Use of Seemingly Unrelated Parametric and Semiparametric Panel Models in the Environmental Kuznets Curve Estimation

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We estimated the environmental Kuznets curve for point (mercury) and nonpoint (nitrogen, phosphorus, and dissolved oxygen) source water pollutants as a function of income in parametric and semiparametric functional forms of the Panel data model. Seemingly unrelated panel formulation did not provide gain in efficiency over the single equation panel data model.

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There have been numerous theoretical and empirical studies of an income-pollution relationship, which is usually referred to as the EKC. The hypothesis underlying the EKC is that the level of environmental degradation will increase as per capita income increases up to a threshold. Beyond this income threshold, or the turning point, it is assumed that further growth in income would be beneficial to the environment. Hence, the EKC curve is assumed to take an inverted U-shape.

It has been the general tendency to estimate each pollution-income equation separately in the EKC framework to find the income turning point while it is known that several of these pollutants are inherently related to each other. For example, nitrogen and phophorus pollutant primarily come from agriculture sources in most of the water bodies. Yet, when estimating EKC model for these two pollutants, researchers tend to estimate them as if the error terms in between these two equations are uncorrelated. We want to compare the results from single equation parametric panel model to those of the parametric seemingly unrelated regression fixed effects model. An additional issue of econometric interest in this and other applications of panel data analysis is model specification. The true model is never known, thus, plausible alternative specifications should be tested in empirical work. The results from the SUR parametric analysis will be compared to semiparametric seemingly unrelated regression models to see if efficiency of the parameter estimated as well as forecasting ability of the model can be improved in latter specification.

The paper proceeds as follows. The next section briefly reviews recent works on the estimation of the environmental Kuznets curve. Subsequently, the econometric methodology is presented along with a description of the data. The results section emphasizes findings with the parametric specification of a panel data fixed effects model and argues why a seemingly unrelated approach may be reasonable; this discussion is expanded to pave the way to the econometric analysis of a semiparametric seemingly unrelated regression model. The last section of the paper outlines future research opportunities with these emerging semiparametric methods. The paper is rich in citations on recent and forthcoming literature.

Previous Work

Author(s)	Title	Issue	Model Used	Conclusions
Millimet, D; List, J.; Stengos, T. The Review of Economics and Statistics 85, no. 4 (2003)	The Environmental Kuznets Curve: Real Progress or Misspecified Models?	The importance of modeling strategies when estimating the emissions-income relationship. A comparison of the traditional parametric regression against the semi parametric partially linear regression model is presented in the paper.	Two models used: Parametric model using a two-way fixed effect panel data using a cubic specification. *Pit= ai+ ft+ Yitd +eit* Where: *Pit*= Emissions of NO2 and SO2. *f t*= Time effect *Yit*= Per capita Income *d*= A vector of slope coefficients *eit*= Contemporaneous error term. Semi-parametric model: *Pit= ai+ ft+ g(Yit)+µit* Where: g (.)= is an unknown fx µit= is a mean zero residual assumed to be uncorrelated with g(.).	Formal statistical comparisons of the results reject the parametric approach. In the semi-parametric model, the data presented an inverted-U shape between pollutant emissions and income. Parametric EKC modeling is especially problematic for sulfur dioxide emissions.

Perman, R, and D. Stern. Australian Journal of Agriculture and Resource Economics 47, no.3 (2003)	Evidence from Panel Unit Root and Cointegration Tests that The Environmental Kuznets Curve does not Exist.	The Environmental Kuznets Curve (EKC) hypothesis is despite considerable criticism on both theoretical and empirical grounds. Cointegration analysis can be used to test the validity of such stylized facts when the data involved contain stochastic trends.	The model applied: $Ln[M/P]_{it=} a_i + ?_t + d_i t + ß_{1,i} ln[Y/P]_{it} + ß_{2,i} [ln(Y/P)]_{it}^2 + e_{it}$ Where: *M*= Sulfur Dioxide emissions per year. *Y*= Constant price PPP, GDP. P= Country's population. *t*= A deterministic time trend.	Individual and panel cointegration tests cast doubt on the general applicability of the hypothesized relationship between environmental quality and per capita income. The results show that the EKC is a problematic concept, at least in the case of sulfur emissions.

Van, Phu. N. Applied Economics Letters 10, no.10 (2003)	A Semi parametric Analysis of Determinants of a Protected Area.	A semi parametric additive model is used to study the relationship between protected area, income, trade, population, education, and political institutions in a sample of 89 countries.	The model used: $Y= a+ S fj(Xj)+ Z'?+ e$ Where: *Y*= Environmental Indicator. *Xj*= Represents real GDP per capita, trade, population density, and rate of secondary enrollment. These variables are continuous. *Z*= Discrete variables: Political institutions and regional dummies	The results show the nonexistence of an environmental Kuznets curve in the data sample. The study also points out the existence of nonlinearity in the relationship between protected area and the ratio of net secondary school enrolment.

Barbier, E. Australian Economic Papers 42, no.2 (2003)	The Role of Natural Resources in Economic Development	Does the existence of EKC relationships suggest that environmental degradation will eventually decline with growth?	No Model used in this journal. The author presents several examples about different pollutants and its relationship with economic growth.	EKC analysis for air pollutants fit better for short term and selected countries. Economic growth does not necessarily lead to improved environment conditions. EKC model can differ from developed to developing countries.
Raghbendra, J and K.V. Bhanu New Economic Papers (2003)	A consumption Based Human Development Index and The Global Environmental Kuznets Curve	Construct an Environmental Degradation Index (EDI) for each country and global environmental degradation (GED) as the sum of the EDI's to identify outliers and influential observations among both the environmental and consumption related variables.	Canonical Discriminant analysis is used to classify development classes along environmental lines. They then estimate a simultaneous equation model to analyze the pattern of causation between per capita income, consumption and environmental degradation.	A. A cubic representation is most appropriate with high-consumption countries contributing excessively to GED and middle-consumption countries slightly less. B. Low-consumption countries are contributing insignificantly to Global Environmental Degradation.
Harbaugh, W; Levinson, A; Wilson, D. The Review of Economics and Statistics 84 no.3 (2002)	Reexamining the Empirical Evidence for An Environmental Kuznets Curve	This paper examines the robustness of the evidence for the existence of an inverted U-shaped relationship between national income and pollution.	The model used: $Y_{it} = G_{it}\beta_1 + G^2_{it}\beta_2 + G^3_{it}\beta_3 + L_{it}\beta_4 + L^2_{it}\beta_5 + L^3_{it}\beta_6 + X'_{it} + \mu_i + ?_{it}$ Where: Y= Sulfur dioxide emissions. G= Per capita GDP. L= is a three year average of lagged per capita GDP. X= are country-site specific descriptors. μ= a site specific effect uncorrelated with the independent variables. ?= normally distributed normal error.	The results conclude that there is little empirical support for an inverted U-shaped relationship between several important air pollutants and national income in these data.

Hill, R; Magnani, E. Australian Economic Papers 41 no.2 (2002)	An Exploration of the Conceptual and Empirical Basis of the Environmental Kuznets Curve	Examine the conceptual and empirical basis of the environmental Kuznets curve. The empirical relationship is highly sensitive to the choice of pollutant, sample of countries and time period.	The model used: $M_{it}= a+ f(ß,Y_{it})+ \mu_{it}$ $i= 1..152$ $t= 1..T$ Where: *M*= per capita emissions of a pollutant. *Y*= per capita income *f(.)*= is a polynomial of degree n(n=2 or 3) in per capita income, $Y_{it,}$ with parameters $ß_1 \ldots ß_n$	Highly sensitive conditions suggest that there is a problem of omitted variables. Two important omitted variables in the model are education and inequality. Observed relationship is sensitive to the measure of income/welfare used. It is important to remember the differences cross-countries because the EKC curve hypothesis is very sensitive to the data characteristics.
Lekakis, J; Konsis, M. Applied Economics Letters 8, no.3 (2001)	Demand for and Supply of Environmental Quality in the Environmental Kuznets Curve Hypothesis	Demand for and supply of environmental quality, which constitute the underlying forces that lead to turning points of Environmental Kuznets Curves (EKCs), are only implicitly referred to in the fast growing literature. The author estimates the impact of GDP per capita on all actions per capita seeking environmental quality in Greece, Spain and Portugal during the period 1974-1994.	The model presented in the paper is: $Ln(Act)_t= a+ ßY_t+ ?Ln(Act)_{t-1}+ \mu_t$ Where Act_t= Environmental actions per 100,000 persons. Y_t= GDP/head and measured in dollars	The findings indicate that rising GDP per capita leads to higher environmental actions per capita. The implications of the results suggest that these three countries are on the rising segment of an EKC or that the Environmental Kuznets curves do not exist.

Panayotou, T. Environment and Development Paper no.4 (2000)	Economic Growth and the Environment	Will the world be able to sustain economic growth indefinitely without running into resource constraints or despoiling the environment beyond repair? What is the relationship between steadily increasing incomes and environmental quality?	This paper does not present a specific model to analyze the relationship between economic growth and the environment. Its main objective is to critically review, synthesize and interpret the literature on the relationship between economic growth and environment. The literature has followed two distinct but related strands of research: an empirical strand of ad hoc specifications and estimations of a reduced form equation, relating an environmental impact indicator to income per capita; and a theoretical strand of macroeconomic models of interaction between environmental degradation and economic growth, including optimal growth, endogenous growth and overlapping generation’s models.	The author concludes that the macroeconomic models generally support the empirical findings of the Environmental Kuznets Curve literature. He suggests further empirical investigation related to the assumption of additive separability, as well as development of additional macroeconomic models that allow for a more realistic role for government.
Galleoti, M and A. Lanza Journal of Environmental Economics and Management (1999)	Desperately Seeking Environmental Kuznets Curve	The number of studies seeking to empirically characterize the reduced-form relationship between a country's economic growth and the quantity of various pollutants has increased lately, but in the case of CO2 emissions the evidence is at best mixed.	The article utilizes two models. A linear and a log model are presented to analyze which one explains better the relations among pollution and economic growth. Both models use the same variable. $CO2_{it} = i + t + GDP_{it} + GDP^2_{it} + GDP^3_{it} + \mu_{it}$ Where: CO2= is carbon dioxide emissions GDP= Real GDP	Non-nested tests have produced the result that essentially Gamma and Weibull are to be preferred to the usual log-linear functional form. When alternative functional forms are employed, the emergence of a bell-shaped Environmental Kuznets Curve with reasonable turning points is a possibility.

Wang, P; Bohara, A; Berrens, R; Gawande, K. Applied Economics Letters 5, no.12 (1998)	A risk-Based Environmental Kuznets Curve for US Hazardous Waste Sites	The Environmental Kuznets Curve (EKC) hypothesis is investigated for US hazardous waste sites. US county level data and assessed risk is used as the measure of environmental degradation.	A tobit model was used in this journal. The model was only described in the paper. The authors included Aggregated Hazard Ranking Scores as the dependent variable. Per capita income and per capita income square were the right hand side variables. The EPA calculates and evaluates four threat pathways to measure Hazard Ranking Scores including: ground water migration, surface water migration, soil exposure, and air migration. An extended model was also used in the analysis of this paper. The authors include the above variables plus %or rural population, %of white people, % of homeowners, and % of college graduates.	The EKC holds using assessed risk to toxic hazardous waste exposure. They also urge caution in generalizing and interpreting the results.
Laszlo, M; Laszlo, K; Lachlan, M. Applied Economics Letters 5, no.11 (1998)	The Kuznets U-Curve Hypothesis: Some Panel Data Evidence	In this paper Kuznets' U-curve hypothesis is tested on two unbalanced panel data sets of 47 and 62 countries, for the period 1970-93, using two-way fixed and random effects models.	The model formulated in the paper was: $INQ_{it} = \beta_0 + \beta_1 Y_{it} + \beta_2 Y^2_{it} + a_i + ?_t + \mu_{it}$ Where: INQ_{it}= Measure of income inequality. Y_{it}= Per capita GDP. a_i= Country effects. $?_t$= Time effects	It is shown that there is no hard empirical evidence to support the usual econometric model formulations and the U-curve hypothesis. Income inequalities are more likely to be explained by complex country specific factors, and they essentially do not depend on the level of development.

Kahn, M. Public Economics Papers (1995)	Micro Evidence on the Environmental Kuznets Curve	It is important to quantify how vehicle pollution varies with individual income when considering the equity and efficiency of stringent vehicle emissions testing or vehicle scrap page programs.	The model used assumes a log-linear relationship among vehicle's emissions in California and car model, year, mileage, engine type, and owner income	Richer people in California pollute less than poor people at least than richer people drive a lot of miles. It is obvious that if richer people are polluting more the environment in California, then public policy should target the wealthy people because they have the resources to pay for better environment conditions.

Data and Methods

Environmental Kuznets curve models have been estimated either in quadratic or in cubic specifications between pollutant concentration and per capita income. We adopt both of these specifications in our analysis. The general form of the panel data model used to describe the relationship between pollution and income in this study is given in equation (1).

$$p_{it} = a + \sum_{k=1}^{m} b_k y_{it}^k + b_{m+1} W_{it} + b_{m+2} D_{it} + u_{it} \qquad (1)$$

Here, p is a water pollutant (nitrogen, phosphorus or dissolved oxygen), y is per capita income, i and t represent indices of parish and time, respectively. Population density (persons per square mile) is accounted by D, and W represents a weighted income variable used to represent the spillover effect of pollution. For example, equation 1 has been traditionally estimated for each pollutant although a clear correlation seems to exist between error terms in different pollutant equation. We incorporate this fact in this paper.

A set of M equations each describing pollutant j (N, P, DO, Mercury) can be shown in SUR Panel model as follow:

$$P_j = Z_j d_j + u_j \qquad\qquad j = 1, ..., M$$
$$u_j = Z_m m_j + v_j$$

Here v_j are random vectors with zero mean and $\sum_v \otimes I_{NT}$ variance. Each error component follows the SUR assumptions imposed on classical disturbances.

Because the cross-section represents individual states (which are fixed in a sample size context) and t represents the time series, a reasonable approximation to estimate the above model is the fixed effects model whereby the individual states have their intercept value (this model is typically known as a dummy variable model). Empirically, it is possible that a pooled regression model (estimating an OLS model on the entire sample) works as well if the fixed effects are not significant. Therefore, Hausman test is used to test whether FE are significant. Because environmental regulations and quality standards for collecting environmental data may be similar from state to state, if may be possible to improve on single equation estimates of the FE panel data model via a seemingly unrelated regression model for various pollutants. A Lagrange Multiplier (LM) test for diagonal residual covariance matrix for pairs of equations (N,M), (P,M) and (DO,M) can be carried out (Greene, p.621). The LM test is distributed Chi-squared with

M(M-1)/2 degrees of freedom; since there are two equations in each system, the degrees of freedom equals 1 in this application. If the null hypothesis of zero covariance is rejected, then SUR estimation of the fixed effects model is appropriate.

The true model specification is never known. Therefore, alternative model specifications should be considered in practice. Recent contributions on semiparametric modeling of the environmental Kuznets curve hypothesis (Paudel *et al.* 2005; Millimet *et al.* 2003) suggest the specification of a semiparametric partial linear regression (PLR) model such as that in Engel *et al.* (1986) and Robinson (1988). The model is flexible in capturing non-linearities between environmental quality and per capita income, and it minimizes the tradeoff between variance and bias (Hardle, 1990). Consistent with preliminary parametric diagnostics, the panel data model is specified as a fixed effects error-components model (also referred to as a dummy variable model), which can be rewritten as:

$$p_{it} = \mathbf{v}_i + X_{it} b + g(Y_{it}) + Z_{it} \qquad (2)$$

Here, X_{it} is a set of parametric variables of state characteristics such as population density and weighted income, v_i measures individual (state) effects, $g(Y_{it})$ is an unknown, assumed to be relatively smooth, function of powers of income (the smoothing variables) and is assumed that $g(Y_{it})=E(p_{it}/Y_{it})$, $E(Z_{it}/Y_{it})=0$, and variance $V(Z_{it}/Y_{it})=\sigma^2(Y_{it})$, and (p_{it}, Y_{it}) are i.i.d. The nonparametric estimate of $g(Y_{it})$ is the smoothed average of the p_{it} which correspond to the Y_{it} values in a small interval of Y with interval width (window) h, and h tends to zero as NT goes to infinity (e.g., Hardle, 1990; Ullah and Roy, 1998; and Yatchew,2003). The degree of smoothness, often called the smoothness parameter, controls the tradeoff between smoothness and goodness of fit. For this study, the smoothness parameter was chosen by minimizing the generalized cross-validation (GCV) function (Yatchew, 2003), and plots of the GCV function were obtained to ascertain that this function achieved a minimum for the data at hand.

The question of how to best test the parametric model in equation (1) versus the semiparametric specification in equation (2) has been the subject of much recent research (e.g., Ullah and Roy, 1998). We use Hong and White's test for the purpose. We used disaggregated nature of the data on nitrogen, phosphorus (primarily nonpoint source), and mercury (primarily point source) concentration in water from each watershed collected by the Louisiana Department of Environmental Quality. The pooled data consisted of observations from 1985 to 1999 for 53 parishes in Louisiana.

Results

Three parametric models were estimated: the pooled OLS, a fixed effects model, and a SUR of the dummy variable version of the fixed effects. The results are presented in Table 1. The first column in table 1 corresponds to the dependent variable (nitrogen, phosphorus, dissolved oxygen, and mercury) often used in the estimation of the EKC. The independent variables for the first three pollutants (nitrogen, phosphorus and dissolved oxygen) are the same. The specification of the mercury model, however, differs from the others by the inclusion of the *permit* variable instead of cropland acreage. Therefore, bivariate SURE models for the FE dummy variable model are estimated for nitrogen and mercury, phosphorus and mercury, and dissolved oxygen and mercury. For example, the nitrogen block in table 1 provides estimates for single equation pooled OLS (labeled OLS), fixed effects (FE) and SURE between nitrogen and mercury for nitrogen; the mercury equation estimates from the above bivariate SURE are provide in the SURE(N) line of the mercury block in table 1. The income effects are shown in columns 3-5, the weighted income effect in column 6, and the crop acreage for the nitrogen, phosphorus and dissolved oxygen equations or the permit variable for the mercury equation in column 7. Some goodness of fit statistics (R-squared and F-tests for model significance are shown in columns 8 and 9). The last column in table 1 is a Hausman specification tests for fixed effects, and the lower left-indented portion of this column is the LM statistics. The results in table 1 highlight the following main findings. Low R-squares are associated with the pooled least squares estimates for all pollutants, suggesting a lack of fit. The Hausman test values in the last column of table 1 indicate that fixed effects are significant and offer an improvement over the pooled the model. Note that all R-squares are significantly higher for the FE models, in fact these are the highest of models. SURE estimates of the dummy variable FE model do not seem to improve the model fit (R-squares are lower than those of the non-SURE FE but much higher than those of the OLS). Therefore, the tentative specification that seems to work best is that of the FE panel data model.

Recent work with panel data (Ullah and Roy) suggests that model misspecification can lead to inconsistent and inefficient estimates and suboptimal test statistics. It is argued that nonparametric and semiparametric estimation procedures of the fixed effects model could be more robust to misspecification. The contribution of this empirical study is to test whether a single equation semiparametric specification of the FE model is consistent with the data (relative to the parametric FE model). In turn, it is also tested whether efficiency gains can be achieved through seemingly unrelated regression estimation, similar to gains in the parametric counterpart (Greene). Table 2 reports the results of the semiparametric estimation of the kuznets curve. Columns 2 and 3 report the Hong-White test statistics and its p-value for single equation FE model estimates for nitrogen, phosphorus, dissolved oxygen and mercury. The null model, therefore, is the parametric fixed effects model and the alternative model is the semiparametric FE model. In all cases, the null hypothesis of a parametric FE model is strongly rejected. Columns 4 and 5 in table 2 contain the Langrange Multiplier tests statistic for testing the null hypothesis of a diagonal covariance matrix from the residuals of the single-equation semiparametric estimates for nitrogen and mercury (N,M), phosphorus and mercury (P,M), and dissolved oxygen and mercury (DO,M). Similar to the parametric results, the hypothesis of zero correlation between equation residuals is not rejected.

Conclusions and Future Work

This study reports a parametric and semiparametric evaluation of the environmental Kuznets curve using annual data (1985-2000) for 53 parishes in Louisiana. The following conclusions are derived. First, similar to other works, the parametric fixed effects model is a more adequate specification of the pollution-income relationship for Louisiana. Second, estimation efficiency gains through SUR estimation do not appear to be signification for the data at hand with a FE specification. Third, single-equation semiparametric estimates of the EKC works well for all four pollutants: nitrogen, phosphorus, dissolved oxygen and mercury. Lastly, no estimation efficiency gains can be achieved by estimating the EKC as a semiparametric seemingly unrelated regression specification. Work in progress studies the time series properties of the EKC data using panel data procedures and will reassess the validity of SUR findings in a more general model specification.

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Table 1. OLS, Fixed Effects and SURE Estimates and Specification Tests, Environmental Kuznets Curve, Louisiana 1985-2000.

Equation	Method	Income	Income2	Income3	Weighted Income	Crop Acreage/point sources	R2	F p-value	H-Test (p-value)
Nitrogen	OLS	-0.84	0.0994	-0.0038	-0.000009	2.758e-7	0.01	0.03	
		(0.5495)	(0.0584)	(0.0023)	(8.1e-6)	(1.319e-7)			
	FE	-0.7940	0.0943	-0.0035	-0.000008	5.9e-7	0.51		13.31
		(0.4923)	(0.0569)	(0.0021)	(8.1e-6)	(2.27e-7)			(0.0001)
	SURE	-0.7936	0.0942	-0.0035	-0.00002	5.9e-7	0.37		
		(0.4923)	(0.0569)	(0.0021)	(8.1e-6)	(2.2e-7)			
Phosphorus	OLS	-0.2495	0.0288	-0.0011	-0.000007	1.8063e-7	0.02	0.001	
		(0.1930)	(0.0228)	(0.00087)	(0.000003)	(5.143e-8)			
	FE	-0.1613	0.0212	-0.0008	1.447e-6	4.073e-8	0.65		23.34
		(0.1635)	(0.0189)	(0.0007)	(2.695e-6)	(7.537e-8)			(0.0001)
	SURE	-0.1611	0.0212	-0.0008	1.441e-6	3.943e-8	0.50		
		(0.1635)	(0.0189)	(0.0007)	(2.695e-6)	(7.535e-8			
Dis. Oxygen	OLS	-8.0909	0.8723	-0.0298	-0.00002	9.752e-7	0.05	0.0001	
		(2.1054)	(0.2483)	(0.0096)	(0.00003)	(5.61e-7)			
	FE	-3.5960	0.3813	-0.0128	4.266e-6	1.011e-6	0.74		34.18
		(1.5658)	(0.1810)	(0.0068)	(0.000026)	(7.218e-7)			(0.0001)
	SURE	-3.5946	0.3812	-0.0128	4.205e-6	9.995e-7	0.60		
		(1.5946)	(0.1810)	(0.0068)	(0.000026)	(7.217e-7)			
Mercury	OLS	0.4134	-0.0469	0.00173	0.000005	-0.00094	0.04	0.68	
		(0.4764)	(0.0562)	(0.00216)	(0.000007)	(0.00084)			
	FE	0.0676	-0.0087	0.0004	0.000015	-0.0004	0.12		1.67
		(0.6327)	(0.0731)	(0.0027)	(0.00001)	(0.00001)			(0.0029)
	SURE(N)	0.0681	-0.0087	0.0004	0.000015	-0.0004	0.37		**0.298 LM**
		(0.6327)	(0.0731)	(0.0027)	(0.00001)	(0.0009)			**(0.41)**
	SURE(P)	0.0687	-0.0088	0.0004	0.000015	-0.0004	0.50		**0.328 LM**
		(0.6327)	(0.0731)	(0.0027)	(0.00001)	(0.0009)			**(0.43)**
	SURE(DO)	0.0653	-0.0084	0.00039	0.00015	-0.00034	0.60		**0.307 LM**
		(0.6327)	(0.0731)	(0.0027)	(0.00001)	(0.0009)			**(0.42)**

Table 2. Specification Tests of Parametric Fixed Effects (FE) versus Semiparametric FE, Environmental Kuznets Curve, Louisiana, 1985-2000.

Equation	**Hong-White Test**		**Semiparametric Test for SUR**	
	Statistic	**p-value**	**Statistic**	**p-value**
Nitrogen	100.827	<0.000	0.2693 (N,M)	0.40
Phosphorus	128.699	<0.000	0.2868 (P,M)	0.41
Disolved Oxygen	147.05	<0.000	0.2947 (DO,M)	0.41
Mercury	21.540	<0.000		