS *In-School*s Program

- Provide opportunities for the teachers in each participating school to met with other teachers in the program so that they can share ideas, problems that exist, possible solutions, beneficial organizations that can contribute to the program and general experiences.
- Provide a joint program effort wherein students can observe what the other schools have done in an effort to broaden their own ideas.
- Promote the idea for more teachers (ultimately results in more classes) from the participating schools to become involved in the program.
- Promote the WESS In-Schools program through parental involvement to increase community participation.

Performance-Based Standards Addressed through the Curriculum

The following standards and performances were addressed through the curriculum.

- Earth/Space Concepts: Water Cycle and Natural Resource Management
- Scientific Connections and Applications: Historical and contemporary contributions
- Scientific Thinking: Individual and team efforts to collect and share information and ideas
- Scientific Thinking: Identifies problems, proposes and implements solutions
- Scientific Thinking: Uses Science concepts to explain observations/phenomena
- Scientific Tools and Technology: Acquires information from multiple sources
- Scientific Tools and Technology: Uses technology and tools to observe/measure
- Scientific Communication: Communicates in a form suited to the purpose and the audience.

Speciation of Tributyltin and Triphenyltin Compounds in Clays from Sediments Using Mossbauer Spectroscopy

Basic Information

Title:	Speciation of Tributyltin and Triphenyltin Compounds in Clays from Sediments Using Mossbauer Spectroscopy
Project Number:	2001DC4061B
Start Date:	3/1/2001
End Date:	2/28/2002
Funding Source:	
Congressional District:	DC
Research Category:	
Focus Category:	Sediments, None, None
Descriptors:	Mossbaur spectroscopy, water pollution, sediments, clays, speciation, tripheyltin compounds,Tributyltin compounds
Principal Investigators:	leopold.may.1, George Eng

Publication

Progress Report

October 18, 2002
Subcontract No. UDC-00-01-010
November 1, 2001 – August 31, 2003

Speciation of Tributyltin and Triphenyltin Compounds in Clays from Sediments Using Mõssbauer Spectroscopy

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Introduction

Previously, we had examined the speciation of tributyltin (TBT) and triphenyltin (TPT) compounds directly in sediments from the Anacostia River (5), Baltimore Harbor (1), Chesapeake Bay (2- 4), and Potomac River (5). Tin Mössbauer spectroscopy was used to determine the nature of the tin compounds in the sediments. It was found that the speciation of triorganotin compounds varies with the nature of the sediment. It is important to determine which component or components of the sediment are involved in the speciation of the tin compound. The Anacostia and Potomac Rivers are in the Washington Quadrangle of which one-fourth is in the Piedmont Plateau and the remainder in the Coastal plain (6). Clays are one of the important components of these formations. For example, it has been reported that kaolin is one of the clays that have been found (6, p. 27).

X-Ray Diffraction of Sediments

X-ray diffraction of dried sediments from the Anacostia (AR-1) and Potomac Rivers (PR10) was measured using the LabX, XRD-6000 (Shimadzu, Co.). Some of the major lines in the x-ray patterns are shown in Table 1 with the assignments of the lines. Both samples contained as a major constituent, a-quartz, and clays plus other constituents such as goethite. The clays included kaolinite, illite, smectite, and chlorite.

Mössbauer Spectroscopy

The following procedure was used in all experiments: Mixtures of 5 g of the clay sample (kaolinite, Sullivan's Grove, Md., Potomac River) or sand and 5 mL of solution containing the organotin compound amounting to 3.3 % were shaken mechanically in closed test tubes for two weeks at room temperature. After remaining at room temperature for two additional weeks, the sample was removed by gravity filtration and kept frozen until the Mössbauer spectrum is measured. The Mössbauer spectra were measured at 80K on a Mössbauer spectrometer model MS-900 (Ranger Scientific Co.) in the acceleration mode with moving source geometry.

The results are presented in Tables 2 and 3 compared with results of spectra found with speciation studies in sediments from the Anacostia (AR) and Potomac (PR) Rivers (5). The initial results show that the TPTCl has the same Mössbauer parameters in kaolinite as in the sediments and as a neat sample. This suggests that it was unchanged in these media. The same is found for TPTOH in kaolinite and sand indicating that the compound was probably converted to the chloride. The results for TBTO are not reproducible and require additional samples to be mixed with both the clay and sand. Both the quadrupole splittings and the isomer shifts are different in the two sets of samples. In one sample of TBTCl and kaolinite, the Mössbauer parameters of the tin compound was the same as the parameters of the neat sample of the tin compound.

Future Studies

It is planned to continue the studies on the speciation between the clay and sand and the triorganotin compounds TPTCl, TPTOH, TBTO, TBTCl and expand the speciation with the acetates of TPT and TBT. Other clays that can be purchased include illite, montmorillonite and smectite (nontronite). We are also starting the study of the infrared spectra of the tin compounds with the components to determine the nature of the interaction.

Literature Cited

(1) Eng, G.; Bathersfield O.; May, L. *Water, Air, Soil, Pollut*., **1986,** *27*, 191.

(2) Lucero, R. A.; Otieno, M. A.; May L.; Eng, G. *Appl. Organomet. Chem*., **1992**, *6*, 273.

(3) Whalen, D.; Lucero, R.; May, L.; Eng, G., Appl*. Organometal. Chem.*, **1993**, *7*, 219-22.

(4) May, L.; Berhane, L.; Berhane, M.; Counsil, C.; Keane, M; Reed, B. B.; Eng, G. *Water, Air, Soil, Pollut*., **1994**, *75,* 293.

(5) Eng, G.; Destal, D.; Biba, E.; Song, X.; May, L., *Appl. Organomet. Chem.*, **2002**. *16*, 1-5.

(6) Williams, M. T. *A History of Erosion in the Anacostia Drainage Basin*, Ph. D. Dissertion, The Catholic University of America, Washington, DC, 1942.

Table 1.Selected Lines in the X-Ray Patterns of Sediments from the Anacostia (Left-AR 1) and Potomac (Right-PR 10) Rivers

Number	2?	I/I_{max}	Assignment	Number	2?	I/I_{max}	Assignment
1	8.88	9	Illite	1	5.80	3	Smectite
3	17.79	6	Goethite	2	8.96	22	Illite
4	20.85	16	a-Quartz	5	17.79	9	Goethite
6	26.63	100	a-Quartz	7	20.85	20	a-Quartz
9	45.58	8	Kaolinite	10	26.63	100	a-Quartz
				14	40.32	4	Chlorite

Table 2. Mössbauer Spectra of Triphenyltin (TPT) Compounds in Sediments and Components

Compound	Medium	QS Aerobic	IS Aerobic	QS Anaerobic	IS Anaerobic	Ref.
TPTCl	Neat	2.62(7)	1.35(2)			2
	AR 1	2.81(5)	1.20(1)	2.83(3)	1.13(1)	5
	AR 2	2.80(7)	1.30(2)	2.82(3)	1.23(1)	5
	AR 4	2.60(3)	1.28(7)	2.83(3)	1.22(1)	5
	AR 6	2.74(5)	1.17(1)	2.79(3)	1.21(1)	5
	PR 4	2.75(3)	1.17(1)	2.74(2)	1.17(1)	5
	PR 7	2.85(7)	1.20(2)	2.79(3)	1.22(1)	5
	PR 9	2.83(3)	1.19(1)	2.85(2)	1.20(1)	5
	PR 10	2.88(3)	1.21(1)	2.84(2)	1.20(1)	5
	Kaolinite	2.70(3)	1.34(1)			a.
	Kaolinite	2.61(5)	1.26(1)			a
	Sand	2.56(5)	1.34(1)			a
TPTOH	Neat	2.95(7)	1.23(7)			2
	AR 1	2.76(3)	1.18(1)	2.76(3)	1.16(1)	5
	AR 2	2.91(4)	1.21(1)	2.74(2)	1.18(1)	5
	AR 4	2.75(3)	1.17(1)	2.77(3)	1.19(1)	5
	AR 6	2.74(5)	1.18(1)	2.76(2)	1.21(1)	5
	PR 4	2.79(3)	1.18(1)	2.78(2)	1.18(1)	5
	PR 7	2.76(5)	1.18(1)	2.73(3)	1.20(1)	5
	PR 9	2.83(4)	1.23(1)	2.72(3)	1.14(1)	5
	PR 10	2.75(3)	1.18(1)	2.79(4)	1.22(1)	5
	Kaolinite	2.73(2)	1.14(1)			a
	Sand	2.78(5)	1.20(1)			a

a- This work.

QS = Quadrupole Splitting; IS = Isomer Shift

Table 3. Mössbauer Spectra of Tributyltin (TBT) Compounds in Sediments and Components

Compound	Medium	QS Aerobic	IS Aerobic	QS Anaerobic	IS Anaerobic	Ref.
TBTO	Neat	1.55(5)	1.11(1)			1
	Water	3.06(8)	1.41(1)			1
	Seawater	3.06(6)	1.37(2)			1
	AR 1	3.27(4)	1.39(1)	3.21(5)	1.39(1)	5
	AR 2	3.30(6)	1.47(1)	3.32(5)	1.47(1)	5
	AR 4	3.16(6)	1.38(2)	3.19(4)	1.44(1)	5
	AR 6	3.25(6)	1.46(1)	3.23(5)	1.41(1)	5
	PR 4	3.41(7)	1.34(2)	3.13(5)	1.43(2)	5
	PR 7	3.21(6)	1.44(3)	3.17(4)	1.41(1)	5
	PR 9	3.10(8)	1.47(2)	3.07(3)	1.36(1)	5
	PR 10	2.97(5)	1.44(1)	3.10(3)	1.43(1)	5
	Kaolinite	3.84(3)	1.49(1)			a
	Kaolinite	2.16(3)	1.03(1)			a
	Sand	2.96(5)	1.42(1)			a
	Sand	2.11(3)	1.05(1)			a
TBTCl	Neat	3.43(4)	1.56(1)			1
	Water	3.40(4)	1.55(1)			1
	Seawater	2.81(7)	1.36(7)			1
	AR 1	3.42(4)	1.53(1)	3.25(2)	1.43(6)	5
	AR 2	3.23(8)	1.39(2)	3.32(2)	1.45(1)	5
	AR 4	3.30(5)	1.39(1)	3.23(3)	1.39(1)	5
	AR 6	2.91(5)	1.25(1)	3.32(4)	1.43(1)	5
	PR 4	3.19(5)	1.43(1)	3.06(7)	1.37(1)	5
	PR 7	3.24(8)	1.33(2)	3.38(7)	1.45(2)	5
	PR 9	3.29(4)	1.41(1)	3.40(7)	1.51(2)	5
	PR 10	3.76(6)	1.62(2)	3.35(3)	1.44(1)	5
	Kaolinite	3.43(3)	1.47(7)			a

a-This work.

QS = Quadrupole Splitting; IS = Isomer Shift

Program Administration Project

Basic Information

Title:	Program Administration Project
Project Number:	2001DC4582B
Start Date:	3/1/2001
End Date:	2/28/2002
Funding Source:	104B
Congressional District:	
Research Category:	Not Applicable
Focus Category:	Management and Planning, None, None
Descriptors:	
Principal Investigators:	Roland Holstead

Publication

Program Management

The core of program development will continue to be active participation in the DC community concerned with water resources and local environmental issues. WRRI must continue to establish and maintain relationships with the following groups of persons and organizations:

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

Updating our webpage to include reports or abstracts of past project funded by WRRI and our pool of experts in the DC consortium of universities will be the main focus of next fiscal year. The Institute will continue to identify the priority water resource and watershed environmental issues, locate additional non-federal match, and solicit credible investigators and project teams for a vibrant program.

Program Goals

Goal one: Formation of Peer Review Committee

Highly qualified and respected researchers in the DC Metropolitan Area will be identified to:

- Evaluate proposed research projects;
- Evaluate research for Seed Grant Program;
- Review completed research projects.

The peer review committee will review proposals to measure researcher(s) expertise; appropriateness of research; benefits to stakeholders, and other required elements prior to submission for administrative approval. They will also review completed research reports to measure strengths, weaknesses, and completeness of objectives. Recommendations for technical and general publications of reports for dissemination to stakeholders will also be determined by the committee.

Goal two: Strengthen Relations with other District of Columbia Universities

The DC WRRI continues its efforts to develop and strengthen its ties with its consortium counterparts via research collaboration and Seed Grant projects. The Institute intends to update its database of water resources experts and continue to pursue research ventures with other area universities through networking, web page announcement, and written announcements.

Goal three: Improve Outreach to Stakeholders & Advisory Committee Input

Outreach to stakeholders to provide better judgment on issues related to program priorities, sources of non federal matching funds, training, and dissemination of information must be enhanced. The Institute will upgrade its webpage to provide more visibility of activities and programs. Increased partnership with other universities will continue to provide the Institute with a broader capacity to respond to major water resource issues of the District of Columbia.

Program Priorities

The restoration of the Anacostia River, strong minority training, public education on water resources issues, and outreach continue to be the priorities of WRRI. The Institute will develop new and maintain old relationships, identify researchers, and continue to extend information and education to the community.

Information Transfer Program

Student Support

None

Notable Awards and Achievements

Publications from Prior Projects

None