D.C. Water Resource Research Center
Annual Technical Report
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Introduction

This report summarizes the activities of the District of Columbia (DC) Water Resources Research Institute (WRRI) for the period of March 1, 2002 through February 28, 2003. WRRI is in full operation and progressing toward strengthening a credible program. Proposals submitted to USGS for the 2002 fiscal year was approved and funding provided however; due to change in administration, award letters and subcontracts were not provided to researchers. Fortunately, Dr. Gloria Wyche-Moore, WRRI Interim Director at the time, provided a verbal approval and two of the four approved proposals were initiated and completed. Dean Roland Holstead assumed Directors responsibilities until a new director was hired in mid August to provide new leadership, direction, and address the problem of allocating additional funding, especially non-federal funds, critical to the success of the Institute. Hence, the goals of 2002 fiscal year will continue to fiscal 2003 while the system is being developed.

The Institute and researchers continue to accumulate valuable experience in water resource management as related to water quality and quantity. The two research projects, funded by the Institute with base program funds from United States Geological Survey (USGS) and non-federal matching funds from the University of the District of Columbia (UDC), were related to areas of water chemistry, bio-monitoring of pollutants, and developing statistical methods of analyzing or evaluating environmental data.

WRRI continues to disseminate research results to its stakeholders which include the DC residents, administrators, faculty, students, and staff of UDC, and DC and federal government agencies via fact sheets, brochures, and its webpage. The effort to enhance the Institutes website for added visibility and dissemination of pertinent DC water resources information has been significantly delayed because UDC website, which hosts WRRI webpage, is also being upgraded. We anticipate that UDC new website, with the Institutes upgrade, will be functional soon. Updating the Institutes directory of water resources experts in the District is progressing. This will enable us to reach out to a greater number of researchers in the consortium of DC Universities.

Recent involvement of WRRI with DC Bureau of Environmental Quality, DC Council of Government, and the Chesapeake Watershed Cooperative Ecosystem Studies Unit, of which UDC is a partner, indicate a promising future for additional research and technical funding to address DC water resource problems, train students, and better serve the residents of DC through outreach programs.

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. Four proposals were submitted and approved for funding during the 2002 fiscal year, however; due to change in administration, award letters and subcontracts were not provided to researchers. Fortunately, Dr. Gloria Wyche-Moore, WRRI Interim Director at the time, provided a verbal approval and two of the five approved proposals were initiated and completed. Dr. Harriette Phelps of UDC continued to bio-monitor the Anacostia Watershed using Corbicula and at George Washington University, Dr. Reza Modarres defined a Box-Cox distribution, investigated its properties, and applied it to modal data from a water plant facility. These research findings will be presented to our stakeholders for effective utilization to improve the quality of life of all DC residents.

Properties and Applications of the Box-Cox Distribution

Basic Information

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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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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,*

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

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 $Q_\lambda(p) =$

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

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 $0 \leq \lambda \leq 1$ 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 $\vec{\lambda}$.

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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)	$\rho\sigma_1\sigma_2$

Bimonitoring Anacostia Watershed Pollutants

Basic Information

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Corbicula Biomonitoring in the Anacostia Watershed

Final Report to the DC Water Resources Research Center
Dr. Harriette L. Phelps
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ABSTRACT

The 10 km freshwater Anacostia River estuary of Washington, DC, is one of Chesapeake Bay's three Regions of Concern and one of America's ten worst 'rivers'. Concerns are a fishing advisory from chlordane and PCBs, and a depauperate benthos. Asiatic clams (Corbicula fluminea) from the nearby healthy Potomac River estuary were translocated to one Anacostia estuary site and 13 tributary sites for eight weeks, with tissues analyzed for 21 pesticides, 28 PCB congenors, 18 PAHs and 6 metalss. One site had clams with total metal bioacumulation significently increased over the Potomac reference level. At ten sites the clam tPAH bioaccumulation was above Potomac reference levels. Clams at two tributary sites had chlordane accumulation above the FDA fish consumption action level, and one site had tPCB accumulation above the FDA action level. Translocated clams showed significently increased contaminant concentrations within two weeks. Repeating clam bioaccumulation at four main tributary sites in 2001 and 2002 found 62% (10 of 16) contaminant levels statistically equivalent. It appears Anacostia estuary fishery-bioavailable contaminants of concern are coming from specific tributary sites, mostly located in Maryland. Corbicula translocation is a rapid freshwater 'Clam Watch' that can identify watershed reaches with major sources of bioavailable contaminants to the Anacostia estuary. These sources need to be considered for any Anacostia River remediation plan to be effective.

INTRODUCTION

The 10 km Anacostia River estuary continues to be a seriously impacted body of water that is a major focus of the District of Columbia. There is considerable evidence of toxic input from the fishing advisory (chlordane and PCBs) (Velinsky and Cummins 1994), fish tumors (PAHs) (Pinkney et al. 2000) and the depauperate benthos (Phelps 1985). Part I and II in 2001 was to begin to find the sources of bioavailable contaminants in the Anacostia watershed (Phelps 2002). Corbicula fluminea clams were translocated from the healthy Potomac estuary to three Anacostia estuary sites and four major tributaries just above head of tide. After eight weeks deployment the clam tissues were analyzed for EPA priority pollutants including 21 pesticides, 28 polychlorinated biphenyl (PCB) congenors, 18 polycyclic aromatic hydrocarbons (PAH)s and five metals (Cd, Cu, Cd, Fe, Zn). Clams at two tributaries (Northwest Branch, MD and Hickey Run, DC) had no contaminant class totals significently exceeding reference. Northeast Branch clam tPAHs exceeded reference clam contaminant levels by 300% and tPesticides by 150%. Lower Beaverdam Creek clam tPCBs exceeded reference by 400%.

Part III in 2002 -2003 developed several objectives. Objective A was to examine clam contaminant accumulation at two major remaining potential sources to the Anacostia, and the large Washington, DC O Street Sewage Pump Station Outfall (O Street outfall) and the Watts Branch tributary (DC/MD). Objective B was to localize contaminant sources in Northeast Branch (MD), Lower Beaverdam Creek (MD) and Watts Branch (MD) upstream subtributaries with clam biomonitoring. Objective C was to determine long term contaminant bioaccumulation with consecutive clam sampling at a single site. Objective D was to repeat the 2001 contaminant bioaccumulation study at four major Anacostia tributaries. All the studies involved University of the District of Columbia undergraduate biology research students.

METHODOLOGY

For the 2002 studies, 18 - 29mm Corbicula fluminea clams were obtained by wading in the Potomac estuary 5 km below the Anacostia branch, at Fort Foote (MD). Clams were kept cool and dry on blue ice during translocation to Anacostia sites, usually the same day (Table 1). Fort Foote control samples were taken. Shellfish mesh bags or weighted cages with 50-60 clams each were placed at the sites, GPS taken and TidbiT temperature monitors attached at reference sites (Table 1, Fig. 1). For the long-term contaminant bioaccumulation study (PBL) two hundred clams were deployed.

Cages were recovered after a minimum of eight weeks deployment (Roesjadi et al 1984) except for the long term bioaccumulation study. The clam size range, mortality and temperature data if present were recorded. Clams were washed, depurated for 24 hours in three changes of spring water at room temperature, frozen to open shells, shucked, and the tissues refrozen and hand-carried to Severn-Trent Laboratories (STL) in Sparks, MD for chemical analyses. STL filled out chain-of-custody forms and carried out EPA Priority Pollutant analysis of the clam tissues, including 21 pesticides, 29 PCB congeners, 18 PAH's and six metals (As, Cu, Cd, Fe, Zn and Cr). Electronic results were available within five weeks. On 9/20/02 the PBL clam cage was found buried in gravel and all clams were dead, so the long-term study ended early. On 10/25/02 the NEB02 cage was found buried in gravel and clams dead so that sample was lost.

Thirty - 50 clams were analyzed per sample and the Severn-Trent Laboratory analytical variability for clam tissue samples is SD = 0.175(mean) - 1.12 (n = 9) (Phelps 2002). Statistical comparison among contaminant totals was by t test and 95% confidence limits of the mean were (2.05 SD) = 0.37 (mean), the basis for graphical error bars.

RESULTS AND DISCUSSION

TidbiT temperature monitors attached to shellfish bags at the O Streed estuary (OS), Paint Branch Longtern (PBL) and Northwest Branch (NWB) sites indicated water temperatures ranged from a high of 32 deg C to a low of 11 deg. C over the course of the 2002 translocations. This is within the activity range for <u>Corbicula</u> clams (Phelps 1997).

Table 1. Study site dates of clam translocation and collection (recovery) and GPS data.

Site	Date Transl.	Date Collected	GPS
Potomac River Estuary			
Fort Foote MD (FF1)		5/3/02	N38^{0}46.460’, W077^{0}01.770’
Fort Foote MD (FF2)		7/2/02	N38^{0}46.460’, W077^{0}01.770’
DC Estuary			
O Street Outfall (OS)*	5/3/02	6/28/02	N38^{0}52.353’, W077^{0}00.237’
Anacostia Watershed, Watts Branch and subtributaries			
Lower Beaverdam Creek High (LBH)*	5/3/02	6/28/02	N38^{0}54.729’,W076^{0}54.539’
Indian Creek Low (ICL)	7/2/02	9/15/02	N38^{0}59.623’, W076^{0}55.161’
Indian Creek High (ICH)	8/31/02	10/25/02	N39^{0}01.364’, W076^{0}54.212’
Beaverdam Creek (BDC)	7/2/02	9/15/02	N39^{0}00.968’, W076^{0}53.862’
Paint Branch Longterm (PBL)	7/25/02	8/5, 8/21	N38^{0}58.541’, W076^{0}55.180’
Little Paint Branch (LPB)	5/3/02	6/28/02	N38^{0}59.437’,W076^{0}56.126’
Watts Branch Low (WTL)	8/30/02	10/27/02	N38^{0}53.481’, W076^{0}54.779’
Watts Branch High (WTH)	8/30/02	10/27/02	N38^{0}53.475’, W076^{0}54.870’
Watts Branch (WAT02A)	5/3/02	6/28/02	N38^{0}54.395’, W076^{0}56.942’
Watts Branch (WAT02B)	8/30/02	10/27/02	N38^{0}54.395’, W076^{0}56.942’
Anacostia Watershed, repeat 2001 sites			
Northeast Branch (NEB02)	8/30/02	10/25/02	N38^{0}57.621’, W078^{0}55.583’
Northwest Branch (NWB02)*	8/30/02	10/25/02	N38^{0}56.741’, W076^{0}56.855’
Lower Beaverdam Creek (LBC02)	8/30/02	10/25/02	N38^{0}54.977’, W076^{0}55.985’
Hickey Run Low (HRL02)	8/30/02	10/25/02	N38^{0}54.586’, W076^{0}57.710’

* TidbiT temperature monitors attached to cages

GPS locations of clam translocation sites in the Anacostia estuary and watershed mapped by ArcView (Table 1, Fig. 1).

Figure 1. Locations of Corbicula clam translocation sites in the Anacostia watershed (red marks).

In cages that were not buried the percent clam survival ranged from 34 to 100 percent (Table 3). Higher mortality was found at Watts Branch Low (WTL), O Street Outfall (OS) and Watts Branch (WAT02A) and Beaverdam Creek.

Table 2. Percent survival of caged clams at Anacostia watershed sites.

WTL	OS	WATA	BDC	LPB	LBH	LBC	WTH	HRL02	ICH	WATB	PBL	ICL	NWB02
34	51	66	79	95	95	95	97	97	99	100	100	100	100

The clam tissue total contaminant levels at the Potomac River estuary Fort Foote site are compatible with the Potomac ecosystem which has been called a Chesapeake Bay recovery success (Phelps 1984). The highest 2001and 2002 Fort Foote sample contaminant totals (*) were selected as references for comparison with Anacostia watershed clam totals (Table 3).

Table 3. Clam tissue contaminant totals (ug/Kg dry weight) in 2001 and 2002 at the Potomac Fort Foote reference site.

	4/01	7/01	9/01	FF1(5/02)	FF2(7/02)
T Metals x .01	94*	74	46	77	71
T PAHs	388	397	361	391	598*
T Pesticides	100*	70	53	48	30
T PCBs	174*	131	97	79	73

* Selected reference totals.

Objectives A and B.

Clams translocated 5/3/02 - 6/28/02 (8 - 9 weeks, Table 1) included a set suspended directly in the large Washington, DC O Street Sewage Pump Station Outfall (OS) entering the lower third or basin part of the Anacostia estuary (Fig. 1). Studies of Anacostia sediment contaminants have found “hot spots” in this region of the Anacostia and implicated the O street outfall as a major source of contaminants (Velinsky and Ashley 2001). Clam survival was relatively low (Table 1). Tissue contaminant totals were not significently different among clams at other sites in the lower basin third of the Anacostia estuary (Navy Yard and Washington Gas Light, Phelps 2002) (Fig. 1, Fig. 2, Table 4, Table 6).

Table 4. Contaminant totals in clam tissues 5/3/02 - 6/28/02 (ug/Kg dry weight).

	FF1	OS	WATA	LPB	ICL	LBH
T Metals x .01	77	47	62	65	66	108
T PAHs	391	1262*	4612*	905*	2789*	2183*
T Pesticides	48	124	103	76	97	72
T PCBs	79	175	130	131	86	88

* Statistically exceeding Potomac (Fort Foote) reference (Table 3) (p < .05)

Key: FF1 (Fort Foote Reference 1), OS (O Street Outfall), WATA (Watts Branch tributary), LPB (Paint Branch subtributary of the Northeast Branch), ICL (Indian Creek Low subtributary of the Northeast Branch), LBH (Lower Beaverdam High subtributary of Lower Beaverdam Creek).

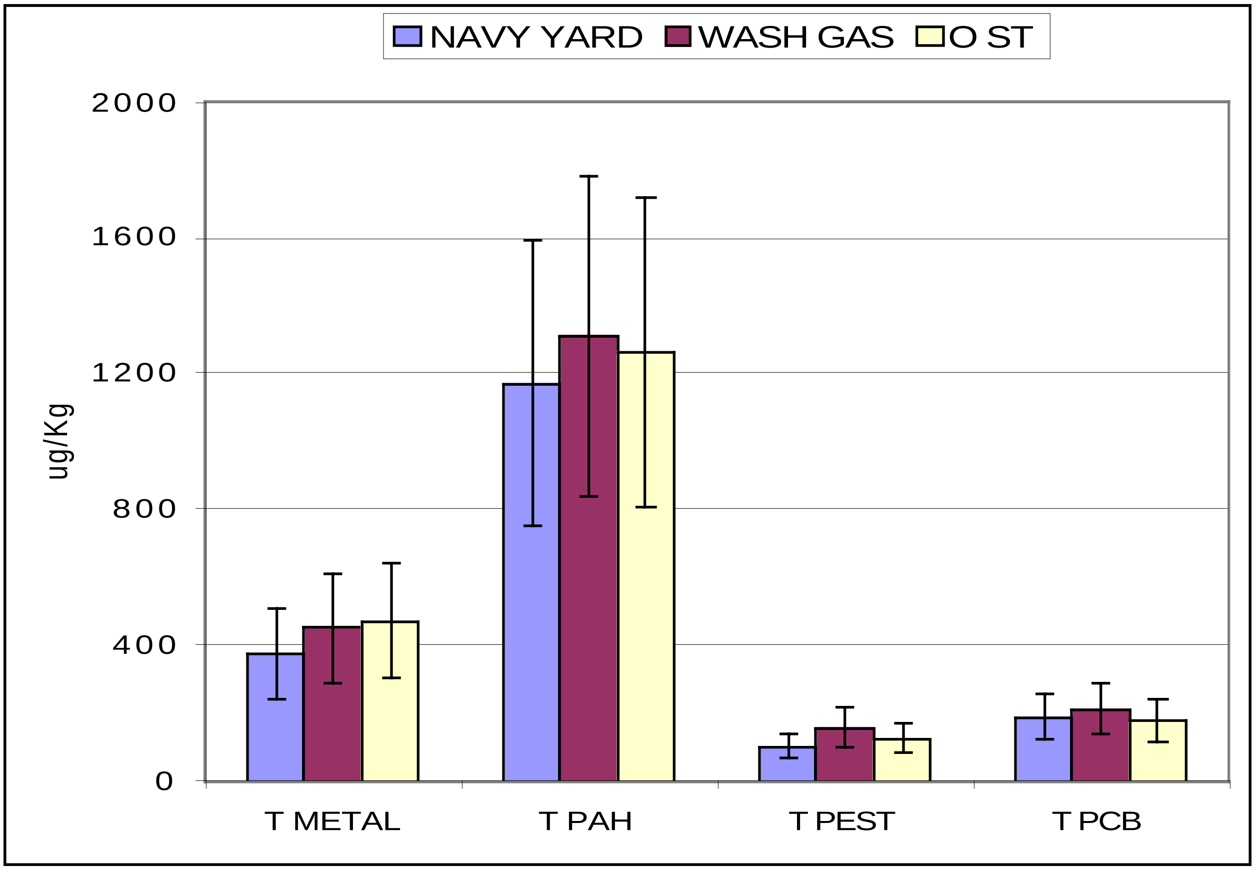

Figure 2. Contaminant class total concentrations in clams translocated to lower Anacostia estuary basin sites.

Key: FF (Fort Foote, Potomac), Wash Gas (Washington Gas Light), O St. (O Street Sewage Pumping Station). Error bars are 2.05 x analytical standard deviation.

Clams translocated to tributary sites 8/30/02 and recovered 10/25-27/02 (8 - 9 weeks) were analyzed by Severn-Trent laboratory as before (Table 5) except at WTL and WTH sites where there was only sufficient tissue for pesticide and PAH analyses.

Table 5. Contaminant totals (ug/Kg dry weight) in clam tissues 8/30 - 10/25/02.

	FF2	NWB02	LBC02	ICH	BDC	HRL02	WATB	WTL	WTH	PBL1	PBL2
t Metals x.01	71	100	166*	96	90	79	94	--	--	73	73
t PAHs	598	933*	1345*	2581*	431	1888*	1193*	1576*	1126*	180	88
t Pesticides	30	58	68	46	42	63	106	225*	98	50	43
t PCBs	73	64	326*	72	59	126	115	--	--	128	107

* Statistically exceeding Potomac (Fort Foote) reference (Table 2) (p < .05)

Key: FF2 (Fort Foote 8/30), NWB02 (Northwest Branch 02), LBC02 (Lower Beaverdam Creek 02), ICH (Indian Creek High), BDC (Beaverdam Creek), HRL02 (Hickey Run Low 02), WATA (Watts Branch 6/02), WATB (Watts Branch 10/02), WTL (Watts Branch Low), WTH (Watts Branch High), PBL1 (Paint Branch Longterm 8/6/02), PBL2 (Paint Branch Longterm 8/21/02)

Northeast Branch Contaminants and Subtributaries

The highly urbanized Northeast Branch tributary contributes about 45% of Anacostia river input (Warner et al. 1997). The 2001 Northeast Branch clams had the highest total pesticides of any tributary (Table 6) (88% chlordane, Fig 7). In 2002 this high pesticide level was not found in Northeast Branch upstream subtributaries: LPB coming from the University of Maryland, ICN coming from the Beltsville Industrial Center and BDC coming from the USDA Beltsville Agricultural Research Center (Table 4, Table 5, Fig. 1, Fig. 3, Table 6).

Table 6. Repeated Priority Pollutant totals in Anacostia tributary clams among 2001 (Phelps 2002) and 2002, and Watts Branch on 6/28/02 and 10/25/02.

	NWB01	NWB02	NEB01	LBC01	LBC02	HRL01	HRL02	WATA	WATB
tMetals(x.01)	66	100	73	189*	166*	50	79	62	94
tPAHs	637	933*	1442*	855*	1345*	785^	1888*^	4612*^	1193*^
tPesticides	77	58	740*	295*^	68^	42	63	103	106
tPCBs	83	64	187	666*	326*	97	126	130	115

* Statistically exceeding Potomac (Fort Foote) reference level (Table 2) (p < .05)

^ Statistically different among 2001 and 2002 concentrations (p < .05)

Key: NWB (Northwest Branch 01,02), NEB (Northeast Branch 01), LBC (Lower Beaverdam Creek 01, 02), HRL (Hickey Run Low 01,02), WAT (Watts Branch, 6/28/02, 10/25/02).

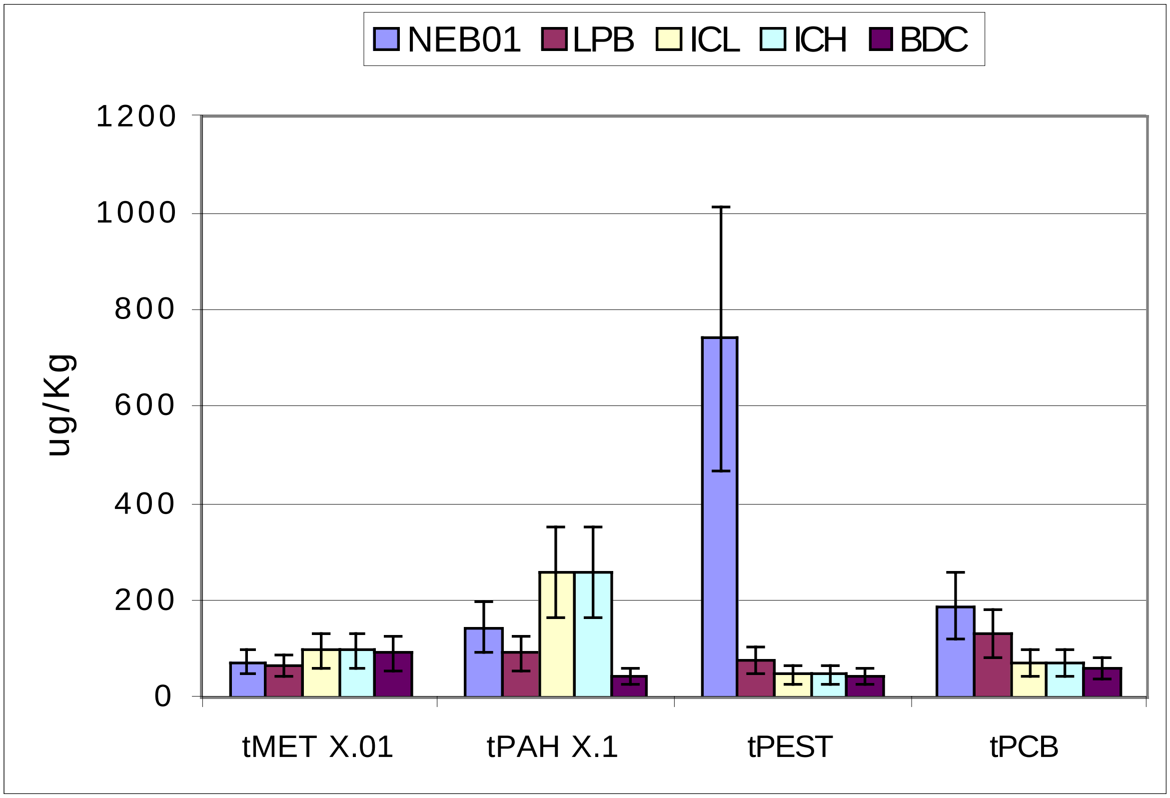

Figure 3. Clam contaminant concentrations in the Northeast Branch and subtributaries. Key: NEB01 (Northeast Branch in 2001), LPB (Lower Paint Branch), ICL (Indian Creek Low), ICH (Indian Creek High), BDC (Beaverdam Creek) (Phelps 2002)

Lower Beaverdam Creek Contaminants and Subtributaries

Lower Beaverdam Creek clams significantly exceeded Potomac reference values in 2001 for total metals, tPAHs, tpesticides and tPCBs and all but tpesticides in 2002 (Table 6). Clams in the one subtributary examined (LBH) had only tPAHs exceeding reference (Fig. 1, Table 4).

Watts Branch Contaminants and Subtributaries.

Although Watts Branch is a relatively small tributary contributing about 3% of total Anacostia tributary input, the clams recovered on 6/28/02 (WATA) had the highest tPAH bioaccumulation of any site (Table 6). The 6/28 PAH profile was high in low-molecular-weight PAHs, especially napthalenes (Fig. 4). The 10/27 WATB tPAH clam accumulation had fallen by 74%. The high WATA 6/28 tPAH may have been from spring runoff or a source of low-molecular-weight PAHs dispersed by 10/27. There was no statistically significant difference in total metals, pesticides or PCBs among WATA and WATB clams (Table 6).

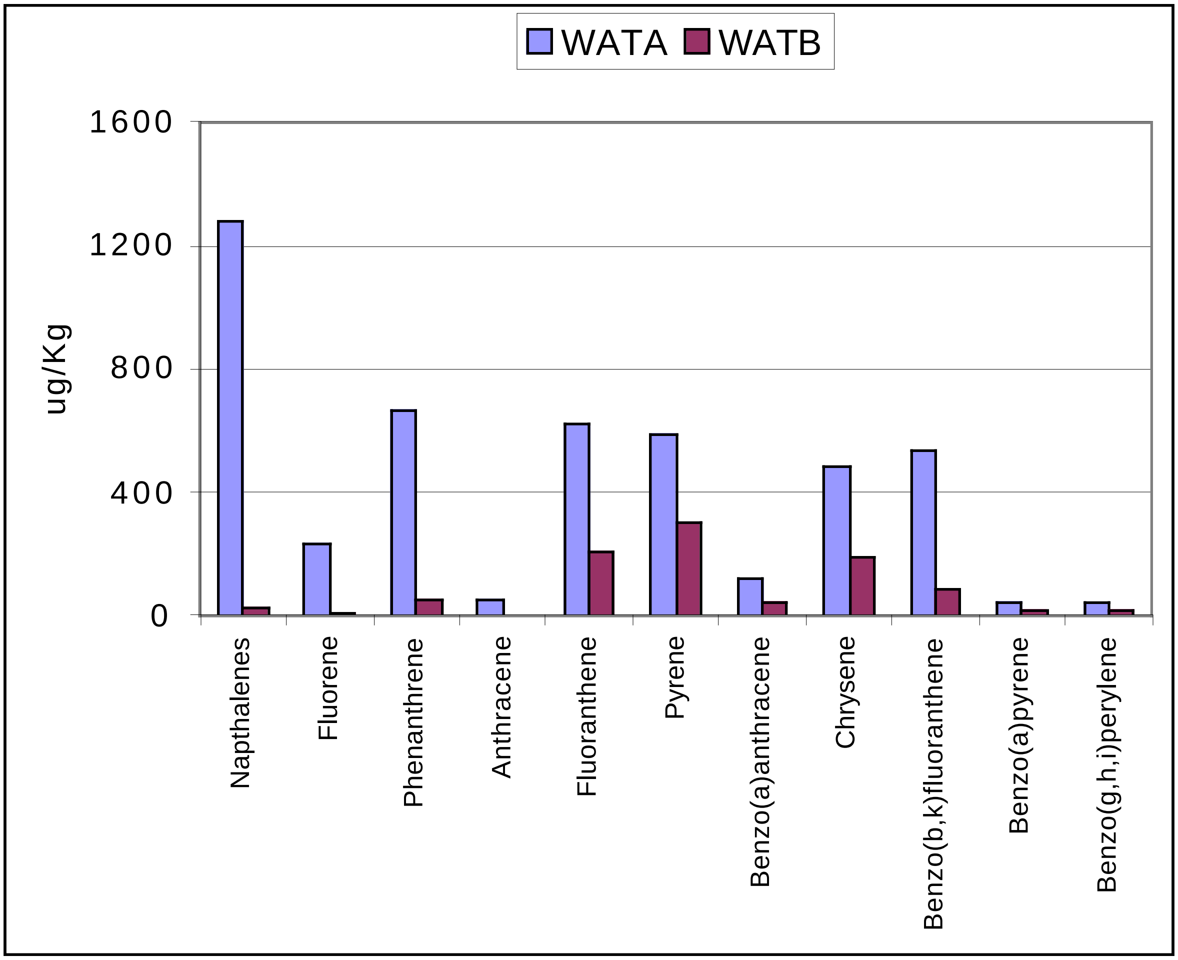

Figure 4. PAH congenors in Watts Branch clams collected 6/28/02 (WATA) and 10/2702 (WATB).

Chlordane and PCBs in the Anacostia watershed.

Chlordane is one of two Anacostia fish tissue contaminants responsible for the fishing advisory and a pesticide shown to cause liver and nerve damage. Chlordane use except for termite control was banned by EPA in 1983, and all use was banned in 1988. Chlordane in clams exceeded the FDA fish consumption chlordane action level of 100 ug/Kg. at the 2001 Northeast Branch site (NEB01, 240 ug/Kg) and 2002 Watts Branch Low site (WATL,172 ug/Kg) (Fig. 5).

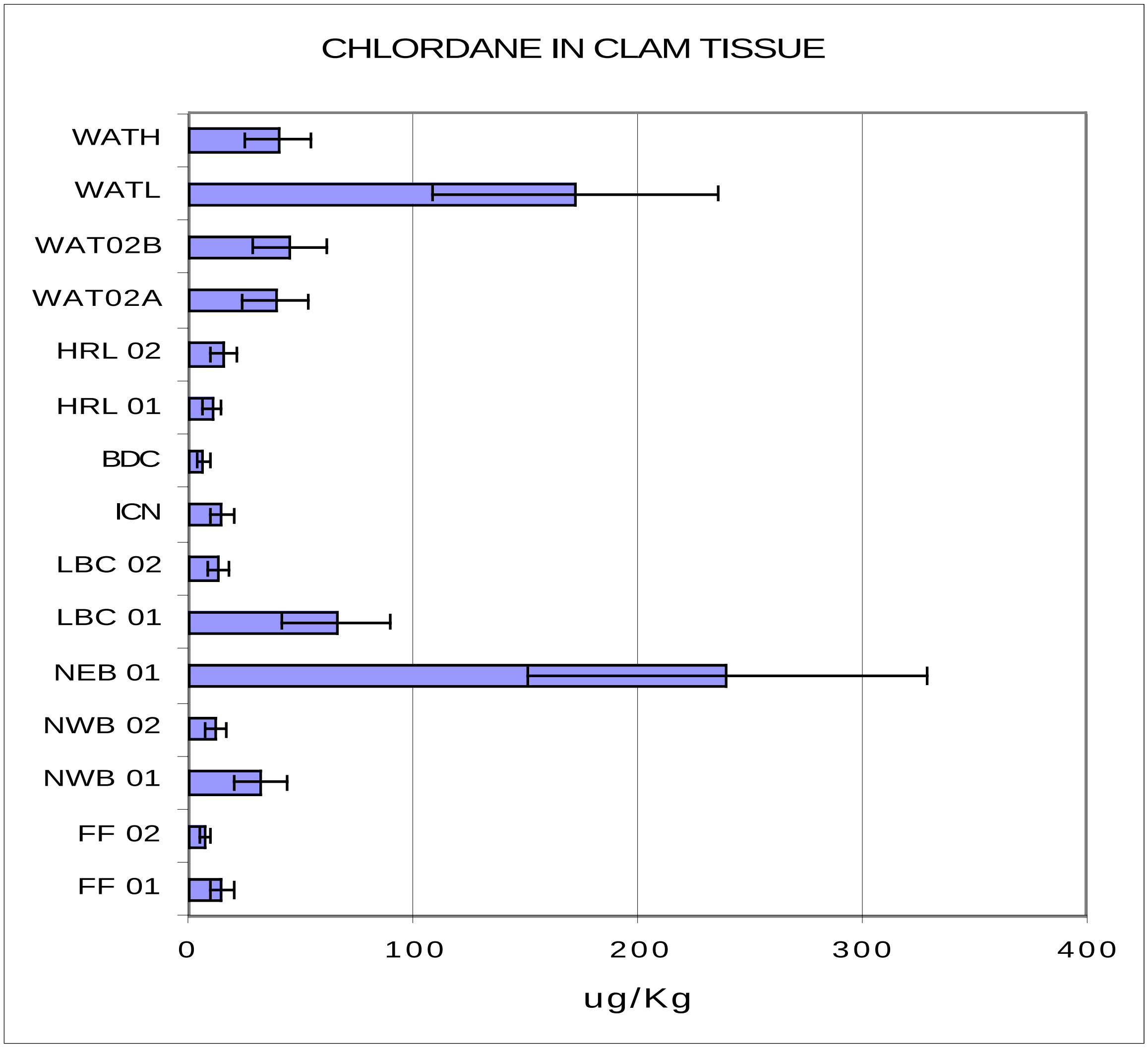

Figure 5. Chlordane bioaccumulation by clams at 2001 and 2002 Anacostia sites and reference. Key: FF1,2 (Fort Foote reference); NWB01,02 (Northwest Branch in 2001, 2002); LBC01,02 (Lower Beaverdam Creek); ICN (Indian Creek North subtributary of the Northeast Branch); BDC (Beaverdam Creek subtributary of the Northeast Branch); HRL01,02 (Hickey Run Low); WATA,B (Watts Branch); WTL (Watts Branch Low subtributary of Watts Branch); WTH (Watts Branch High subtributary of Watts Branch).

PCB contaminant levels in Anacostia fish tissues are also responsible for the Anacostia fishing advisory (Velinsky and Cummins 1994). PCBs have 209 congenors, produce health effects, can bioaccumulate to high levels in aquatic animals and have not been manufactured in the US since 1977 (Safe 1994). Total PCBs in clams at Lower Beaverdam Creek exceeded the FDA food action level of 200 ug/Kg in 2001 and 2002 (Table 6). The PCB congenor homologs in clams at tributary sites with increased tPCBs (Table 4, Table 5) showed PCBs in Lower Beaverdam Creek clams had high levels of volatile tri, tetra and penta homologs (Fig. 6).

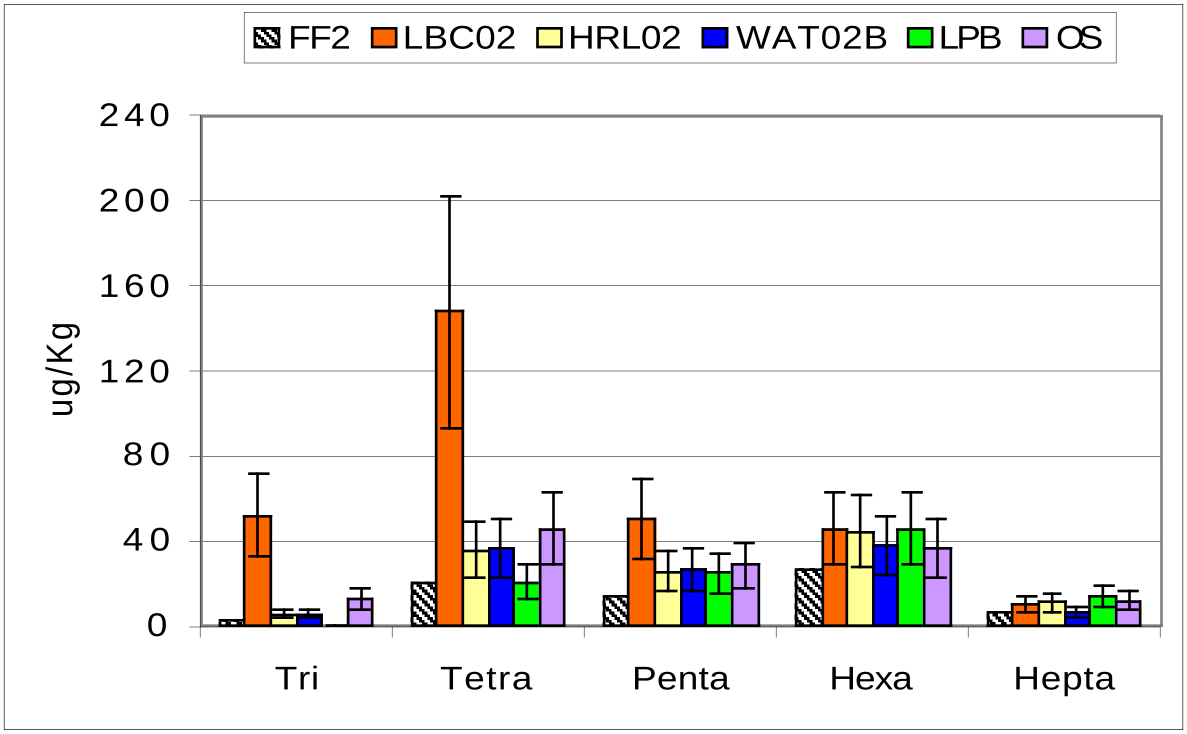

Figure 6. PCB homolog groups in clams at the Potomac Fort Foote site (FF) and at Anacostia watershed sites with significently increased total PCBs (2002): Lower Beaverdam Creek (LBC02), Hickey Run Lower (HRL02) and Watts Branch (WAT2).

Objective C. Long-term contaminant bioccumulation.

Clams sampled sequentially at the Lower Paint Branch site had statistical increases over original Potomac clams in levels of tPAHs, tPCBs and tPesticides at 11 and 27 days, but not tMetals which seldom exceed the Potomac reference level (Table 7).

Table 7. Consecutive contaminant accumulation (ug/Kg dry weight) in clam tissues at 11 and 27 days (Lower Paint Branch) and at the Potomac reference site FF2.

	FF2	11 days	27 days
T Metals x.01	71	73	73
T PAHs	598	1804*	882*
T Pesticides	30	50*	43*
T PCBs	73	128*	107*

* Statistically greater than original Potomac (Fort Foote) clams (p < .05)

Objective D. Repeat of the 2001 clam contaminant study at tributary sites.

Clam tissue contaminant totals were compared among 2001 and 2002 at three major tributary sites, Northwest Branch (NWB), Lower Beaverdam Creek (LBC) and Hickey Run (HRL) , and among Watts Branch tributary samples in 2002 (Table 6).

CONCLUSIONS

In the lower Anacostia estuary the contaminant concentrations in clams placed directly in the Washington DC O Street Sewage Pump Station Outfall were not statistically significantly different from concentrations at two other sites in the lower basin in 2001 (Fig. 1, Fig. 2). Stationary Passive Monitoring Device (SPMD) contaminant monitoring in this area had similar results (Pinkney et al., 2003). Tidal mixing apparently prevents contaminant source localization in the lower estuary portion of the Anacostia.

Clams translocated from the freshwater Potomac to sites in the fluvial Anacostia watershed in 2001 and 2002 had significantly increased tPAHs at all sites except the Northwest Branch (2001) and the Beaverdam Creek subtributary of the Northeast Branch. Total pesticide levels were significantly higher than Potomac reference at two sites, higher tPCBs at one site, and higher tmetals at one site (Table 6). This eliminated several tributaries and subtributaries as major sources of contaminants, and implicated others. Specifically, in Lower Beaverdam Creek the Lower Beaverdam High subtributary was not a significent contaminant source (Table 4); in Watts Branch the Watts Branch Low (WTL) subtributary contributed a majority of the chlordane and PAH contamination (Table 4); at the Northeast Branch tributary (NEB) the Beaverdam Creek subtributary (BDC) did not contribute significent bioavailable contaminants or pesticides although draining the large Beltsville Agricultural Research Center which has a CERCLA site (Table 4). However the Indian Creek North (ICN) subtributary from the Beltsville Industrial Center had very high (4X) clam tPAH levels (Table 4). The majority (3 of 4) upstream subtributary sites with significantly increased clam contaminant levels were in Prince Georges County, MD.

Chlordane concentrations (along with PCBs) are responsible for the present Anacostia fishing advisory (Velinsky and Cummins 1994). Chlordane is persistant in soil, slow to break down and not very soluble in water. Because of chlordane's 30 year ban and extensive former use for termite control in this area point sources were not expected. However, the finding of two tributaries/subtributaries (Northeast Branch below Lower Paint Branch and Watts Branch Low) with high clam chlordane levels suggests there may be deposits of chlordane-contaminated sediments eroding into those watersheds. Using Corbicula monitoring it is hoped to more closely define the stream reaches that are the source of chlordane. Finding and remediating these two high-level chlordane sources may be both necessary and sufficient to remove the Anacostia fishing advisory based on chlordane.

Total PCBs in some Anacostia fish species above the FDA action level of 200 ug/Kg are responsible for the fishing advisory. Total PCBs in clam tissue exceeded the FDA food action level at Lower Beaverdam Creek in 2001 and 2002 (Table 6). Lower Beaverdam Creek PCBs were high in volatile low-molecular-weight congenors, suggesting a recent source (Fig. 6). Lower Beaverdam Creek has the highest industrial watershed area of the 13 Anacostia tributaries and is 99% located in Prince George's County (Warner et al. 1997).

Significant increases in contaminant totals were found at Paint Branch Longterm (PBL) site as soon as two weeks after clam translocation. The low levels compared to clams at nearby sites with eight weeks deployment (LPB, ICN) (Table 5) suggested clam tissues had not reached final contaminant concentrations. Completion of this study in 2003 could lead to shortening of the deployment time needed for Corbicula bioaccumulation studies.

Repeating clam monitoring at three tributary just-above-tide sites in 2001 and 2002 and the Watts Branch tributary in 2002 found 10 of 16 contaminant totals statistically similar ($p < .05$). (Table 4, Table 5). All Northwest Branch clam contaminant totals except metals showed no signficant difference among 2001 and 2002. Lower Beaverdam Creek had signficant changes in tPesticides and tPCBs totals among 2001 to 2002 and tPCBs remained the highest of any tributary. At Hickey Run, entirely in DC, there was signficant increase in tPAH's in 2002. Hickey Run has a history of episodic petroleum releases. At Watts Branch the June 2002 clams had signficant higher tPAHs with low-molecular-weight PAHs not found in the October sample. The June tPAH peak may have been due to a spill or spring runoff. In general the 62% statistical similarity among 2001 and 2002 tissue contaminant totals suggests consistent as well as episodic tributary contamination can be detected by Corbicula biomonitoring.

The advantages of using the hardy freshwater Asiatic clam (Corbicula flumina) to locate pollutant sources in watersheds are similar to the use of marine mussels in the worldwide Mussel Watch program to monitor coastal pollutants (Crawford and Luoma 1993, O'Connor and Beliaeff 1995, Sericano 2000, Chase 2001). Shellfish can accumulate suspended and dissolved bioavailable water contaminants without detoxicification or elimination (Dougherty and Cherry 1988). Shellfish can be translocated to specific locations for periods of weeks or months to monitor bioavailable contaminants in aquatic environments. Although the Zebra mussel (Dreissena polymorpha) has been used to monitor freshwater contaminants (Cope et al.1999) it is not yet found in the Potomac river watershed. The Asiatic clam is naturalized in most US states, found on several continents (Asia, North and South America, Europe) and the most common freshwater mollusc species worldwide. Corbicula has been used and deployed for contaminant biomonitoring instead of using endangered local mollusc species (Hartley and Johnston 1983, Elder and Mattraw 1984, Crawford and Luoma 1993, Colombo et al. 1995). The present study demonstrates the usefulness of the translocated Asiatic clam in finding major sources of EPA priority pollutants in an urban watershed. This 'Clam Watch' program can be an effective screening methodology for freshwater watersheds that is far more rapid and less expensive than intensive water monitoring methods that can be employed for more thorough investigations. Although the present focus of Anacostia remediation is on sediments (AWTA 2002), locating and reducing the watershed sources of contaminants must be a priority.

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Program Administration Project

Basic Information

Title:	Program Administration Project
Project Number:	2002DC15B
Start Date:	3/1/2002
End Date:	2/28/2003
Funding Source:	104B
Congressional District:	District of Columbia
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	
Principal Investigators:	William W. Hare, Roland Holstead

Publication

Program Management

The FY 2002 program continues to rebuild the Water Resources Research Institute (WRRI). The Director continues to re-establish the network of relationships that make an Institute viable and is working with the University administrators to provide greater non-cash support. The Watershed Protection Division of the DC Department of Health provided WRRI with $200,000 in non federal in-kind match for the 2003 fiscal year. We anticipate that the relationship building strategies will increasingly allow us to more easily attract donors from other agencies as well as researchers from other universities in the District.

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 is upgrading its database of water resources experts and continues to pursue research ventures with other area universities through networking and web page 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.

Goal four: Bind and Catalog all Past Reports for Distribution in UDC Library

The Institute has over 100 reports in the UDC library, but they are not cataloged for circulation. We will bind these reports by year and have them cataloged for circulation. The reports will also be scanned into a database for display via our website.

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 DC community.

Information Transfer Program

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 RCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	4	0	0	0	4
Masters	1	0	0	0	1
Ph.D.	0	0	0	0	0
Post-Doc.	0	0	0	0	0
Total	5	0	0	0	5

Notable Awards and Achievements

Publications from Prior Projects