FINAL TASK REPORT

TASK 3 - DEVELOPMENT OF ADDITIONAL MULTIVARIATE LINEAR REGRESSION SALINITY MODELS FOR FLORIDA BAY AND THE SOUTHWEST GULF COAST, EVERGLADES NATIONAL PARK

Cooperative Agreement Number CA H5284-05-0006
Between
The United States Department of the Interior National Park Service
Everglades National Park
And
Cetacean Logic Foundation, Inc.

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January 5, 2008
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CESI Project No. CA H5284-05-0006 for Everglades National Park

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I. Introduction

A. General

This report describes the activities that were completed for a task in the -going Critical Ecosystem Studies Initiative (CESI) project that was originally initiated by Cetacean Logic Foundation, Inc. (CLF) for Everglades National Park (ENP) in 2002. The goal of this CLF research is the characterization and simulation of the salinity regime in Florida Bay and the estuaries along southwest coast of the Gulf of Mexico (Gulf) within the Park, which receive freshwater drainage from the Everglades. It is intended that this research yield information regarding the link between the downstream salinity in the estuaries of ENP and the upstream freshwater hydrology of the Everglades.

The subject of the task and this report is the development of multivariate linear regression (MLR) salinity models for some the ENP Marine Monitoring Network (MMN) stations. MLR salinity models were previously developed for about half of the 33 stations in the MMN (Marshall, 2005a; 2005b). The development of models for the remaining MMN stations is described herein.

B. Task Objectives and Evaluation Methods

The objective of this task is presented below as it appears in the modified contract for this CESI project approved by ENP:

> "The year one CESI project focused primarily on the development of models for Joe Bay, Little Madeira Bay, Terrapin Bay, Garfield Bight, North River, and Whipray Basin. The IOP exercise updated some of those models and added a new model for Long Sound, Duck Key, and Butternut Key. The second year CESI project added new MLR salinity models for Taylor River, Highway Creek, Little Blackwater Sound, and Bob Allen Key. Work for the Southern Estuaries Sub-team developed new models for Whitewater Bay East, Clearwater Pass, Shark River, and Gunboat Island. New MLR salinity models will be developed using the longest period of data available at the remaining physical monitoring stations in the ENP MMN. Most of these stations are within the influence of Shark River Slough or relatively more distant from the

Everglades in the open water areas of Florida Bay. The development of new models assumes that the data are adequate and that there is a statistical relationship between salinity at a particular locations and the suite of independent variables that have been assembled for model development. The MMN stations for new models are Broad River, Buoy Key, Broad River Lower, Cane Patch, Harney River, Johnson Key, Lane River, Lostmans River, Little Rabbit Key, Murray Key, Peterson Key, Tarpon Bay East, and Willy Willy.

The deliverable is a task report describing model development activities and new MLR salinity models."

In addition to the stations above, MLR salinity models were also developed for Cannon Bay and Watson Place, in the extreme northwest area of ENP on the coast of the Gulf of Mexico.

II. Data for Model Development

Previous work has shown that daily stage values are useful for salinity modeling because they correlate well with daily salinity, though sometimes there is a lag (Marshall et al, 2003; Marshall, 2003; Marshall et al, 2004). The same is true for daily average sea surface elevation and wind. Coastal aquifer conceptual models and the well-known Ghyben-Herzberg principle provide examples of the connectivity of upstream water levels (both surface and ground water) and downstream salinity in the transition zone of an estuary, and the opposing hydraulic influence of the elevation of the sea surface.

In choosing the data that are to be included in the initial correlation analysis and ultimately the MLR salinity models, the end use of the models has to be considered. To-date, the MLR salinity models have been used primarily for the evaluation of Comprehensive Everglades Restoration Plan (CERP) water delivery alternatives using output from the South Florida Water Management Model (SFWMM, or 2X2 model). The 2X2 model produces daily estimates of stage (water level) and flow of freshwater throughout the Everglades for a number of CERP scenarios over a 36-year period (1965 – 2000). Therefore the MLR salinity models need to be easily utilized with 2X2 Model output as at least one of the applications of these models.

The CERP alternatives re-distribute and augment freshwater deliveries to the Everglades as expressed in the stage data of each of the 2X2 model CERP runs. The MLR salinity models that have already been developed use the 2X2 model stage output in conjunction with available long-term data for wind and sea surface water level to produce estimates of daily salinity for the 36-year period in Florida Bay, the southwest Gulf coast, and Barnes Sound and Manatee Bay.

The independent variable data used with the 2X2 model stage data must be available for most, if not all of the 36-year period in order to populate the models

and obtain estimates of salinity to be of use for the CERP evaluations. Long term sea surface elevation data (i.e. covering the entire 36-year period of record) are only available for at a small number of tide gauging stations along the coast of Florida, and the same is true for wind speed and direction in south Florida. Unfortunately, there are no long-term evaporation data available (particularly at the daily time step) for the 36-year period, because evaporation can play an important role in determining salinity during dry periods when freshwater inflows are at a minimum. Flow data from control structures and tidal creeks do not correlate as well to salinity compared to stage, and observed flow is not as useful for salinity model development and simulation purposes compared to stages (water levels) in the Everglades.

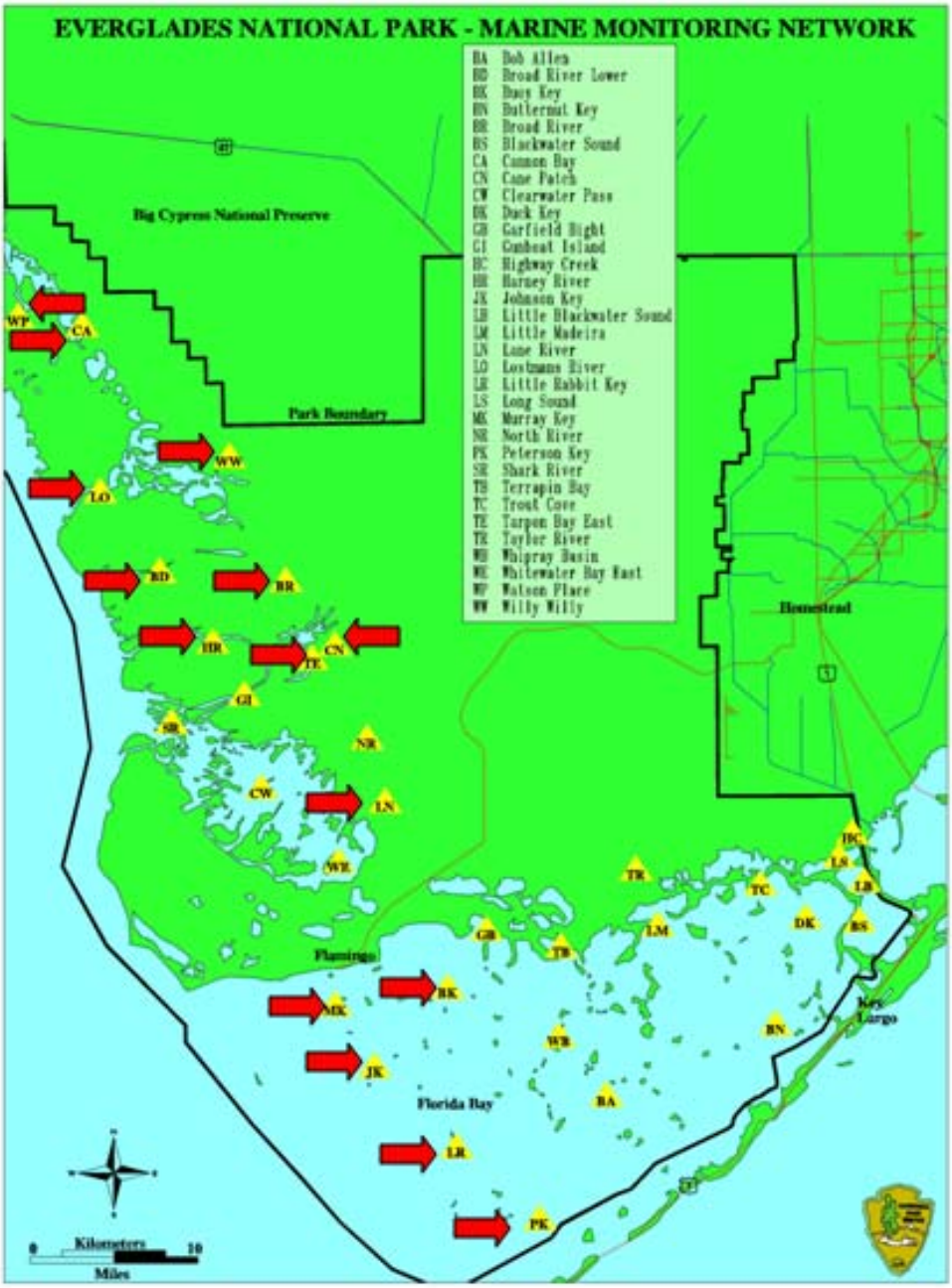
Although rainfall (like evaporation) is an important hydrologic parameter for seasonal salinity variation, rainfall at monitoring stations in the Everglades is not highly correlated with salinity at the daily level. Instead, the stochastic effect of rainfall falling on the Everglades and the upstream watershed is integrated by the coastal aquifer system and expressed adequately in stage data.

For model development, observed stage data are used. Model output data from the 2X2 model and SICS/TIME have previously been used for input to MLR salinity models for simulations. Model development and simulations use the same observed data for wind and sea level although the period of the simulation is longer.

The period of record for model development varied widely because the beginning date for data collection varied widely. Most series contained some missing values. No attempts were made to fill in data gaps or to eliminate outliers in either independent or dependent variable data sets. For all model development activities except the Willy Willy model, data were held from the calibration data and used for a verification exercise.

The models were developed from MMN observed data that have been collected at 15 to 60 minute increments and averaged to daily values. Salinity data were obtained from the ENP Marine Monitoring Network (MMN) data base, Table 1 (http://www.sfnrc.ever.nps.gov/portal/page?_pageid=53,1&_dad=portal&_schema=PORTAL – this website will not be available in the future). Details about these data can be found in Everglades National Park (1997a and 1997b), and Smith (1997, 1998, 1999, and 2001). A map showing the ENP MMN stations and the locations of the water level monitoring stations used for this study is presented as Figure 1. The stage data are ENP Physical Monitoring Network Everglades water levels, as available on the South Florida Water Management District DBHYDRO website (http://my.sfwmd.gov/portal/page?_pageid=2235,4688582&_dad=portal&_schema=PORTAL) . A limited number of continuous water level (stage) monitoring stations in the Everglades began recording data in the 1950's (see Table 2), but most stage records date from the 1990's.

Figure 1. Map of all ENP Marine Monitoring Stations showing stations where MLR salinity models were prepared during this study (red arrows). At all other locations, models were previously prepared as part of other studies



Tide data were obtained from the NOAA Tides Online website (http://tidesonline.nos.noaa.gov/). Because a number of the stations in this study were located north of Cape Sable along the southwest Gulf of Mexico coast, the data from the Naples and Fort Myers tide stations were evaluated for use. However, tide data at both of these stations have only been collected continuously since 1996. Prior to 1996, predicted daily average tide levels are available at these stations. An evaluation of the comparison plots for predicted and actual tide elevations showed considerable local variability likely due to wind or physical condition factors. Therefore, similar to the previous model development activities, the sea surface elevation measured at Key West was used instead as a potential independent variable, and the data span the entire 36-year period.

Wind data are available at a number of locations in the region. National Weather Service wind data used for MLR modeling were obtained from the Southeast Regional Climate Center. Wind data from Key West and Miami were used as these locations had the longest continuous records for wind and were considered to be representative of the regional wind patterns. Hourly wind speed and direction data were processed into vector quantities then daily averages were computed. The independent variables UWNDMIA and VWNDMIA are the *U* and *V* vectors of wind measured at the Miami weather station; UWNDKW and VWNDKW are the *U* and *V* vectors of wind measured at Key West. These components are computed as follows:

U = (Resultant wind speed) * Cosine (Resultant direction)

V = (Resultant wind speed) * Sine (Resultant direction).

For the MLR salinity model development the units of wind speed are ft/sec and the units of direction are bearing degrees.

Table 1. Summary of information about the monitoring stations and salinity data used in model development and verification for additional Florida Bay and southwest Gulf coast MLR salinity models. All data were collected by ENP.

Station Name	MMN ID	Location	Beginning 0f Record
Blackwater Sound	BS	Northeastern Florida Bay	11/09/1991
Broad River	BR	Shark River Slough Estuary	01/18/1990
Broad River Lower	BD	Shark River Slough Estuary	04/12/1996
Buoy Key	BK	Central Florida Bay	04/27/1988
Cannon Bay	CA	Upper West Coast	09/20/2000
Cane Patch	CN	Shark River Slough Estuary	01/19/1990
Harney River	HR	Shark River Slough Estuary	03/13/1996
Johnson Key	JK	Western Florida Bay	01/01/1988
Lane River	LN	Whitewater Bay	04/18/1996
Lostmans River	LO	Upper West Coast	10/16/1997
Little Rabbit Key	LR	Western Florida Bay	04/27/1988
Murray Key	MK	Western Florida Bay	04/27/1988
Peterson Key	PK	Western Florida Bay	04/27/1988
Tarpon Bay East	TE	Shark River Slough Estuary	04/04/1996
Watson Place	WP	Upper West Coast	09/20/2000
Willy Willy	WW	Upper West Coast	08/25/1997

Table 2. Data summary for the independent variable database used in model development and verification for Florida Bay MLR salinity models.

Variable Name	Variable Type	Units	Data Source	Location	Beginning Date of Data Record
Little Madeira Bay	Salinity	psu	ENP	North Central Florida Bay, near-shore embayment	04/28/1988
Terrapin Bay	Salinity	psu	ENP	North Central Florida Bay, near-shore embayment	09/12/1991
CP	Stage	Ft, NGVD 29	ENP	Craighead Pond	10/01/78
E146	Stage	Ft, NGVD 29	ENP	Taylor Slough	03/24/94
EVER4	Stage	Ft, NGVD 29	ENP	So. Of FL City	09/20/85
EVER6	Stage	Ft, NGVD 29	ENP	So. Of FL City	12/24/91
EVER7	Stage	Ft, NGVD 29	ENP	So. Of FL City	12/24/91
G3273	Stage	Ft, NGVD 29	ENP	East of S.R. Slough	03/14/84
NP206	Stage	Ft, NGVD 29	ENP	East of S.R. Slough	10/01/74
NP46	Stage	Ft, NGVD 29	ENP	Rocky Glades	01/15/66
NP62	Stage	Ft, NGVD 29	ENP	East of S.R. Slough	01/04/64
P33	Stage	Ft, NGVD 29	ENP	Shark River Slough	02/15/53
P35	Stage	Ft, NGVD 29	ENP	Shark River Slough	02/15/63
P37	Stage	Ft, NGVD 29	ENP	Taylor Slough	01/15/53
P38	Stage	Ft, NGVD 29	ENP	Shark River Slough	01/10/52
R127	Stage	Ft, NGVD 29	ENP	Taylor Slough	04/11/84
PA8	Stage	Ft, NGVD 29	SFWMD	Big Cypress Preserve	10/12/95
PA9	Stage	Ft, NGVD 29	SFWMD	Big Cypress Preserve	10/06/95
PA10	Stage	Ft, NGVD 29	SFWMD	Big Cypress Preserve	10/05/95
PA11	Stage	Ft, NGVD 29	SFWMD	Big Cypress Preserve	09/11/95
UWNDKW	E-W Wind	N/A	NWS	Key West	01/07/57
VWNDKW	N-S Wind	N/A	NWS	Key West	01/07/57
UWNDMIA	E-W Wind	N/A	NWS	Miami	01/07/57
VWNDMIA	N-S Wind	N/A	NWS	Miami	01/07/57
KWWATLEV	Sea Surface Elevation	Ft, MSL	NOS	Key West	01/19/13

III. Model Development

A step-wise multivariate linear regression process was used to determine the most appropriate linear combination of independent variables for each salinity model. To begin the model development procedure, all independent variables were subjected to a cross-correlation analysis with daily salinity using SARIMA techniques to determine which of the variables were correlated with salinity, to check for lagged relationships, and to evaluate the level of correlation. Lags up to 50 days were initially reviewed, though it was found that significant lagged correlations never exceeded six days. Then the observed data of the significant correlated variables (current and lagged values) were input to a SAS© PROC REG routine that uses a step-wise regression process to identify the most statistically significant parameters for a multivariate linear regression equation. To ensure that only the most highly significant parameters were selected by this process and to limit the number of variables in a model, the significance level for parameter inclusion in the model was set at 99.9%, a very high level. Parameter inclusion in a model was also manually controlled by eliminating any seemingly correlated variables that acted contrary to known physical relationships (such as an increasing stage in the Everglades indicating an increase in salinity) which can occur when there are cross-correlation effects. These parameters were eliminated, and the step-wise process re-run iteratively.

For the development of each model, some of the available data were held out of the calibration process and used for verification purposes. The periods for calibration and verification are presented in Table 3.

For the open-water stations in central Florida Bay and MMN stations along the open west boundary of the Bay with the Gulf, it was found that the best-fit salinity models included salinity at the near shore stations of Little Madeira Bay and Terrapin Bay in the model as well as stage in the Everglades, wind vectors and sea surface elevation. In fact, without the inclusion of Little Madeira Bay and Terrapin Bay salinity the open-water models were insufficient to explain variability beyond about 30%. This means that, for these stations, simulation will be a two-step process with the simulation of salinity at Little Madeira Bay and Terrapin Bay required before salinity at the open-water stations can be simulated.

For the stations that are located in Whitewater Bay, the Shark River Slough estuary, and along the northernmost Gulf coast in ENP, the use of the daily average sea surface elevation from the Naples, Florida station (ID No. 8725110) instead of the data from the Key West station (ID No. 8724580) improved model fit by about 3-5%. For the Florida Bay stations along the western boundary with the Gulf, both Key West and Naples data were significant. However, the Naples data are predicted values prior to 1995, so Key West water level was used for model development purposes as in the past.

Table 3. Periods used for calibration and verification for MLR salinity model development.

Station Name	Calibration Period	Verification Period
Blackwater Sound	07/16/1994 – 12/31/2000	01/01/2001 - 12/31/2001
Buoy Key	09/07/1997 - 12/31/2000	01/01/2001 - 10/31/2002
Broad River	01/12/1996 - 12/31/1999	01/01/2000 - 12/31/2000
Broad River Lower	05/09/1996 - 12/31/1999	01/01/2000 - 12/31/2000
Cane Patch	05/09/1996 - 12/31/1999	01/01/2000 - 12/31/2000
Cannon Bay	10/16/1997 - 02/30/2002	01/01/2003 - 03/13/2003
Harney River	06/14/1996 - 12/31/1999	01/01/2000 - 12/31/2000
Johnson Key	08/19/1994 - 12/31/2000	01/01/2001 - 10/31/2002
Lane River	05/09/1996 - 12/31/1999	01/01/2000 - 12/31/2000
Little Rabbit Key	09/10/1997 - 12/31/2000	01/01/2001 - 10/31/2002
Lostmans River	10/16/1997 - 12/31/2000	01/01/2001 - 10/31/2002
Murray Key	10/21/1997 - 12/31/2000	01/01/2001 - 10/31/2002
Peterson Key	07/16/1994 - 12/31/2000	01/01/2001 - 10/31/2002
Tarpon Bay East	05/09/1996 - 12/31/1999	01/01/2000 - 12/31/2000
Watson Place	09/20/2000 - 12/31/2002	01/01/2003 - 03/13/2003
Willy Willy	08/25/1997 - 12/31/2001	01/01/2002 - 03/01/2003

Additional details on model development can be found in Marshall, et al (2003a; 2004) and Marshall (2003b; 2005). The daily salinity models that were developed for this task and the associated adjusted-R^2 value are shown below by sub-region. All independent variables in these models are significant at the 99.9% level, except for Cannon Bay (95% significance level).

Figures 2 to 17 present the salinity simulated by the models below compared to the observed data for the calibration and verification periods. These figures are presented at the end of the report following the references.

Central Florida Bay

Buoy Key = 24.82836 – (1.13942 cplag4) + (0.23472 terbay) + (0.14891 terbaylag4), adj-R^2 = 0.79

Western Florida Bay

Murray Key = 50.44369 – (3.15719 p33) + (0.14449 terbaylag4), adj-R^2 = 0.51

Johnson Key = 53.13962 – (3.53830 p33) + (0.09932 ltmadlag4) + (0.07948terbaylag4) + (0.04843 vwndmia) + (0.55111 kwwatlev), adj-R^2 = 0.55

Little Rabbit Key = 51.31785 – (3.18926 p33lag1) + (0.19900 ltmadlag4) + (0.59864 kwwatlev), adj-R^2 = 0.46

Peterson Key = 39.76767 – (1.57570 p33lag4) + (0.25200 ltmadlag1) - (0.04663 uwndkwlag1) - (0.06325 vwndkw) + (0.08712 vwndmia), adj-R^2 = 0.56

Whitewater Bay

Lane River = 56.42862 – (1.46788 p35lag2) – (2.82488 p33) - (4.71551 np206lag4) – (0.07508 uwndkwlag1) – (0.13990 vwndkwlag1) - 0.05170 vwndmialag3), adj-R^2 = 0.77

Shark River Slough Estuary

Cane Patch = 7.86280 – (1.20972 np206lag4) + (0.23731 vwndmia), adj-R^2 = 0.42

Tarpon East = 22.18537 – (1.02605 p33lag4) – (2.23641 np206lag4), adj-R^2 = 0.57

Harney River = 51.09667 – (2.84042 p35lag4) – (6.12109 np206lag2) – (0.22464 vwndkw) - (0.11811 vwndkwlag1) – (0.17356 uwndmia) + (2.45632 kwwatlevlag1), adj-R^2 = 0.72

Broad River = 20.82753 – (3.11717 np206lag4) - (0.05780 vwndkwlag1), adj-R^2 = 0.53

Broad River Lower = 73.21431 – (4.82197 p35lag3) – (4.03692 p33) - (4.15505 np206lag2) - (0.31452 vwndkw) – (0.22519 uwndmia) + (0.28467 uwndmialag2) + (0.10788 vwndmialag3) + (4.41540 kwwatlevlag2), adj-R^2 = 0.74

Upper West Coast

Willy Willy = 19.10483 – (2.23072 pa8lag2) – (2.23460 pa11lag2), adj-R^2 = 0.71

Lostmans = 43.18695 – (6.08870 pa8lag2) – (3.11218 pa11lag2) – (0.14135 vwndkw) + (3.25077 kwwatlevlag1), adj-R^2 = 0.76

Cannon Bay = 38.12839 – (5.57603 pa8lag2) – (1.88696 pa11lag2), adj-R^2 = 0.68

Watson Place = 41.54103 – (9.59506 pa8lag1) – (0.10461 uwndkw) – (0.23667 vwndmia) adj-R^2 = 0.86 (Provisional model, limited data),

IV. Error Statistics for Models – Goodness-of-Fit Measures

A. Residuals Analysis

The ability of the MLR salinity models to simulate the observed conditions can be evaluated using a number of error statistics. Many error statistics rely on residuals (defined as the observed value minus the predicted value) as the basis for computation of the statistic. Residual plot characteristics can also be used to evaluate how well a model conforms to the assumptions of normally-distributed errors with a mean of 0. Two plots that are typically examined following model development are the predicted value/residual value plots and the normal probability plots. These two plots are presented in Appendix A for each model that was developed.

Most residual plots in Appendix A show no consistent deviations from typical behavior that would indicate a problem with the normal distribution assumptions. However, residuals for models with observed and predicted values that were in the range of 0 - 10 psu show the effects of a small range of observed values. Stations affected by the small range of salinity with low observed values include Broad River, Cane Patch, Tarpon Bay East, and Willy Willy. These stations with a large number of observed values below about 5 psu show systematic

behavior at predicted values less than 0 psu that can be seen in the predicted/residual value plots. This occurs because it is not possible for observed values to less than 0 psu, but it is possible for a predicted value from the model to be less than 0 psu. In the last step of the model development procedure any predicted value less than 0 psu is automatically set to equal 0 psu. However the SAS © procedure that produced the residual plots in Appendix A does not take this into account so the problem of systematic behavior of residuals seen in the plots when the predicted value is less than zero is not relevant to this analysis. The normal probability residual plots for these models are also affected by this issue.

The error statistics that were computed to measure model performance are described below.

B. Mean Error

The Mean Error is another measure of model uncertainty. It is defined as:

$$ME \quad \frac{1}{N} \quad {}_{n\ 1}^{N} \quad O^{(n)} \quad P^{(n)}$$

where O=observed values, P=predicted values, and N= number of observations used to develop the model. Positive values of the mean error indicate that the model tends to over-predict, and negative values indicated that the model tends to under-predict.

C. Mean Square Error

The Mean Square Error, or MSE, is defined as the mean of the squares of all the errors, as follows:

$$MSE = \frac{1}{N}\sum_{n=1}^{N}(O^{(n)} - P^{(n)})^{2}$$

D. Root Mean Square Error

The Root Mean Square Error is defined as:

$$RMS \quad \sqrt{\frac{1}{N} \quad {}_{n\ 1}^{N} \quad O^{(n)} \quad P^{(n)}\ {}^{2}}$$

The Root Mean Square Error is a weighted measure of the error where the largest deviations between observed and predicted values contribute most to this uncertainty statistic. This statistic has units that are the same as the observed and predicted values. It is thought to be the most rigorous tests of absolute error.

E. Mean Absolute Error

The Mean Absolute Error is defined as:

$$MAE \quad \frac{1}{N} \sum_{n \quad 1}^{N} \left| O^{(n)} \quad P^{(n)} \right|$$

Although the Mean Absolute Error tells nothing about over- or under-prediction, it is considered as another measure of the agreement between observed values and predicted values. It is preferred by some because it tends to cancel the effects of negative and positive errors, and is therefore less forgiving compared to the Mean Error.

F. Maximum Absolute Error

The Maximum Absolute Error is defined as:

$$MAX \quad \max \left| O^{(n)} \quad P^{(n)} \right| \quad : \quad n \quad 1, N$$

The Maximum Absolute Error is the largest deviation between observed and predicted values.

G. Relative Mean Error

Relative measures of error are not as extreme as the absolute measures presented above. Relative error statistics provide a measure of the error relative to the observed value. The Relative Mean Error is defined as:

$$RME \quad \frac{\sum_{n \quad 1}^{N} O^{(n)} \quad P^{(n)}}{\sum_{n \quad 1}^{N} O^{(n)}}$$

H. Relative Mean Absolute Error

The Relative Mean Absolute Error is defined as:

$$RMA \quad \frac{\sum_{n \quad 1}^{N} \left| O^{(n)} \quad P^{(n)} \right|}{\sum_{n \quad 1}^{N} O^{(n)}}$$

Caution must be applied in the use of these two statistics when there can be small values of the observed and predicted variable, and when they can have both positive and negative signs.

I. Relative Mean Square Error

The Relative Mean Square Error is not as prone to error by small values and/or the presence of both positive and negative values and is defined as:

$$RSE \quad \frac{\quad {}^{N} \quad O^{(n)} \quad P^{(n)} \quad {}^{2}}{{}^{N} \quad O^{(n)} \quad \overline{O} \quad {}^{2} \quad P^{(n)} \quad \overline{O} \quad {}^{2}}$$

The Relative Mean Square Error has values between zero and one, with a model that predicts well having a Relative Mean Square Error close to zero.

J. Nash-Sutcliffe Efficiency

The Nash-Sutcliffe Efficiency (NSE) is a measure of model performance that is similar to R^2. It was first proposed for use with models in 1970 (Nash and Sutcliffe, 1970). It is defined as:

$$NSE = 1 - \frac{\sum_{n=1}^{N}(P^{(n)} - O^{(n)})}{\sum_{n=1}^{N}(O^{(n)} - \overline{O})}$$

The value of the NSE roughly corresponds to the percentage of variation that is explained by a model.

K. Coefficient of Determination - R^2

The Coefficient of Multiple Determination (R^2) is the most common measure of the explanatory capability of a multivariate regression model. It is defined as:

R^2 = Sum of Squares Regression/Sum of Squares Total, or
= 1- (Sum of Squares Error/Sum of Squares Total)

$$R^2 = 1 - \frac{\sum_{n=1}^{N}(O^{(n)} - P)^2}{\sum_{n=1}^{N}(O^{(n)} - \overline{O})^2} \qquad R^2 = \frac{\sum_{n=1}^{N}(P^{(n)} - \overline{O})^2}{\sum_{n=1}^{N}(O^{(n)} - \overline{O})^2}$$

R^2 measures the percentage reduction in the total variation of the dependent variable associated with the use of the set of independent variables that comprise the model. When there are many variables in the model, it is common

to use the Adjusted Coefficient of Multiple Determination (adj-R^2), which is R^2 divided by the associated degrees of freedom.

L. Summary of Error Statistics

Table 4 presents a summary of the values of the error statistics for the models that were developed as part of this project. The R^2 values presented with the models above indicate that that the adjusted R^2 values for this suite of models range from 0.40 - 0.86. The error statistics in Table 4 indicate that Nash-Sutcliffe efficiencies of 0.41 – 0.90. The root MSE and the mean absolute error are between 1.23 – 6.12 psu, with most between 2 - 4 psu, meaning that estimation of daily point values produced by the models may have a potential error margin of 2 – 4 psu, on the average. As with all of the daily MLR salinity models produced to-date, the maximum absolute error is large, between about 5 – 20 psu, which means that there is the potential for a point estimate to have an error this large, though that is not considered to be typical.

Comparison of the error statistics in Table 4 with the statistics for other salinity models as presented in Marshall et al (2006) shows that, in general, these models perform as well and better than other salinity model types that have been developed such as hydrodynamic and hydraulic models. However, improvement may have been made for some hydrodynamic models such as USGS TIME and EFDC since the Marshall et al (2006) report was completed.

Table 4. Comparison of Model Error Statistics for MLR Salinity Models.

Station Name	N	Mean error	Mse	Root mse	Mean abs error	Max abs error	Rel mean error	Rel mse	Rel mean abs error	NSE
Blackwater Sound	2448	0.002	10.34	3.22	2.39	11.86	0.001	0.19	0.09	0.66
Broad River	1506	-0.04	5.11	2.26	1.26	13.91	-0.02	0.30	0.57	0.54
Broad Lower	1192	-0.05	15.48	3.94	3.04	16.65	0.00	0.14	0.26	0.75
Cane Patch	1602	-0.02	1.26	1.12	0.53	8.98	-0.02	0.41	0.67	0.42
Cannon Bay	794	0.01	37.50	6.12	4.75	22.87	0.01	0.05	0.26	0.90
Harney River	1600	-0.02	14.60	3.82	2.92	14.09	0.00	0.16	0.35	0.72
Johnson Key	1624	0.05	7.20	2.68	2.21	9.72	0.01	0.29	0.07	0.55
Lane River	1604	-0.14	8.58	2.93	2.13	12.55	-0.02	0.12	0.32	0.79
Little Rabbit	1121	0.09	5.84	2.41	1.92	8.58	0.01	0.37	0.05	0.45
Lostmans River	746	-0.03	21.33	4.62	3.72	12.80	-0.01	0.13	0.30	0.76
Murray Key	867	0.02	8.40	2.90	2.34	11.97	0.01	0.32	0.07	0.51
Peterson Key	1698	-0.01	3.90	1.98	1.58	5.79	-0.01	0.27	0.05	0.57
Tarpon Bay East	1601	-0.05	2.73	1.65	1.00	9.04	-0.02	0.27	0.48	0.58
Watson Place	716	-0.01	23.58	4.85	3.67	20.65	-0.01	0.07	0.18	0.86
Willy Willy	620	-0.31	6.62	2.57	1.57	10.86	-0.12	0.17	0.61	0.72

V. Discussion

The models presented herein for the ENP MMN stations, when added to the models previously prepared (Marshall, et al 2003a; 2004 and Marshall, 2003b; 2005), complete salinity model development for the MMN and provide a method of estimating salinity throughout all of the estuarine areas of Everglades National Park. While there are other salinity models available for salinity estimates in Florida Bay (FATHOM, EFDC, Nuttle's Four-box Model, SICS/TIME) the MLR salinity models developed by this study and the previous studies are the only salinity models available for Whitewater Bay, Shark River estuary, and upper west Gulf coast areas that are capable of producing a 36-year time series simulation. All of the MLR salinity models include the link to the upstream, freshwater hydrology of the Everglades through the stage independent variable, and include the important factors of sea surface level and wind variation. While evapotranspiration is not explicitly included in the model, another CESI study (Marshall, 2006) showed that the effects of evapotranspiration are included in the stage data and are so highly correlated with stage that little error is introduced at the daily time step for these models when evapotranspiration is not included. This is fortunate since long-term measurements of evapotranspiration in south Florida do not exist.

The initial MLR salinity models that were previously developed were in water body areas of specific interest. When the first models were developed they were shown to be capable of reasonably estimating daily salinity such that alternatives for CERP projects could be evaluated through the use of the SFWMD 2X2 model. However, it was noticed in the early modeling that the models are sensitive to both local and regional conditions.

The models presented herein provide additional evidence that the parameter selection process is capable of selecting independent variables that represent the relative effects of both local and regional conditions. For example, salinity at the MMN stations in Whitewater Bay and the Shark River estuary are related to the stage at monitoring stations in the Shark River Slough instead of stage stations in Taylor Slough. In particularly none of the west coast stations show any significant correlation to the stage at Craighead Pond, which was shown to be highly important for explaining the variation in salinity at Florida Bay MMN stations, and particularly the near-shore embayments. Similarly, the stations along the uppermost western Gulf coast within the Park are related to the water levels in Big Cypress Preserve as opposed to the stage in Shark River Slough.

All of the MLR salinity models for the MMN stations along the western open-water boundary of Florida Bay included P33 as a primary independent variable, either un-lagged or with a 4-day lag, as well as salinity in the near-shore embayments of Little Madeira Bay and Terrapin Bay. The importance of P33 provides evidence of the link between the Shark River discharge and the western

boundary stations as has been theorized by researchers who have examined circulation patterns in this area. All of the Shark River estuary salinity models included NP206 as a primary station, lagged and un-lagged. It is important to note that the selection criteria for inclusion of a parameter in the model was very high, 0.999, meaning that the consistent selection of independent variables as the most significant in explaining salinity variability provides additional evidence that certain stations are primary.

Wind vectors were important in explaining salinity variability at almost all stations. Each of these patterns shows that the MLR salinity models are reflecting the important driving forces for salinity in a way that seems to make physical hydrologic and hydraulic sense.

VI. Conclusions and Recommendations

The development of these additional MLR salinity models for the remaining stations in the MMN means that salinity models are now available for all of the estuarine areas within ENP. CERP alternatives can now be examined for their effect in all of the southern estuaries within ENP, providing a complete picture of the effects of meteorological events and water management as well as the potential for restoration. In a general manner the development of all MMN models have shown that there is a definitive link between the upstream hydrologic conditions in the freshwater marshes of the Greater Everglades and the estuaries into which the freshwater is being discharged, be it north or east of Cape Sable. This also means that the restoration of the estuarine areas within Everglades National Park can only happen with the restoration of freshwater levels and volumes in the Greater Everglades.

It is recommended that the models developed herein be used along with the previously developed models for estimating the salinity at the various MMN stations. The models can be used by any application that requires a time series of salinity as input data such as ecological models (e.g. seagrass and shrimp models), paleoecological evaluations, freshwater allocation activities such as minimum flows and levels determinations, and evaluating CERP alternatives.

VII. References

Marshall III, F.E.; D. Smith; and D. Nickerson. 2003. Salinity simulation models for north Florida Bay Everglades National Park. Cetacean Logic Foundation, Inc. New Smyrna Beach, Florida. 41 pp.

Marshall III, F.E. 2003. IOP salinity analysis using statistical models. Cetacean Logic Foundation, Inc. New Smyrna Beach, Florida. 35 pp.

Marshall III, F. E.; D. Smith; and D. Nickerson. 2004. Using statistical models to simulate salinity variation and other physical parameters in north Florida Bay. Cetacean Logic Foundation, Inc., New Smyrna Beach, Florida.

Marshall III, F. E. 2005a. RECOVER Southern Estuaries performance measures: identification of hydrology-salinity relationships for coastal estuaries and analysis of interim CERP update scenarios. Environmental Consulting & Technology, Inc., New Smyrna Beach, Florida.

Marshall III, F.E.; and D. Smith. 2005. Investigation of evaporation surrogates for Florida Bay salinity modeling. Task Report for a Critical Ecosystems Initiative (CESI) Project. Cetacean Logic Foundation, Inc., New Smyrna Beach, Florida.

Marshall III, F.E.; D. Smith; and W. Nuttle. 2006. Simulating and forecasting salinity in Florida Bay: a review of models. Task Report for a Critical Ecosystems Initiative (CESI) Project. Cetacean Logic Foundation, Inc., New Smyrna Beach, Florida.

Figure 2. Comparison of predicted salinity compared to observed salinity for Buoy Key. See Table 3 for calibration and verification periods.

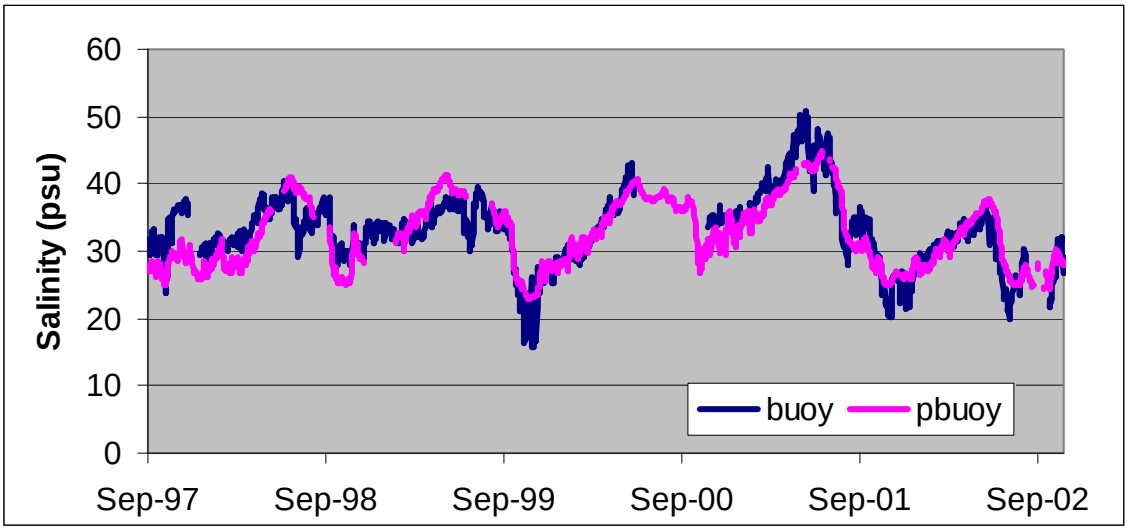


Figure 3. Comparison of predicted salinity compared to observed salinity for Murray Key. See Table 3 for calibration and verification periods.

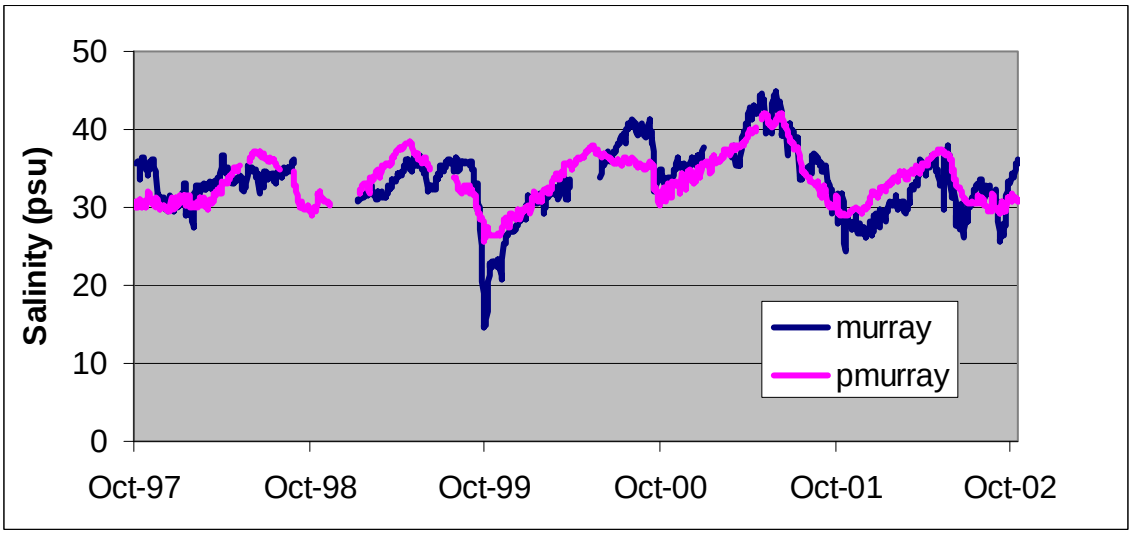


Figure 4. Comparison of predicted salinity compared to observed salinity for Johnson Key. See Table 3 for calibration and verification periods.

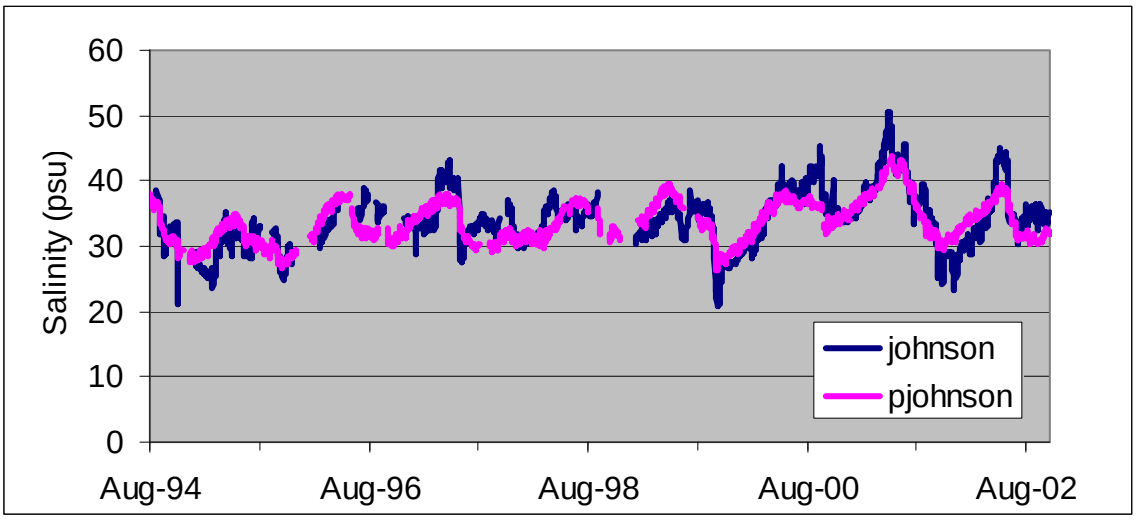


Figure 5. Comparison of predicted salinity compared to observed salinity for Little Rabbit Key. See Table 3 for calibration and verification periods.

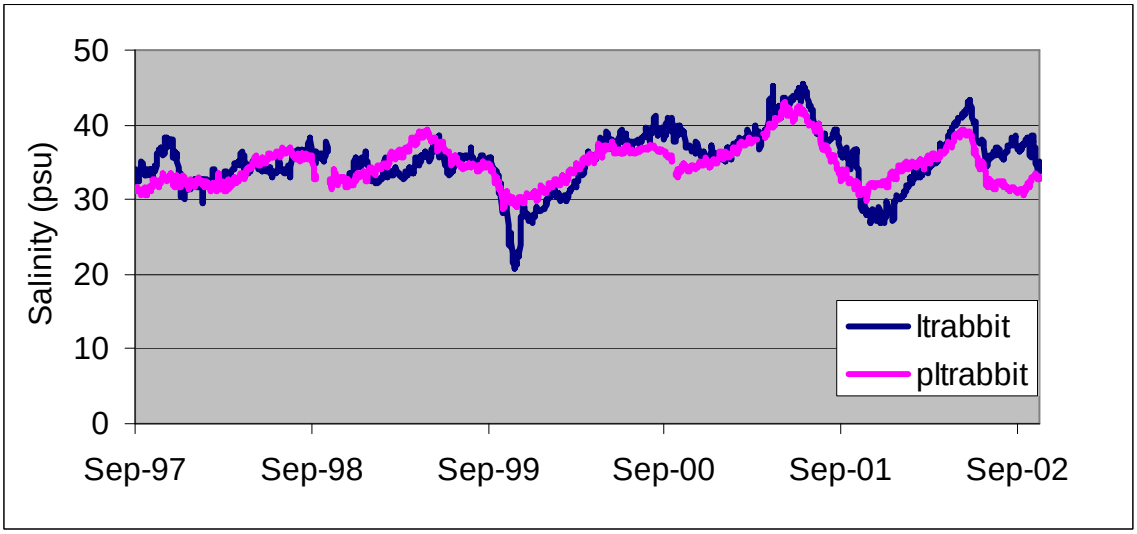


Figure 6. Comparison of predicted salinity compared to observed salinity for Peterson Key. See Table 3 for calibration and verification periods.

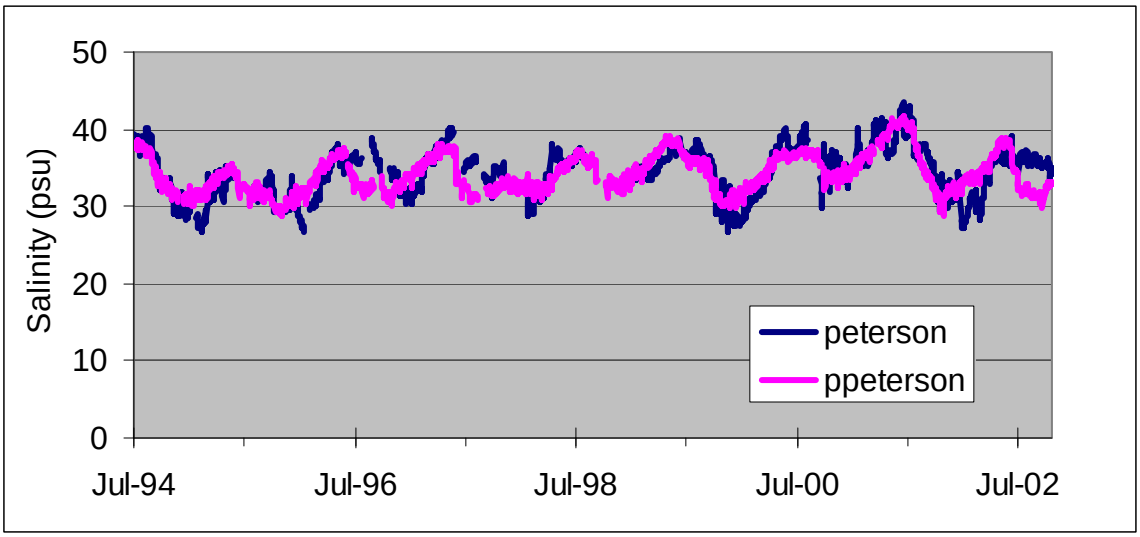


Figure 7. Comparison of predicted salinity compared to observed salinity for Lane River. See Table 3 for calibration and verification periods.

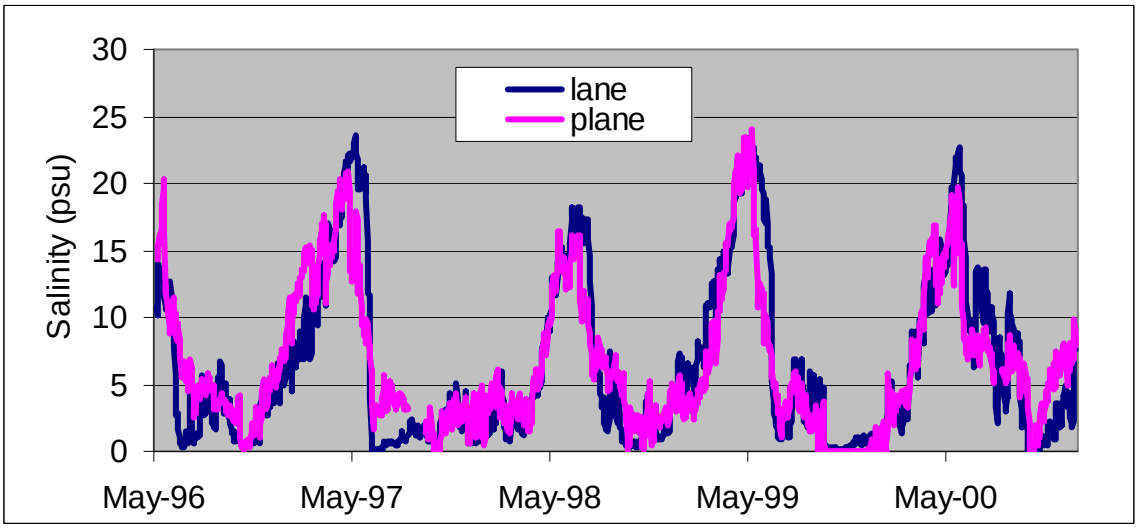


Figure 8. Comparison of predicted salinity compared to observed salinity for Cane Patch. See Table 3 for calibration and verification periods.

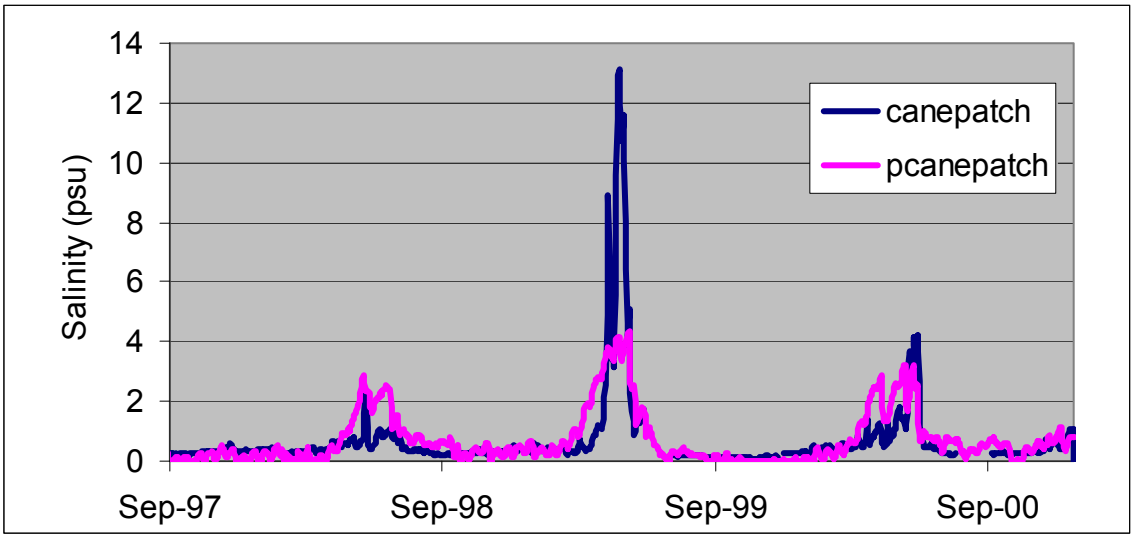


Figure 9. Comparison of predicted salinity compared to observed salinity for Tarpon Bay East. See Table 3 for calibration and verification periods.

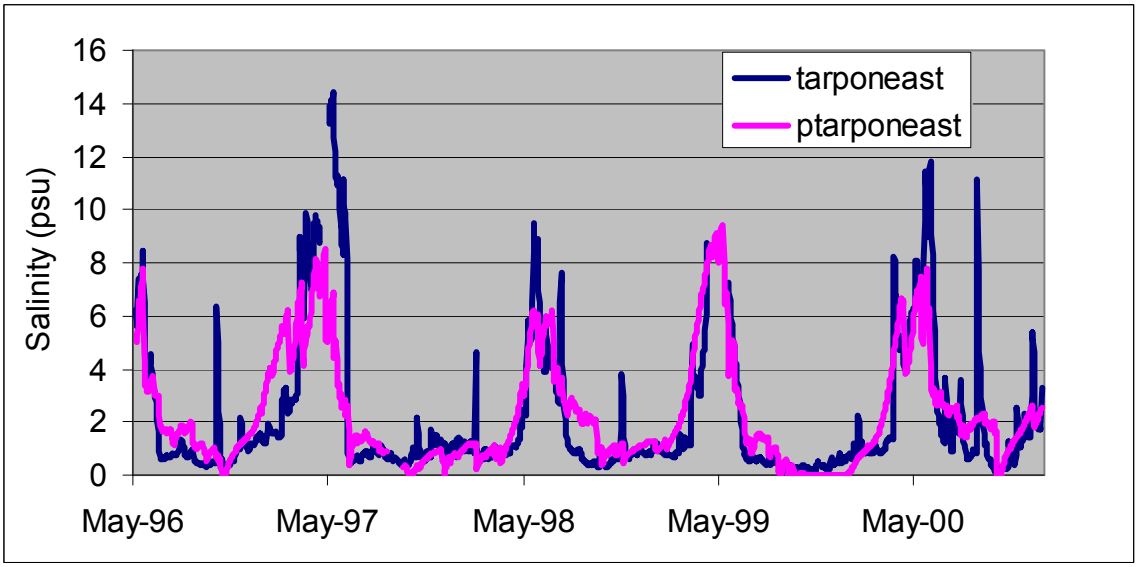


Figure 10. Comparison of predicted salinity compared to observed salinity for Harney River. See Table 3 for calibration and verification periods.

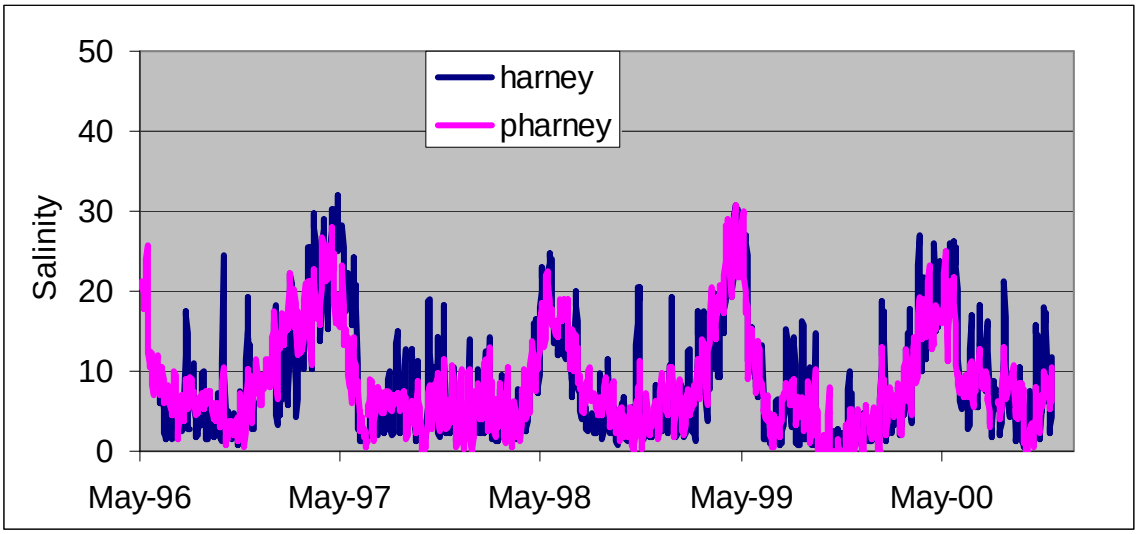


Figure 11. Comparison of predicted salinity compared to observed salinity for Broad River. See Table 3 for calibration and verification periods.

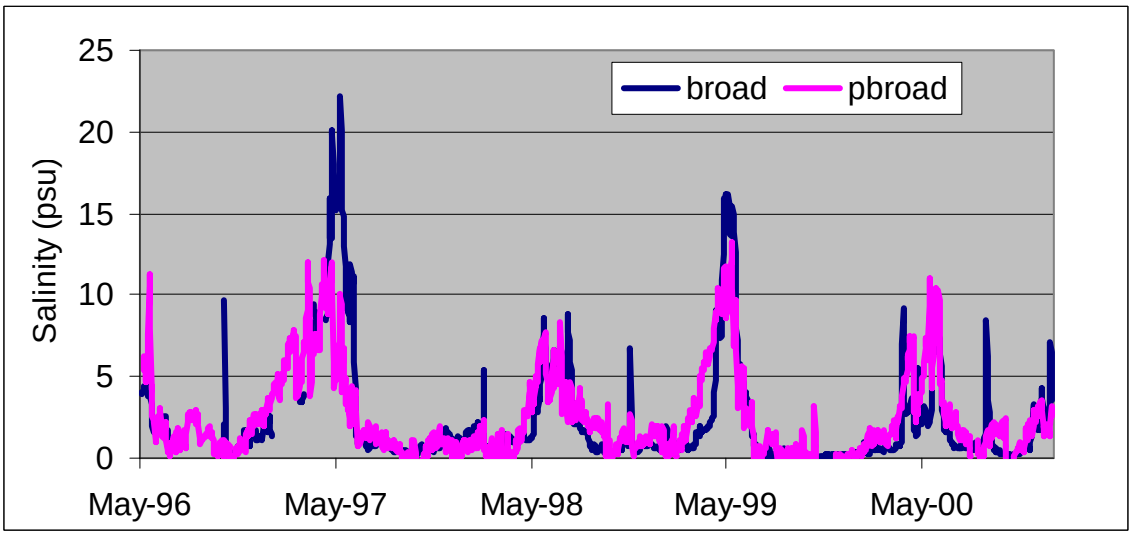


Figure 12. Comparison of predicted salinity compared to observed salinity for Broad River Lower. See Table 3 for calibration and verification periods.

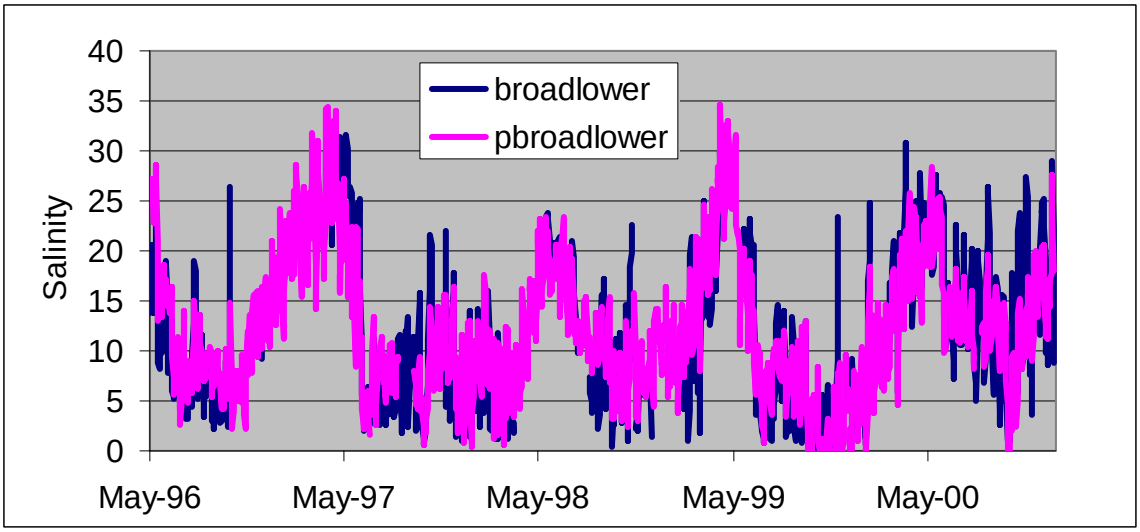


Figure 13. Comparison of predicted salinity compared to observed salinity for Willy Willy. See Table 3 for calibration and verification periods.

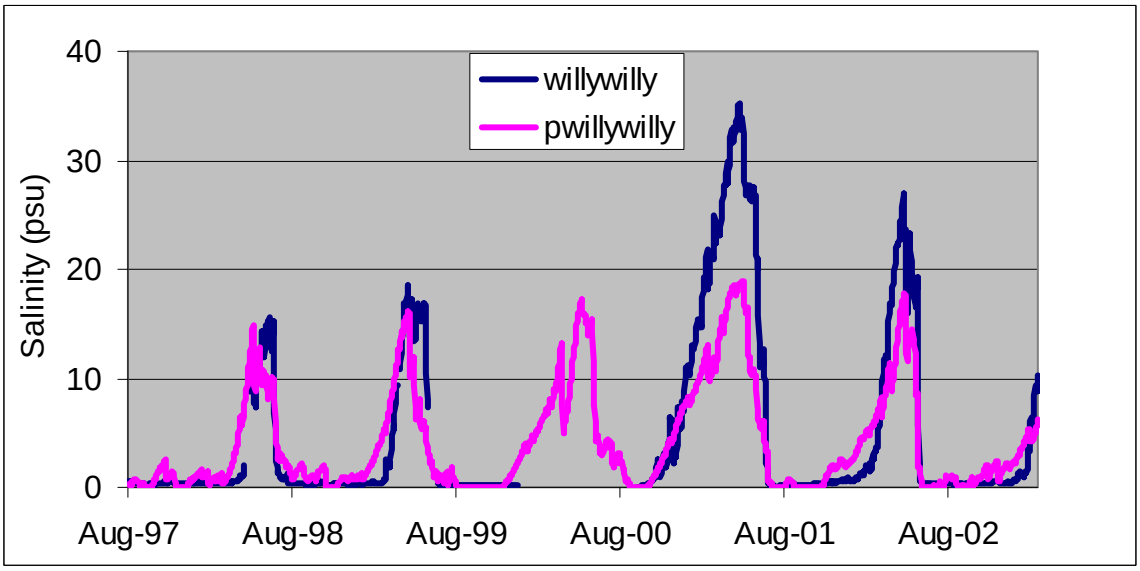


Figure 14. Comparison of predicted salinity compared to observed salinity for Lostmans River. See Table 3 for calibration and verification periods.

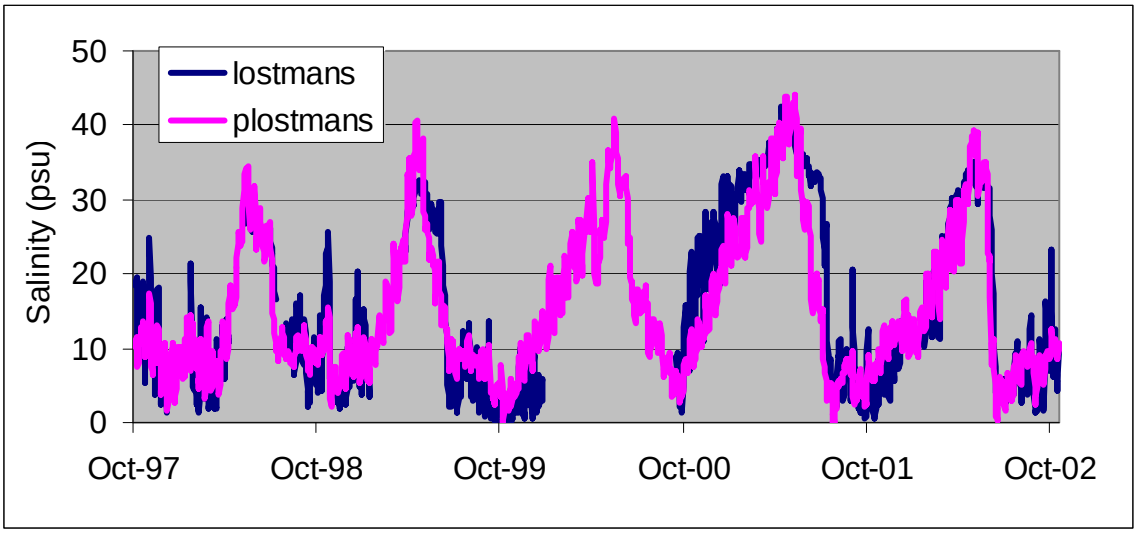


Figure 15. Comparison of predicted salinity compared to observed salinity for Cannon Bay. See Table 3 for calibration and verification periods.

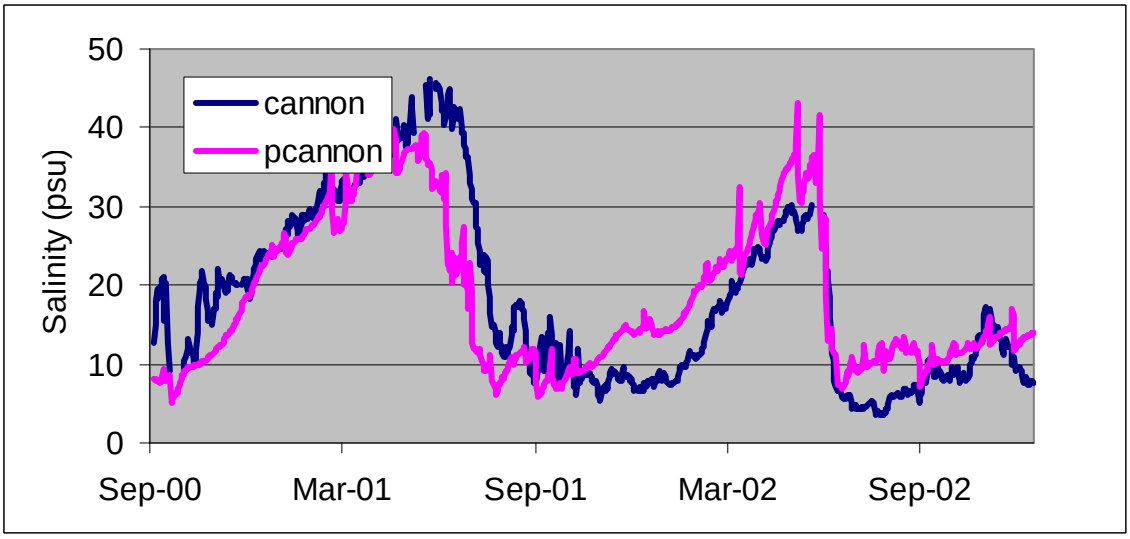


Figure 16. Comparison of predicted salinity compared to observed salinity for Watson Place. See Table 3 for calibration and verification periods.

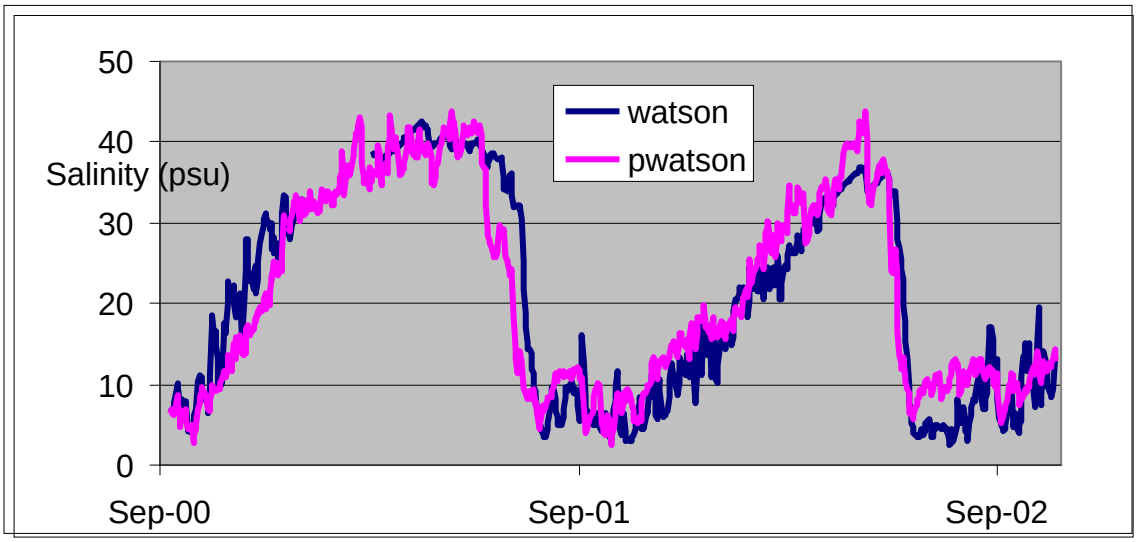
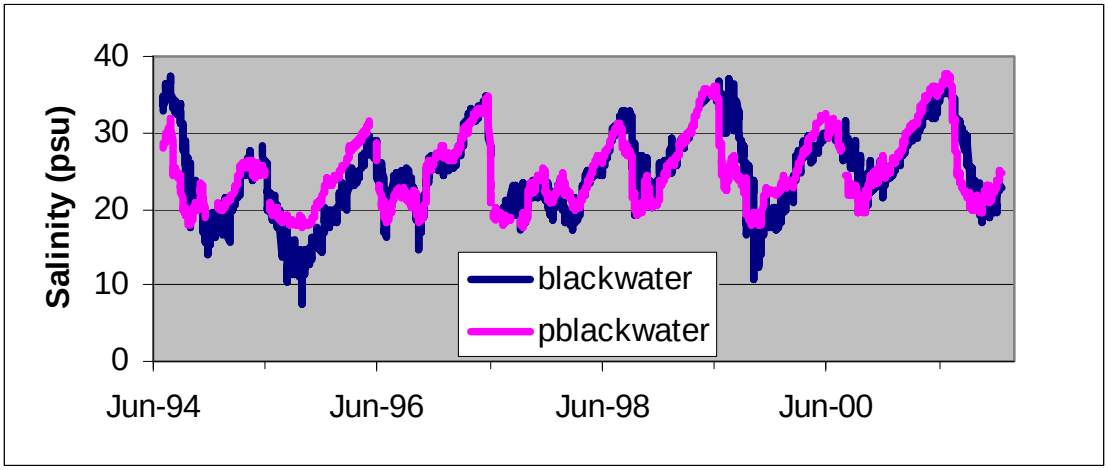
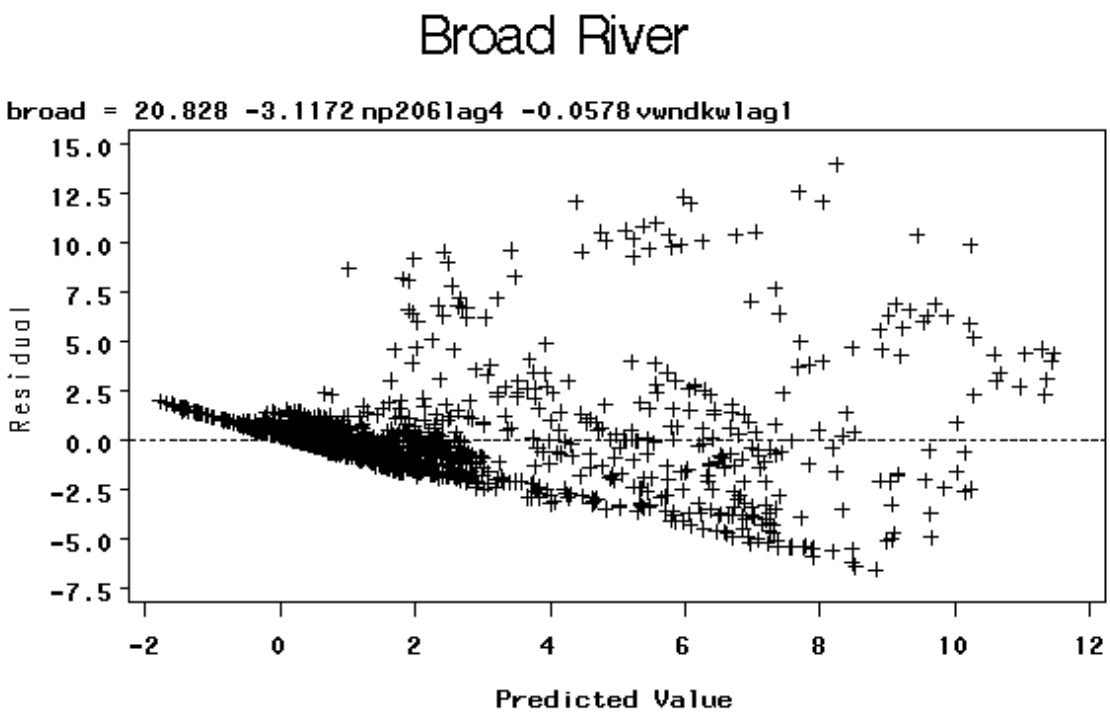


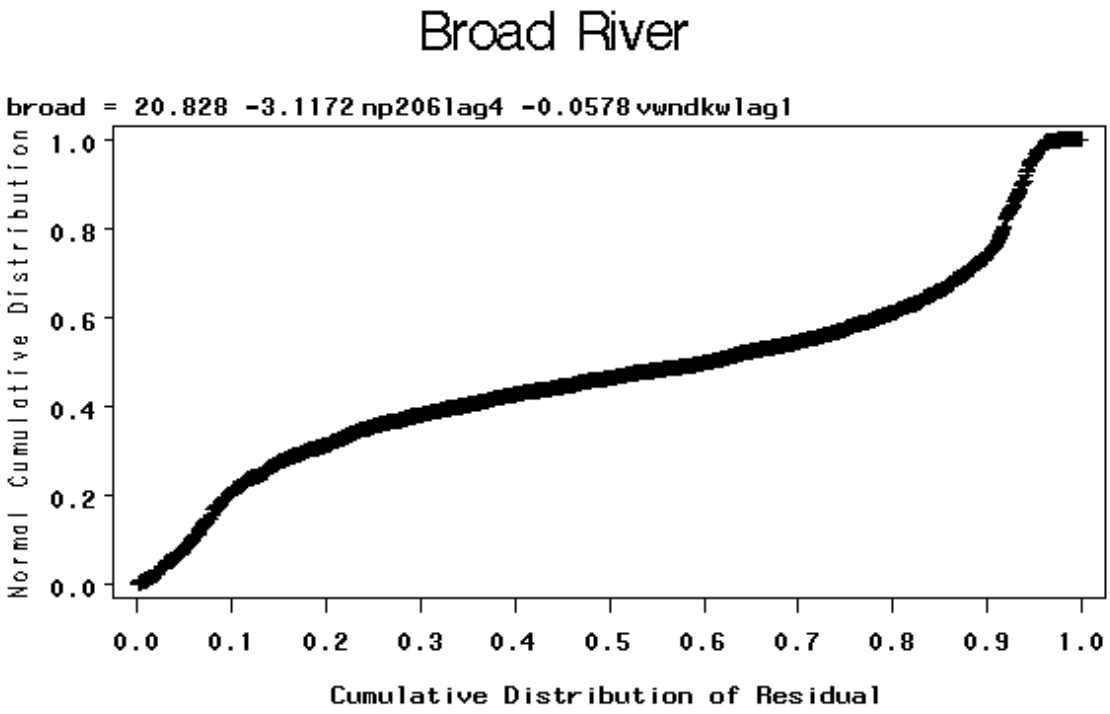
Figure 17. Comparison of predicted salinity compared to observed salinity for Blackwater Sound. See Table 3 for calibration and verification periods.



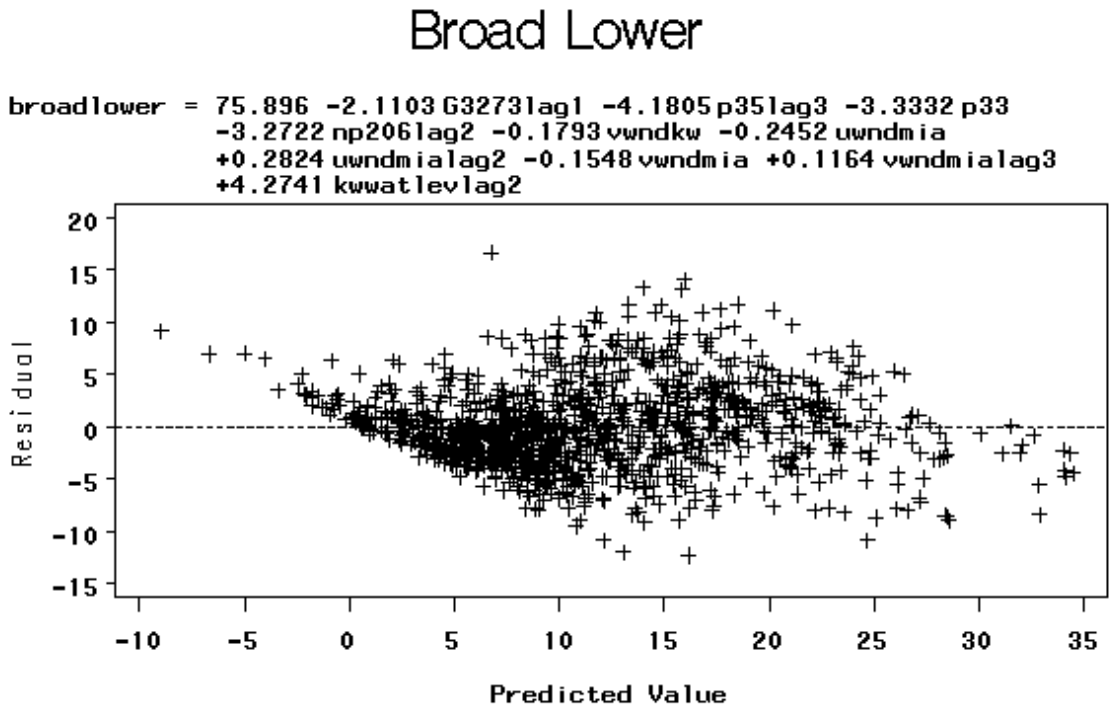
Appendix A. Residual Plots

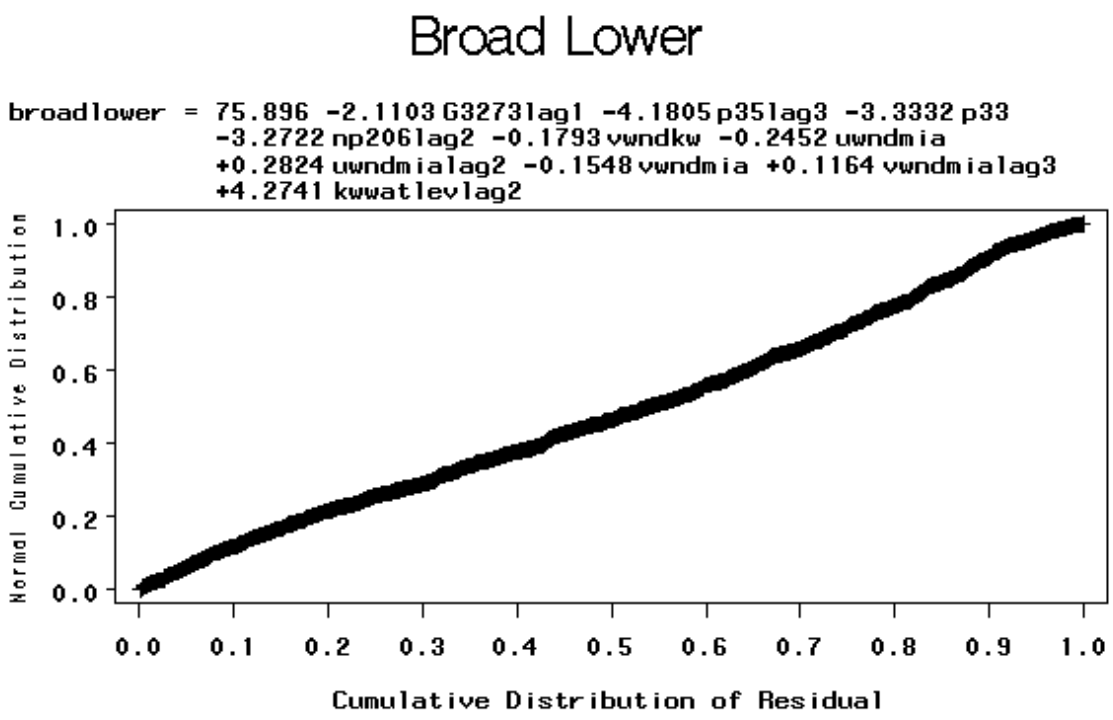
Broad River



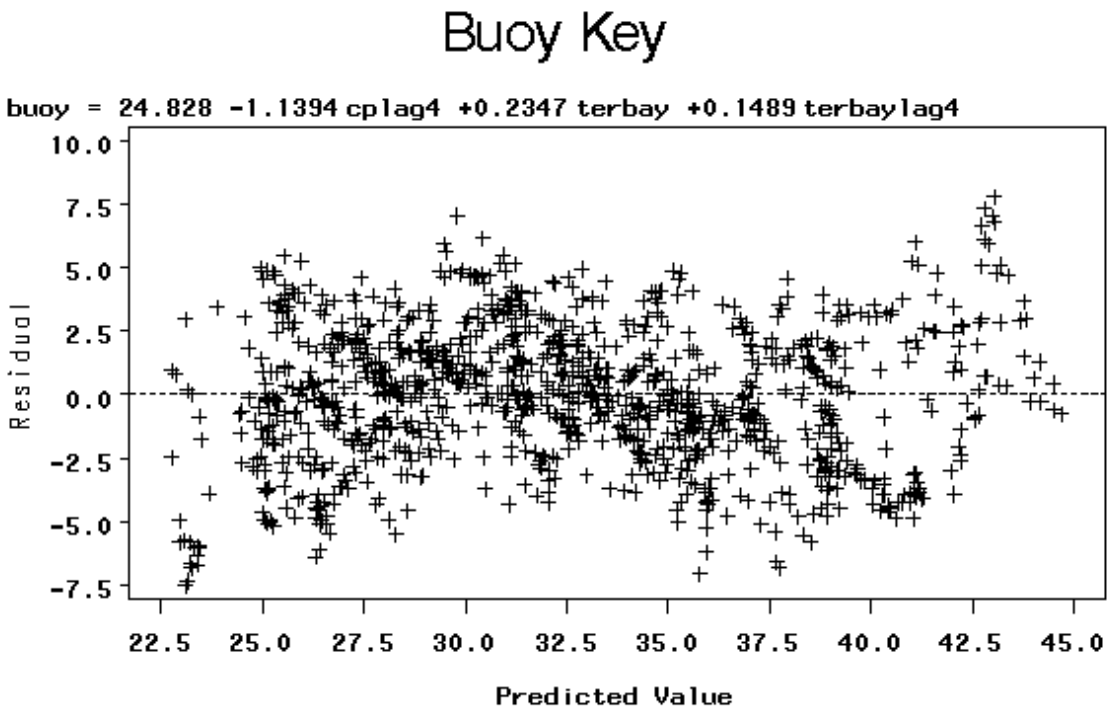


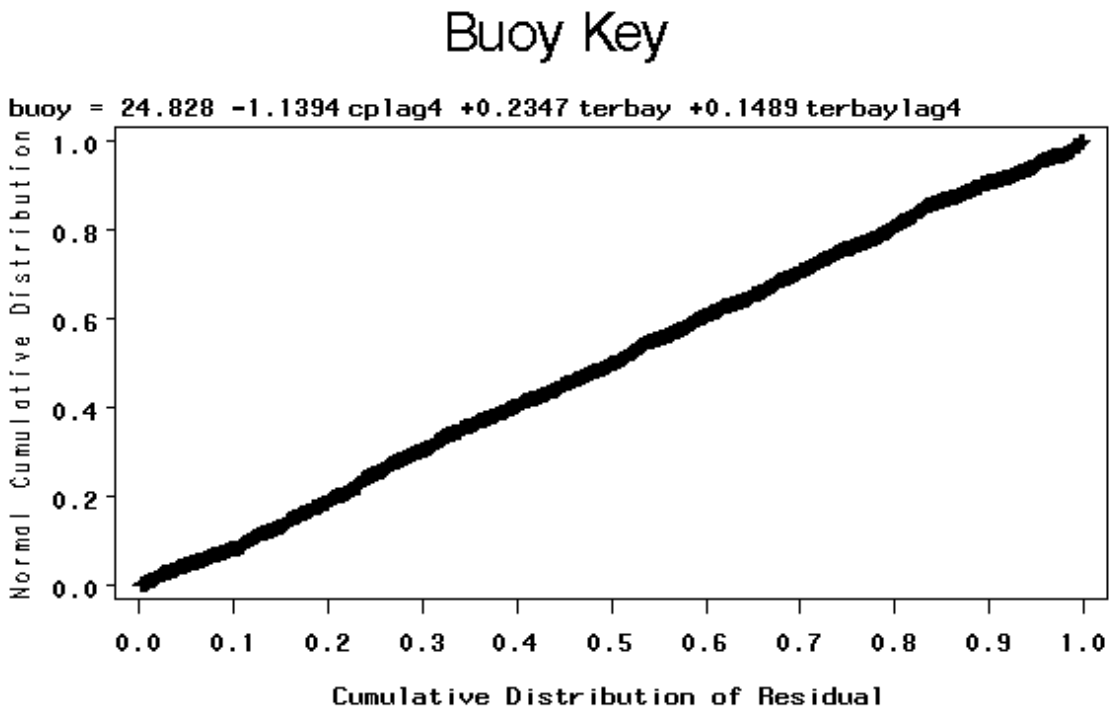
Broad River Lower



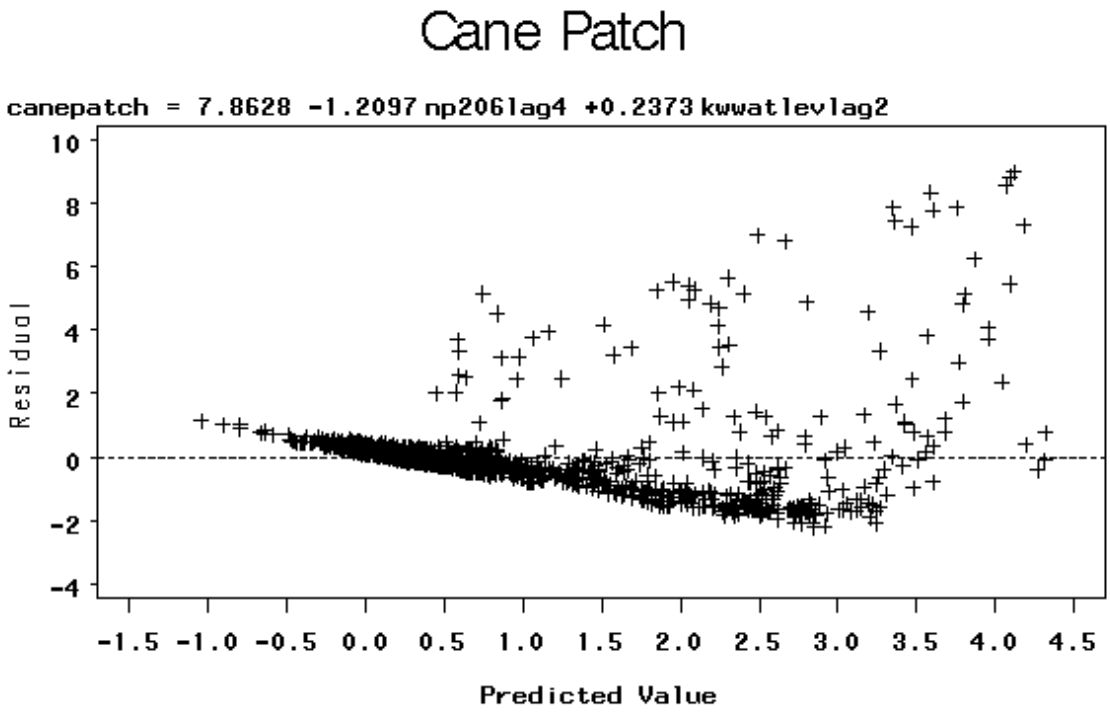


Buoy Key


Buoy Key
buoy = 24.828 -1.1394 cplag4 +0.2347 terbay +0.1489 terbaylag4
Residual
10.0
7.5
5.0
2.5
0.0
-2.5
-5.0
-7.5
22.5
25.0
27.5
30.0
32.5
35.0
37.5
40.0
42.5
45.0
Predicted Value


Buoy Key
buoy = 24.828 -1.1394 cplag4 +0.2347 terbay +0.1489 terbaylag4
Normal Cumulative Distribution
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Cumulative Distribution of Residual

Cane Patch


Cane Patch
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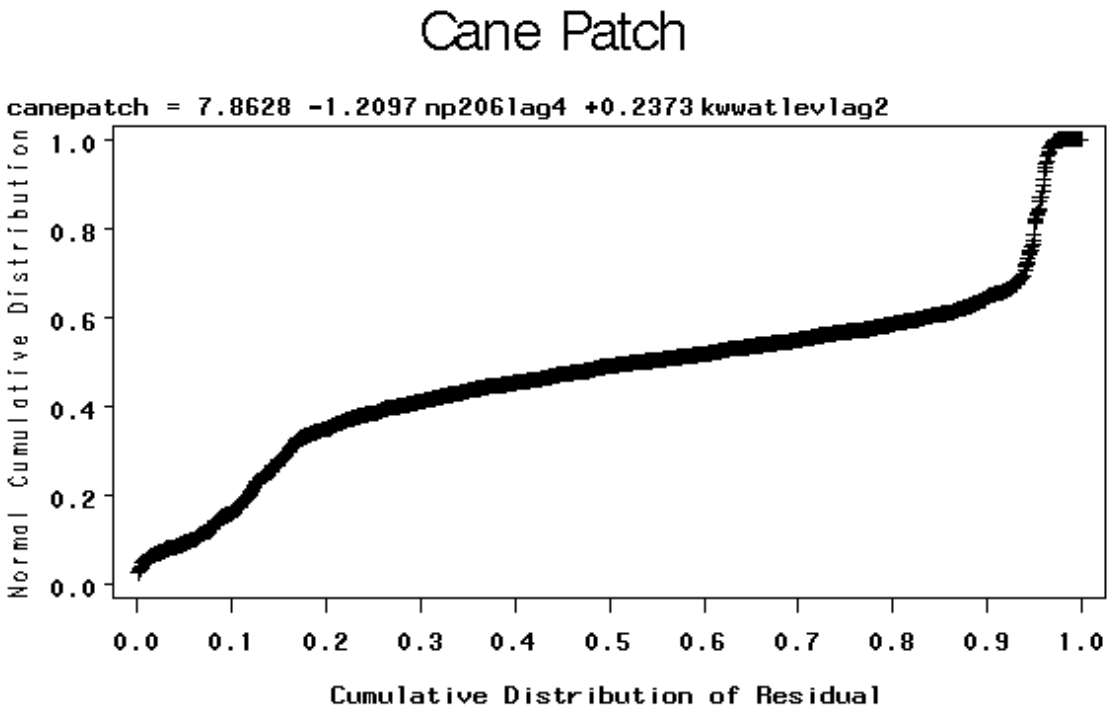
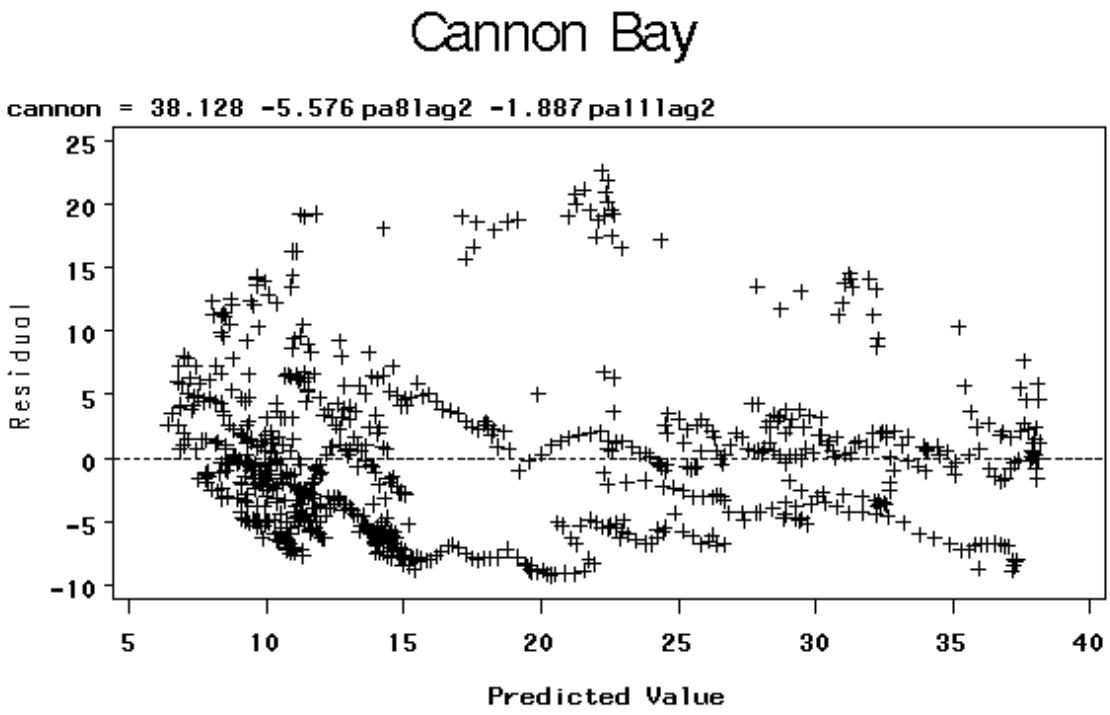
Residual
10
8
6
4
2
0
-2
-4
-1.5 -1.0 -0.5 0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5
Predicted Value


Cane Patch
canepatch = 7.8628 -1.2097 np206lag4 +0.2373 kwwatlevlag2
Normal Cumulative Distribution
1.0
0.8
0.6
0.4
0.2
0.0
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
Cumulative Distribution of Residual

Cannon Bay


Cannon Bay
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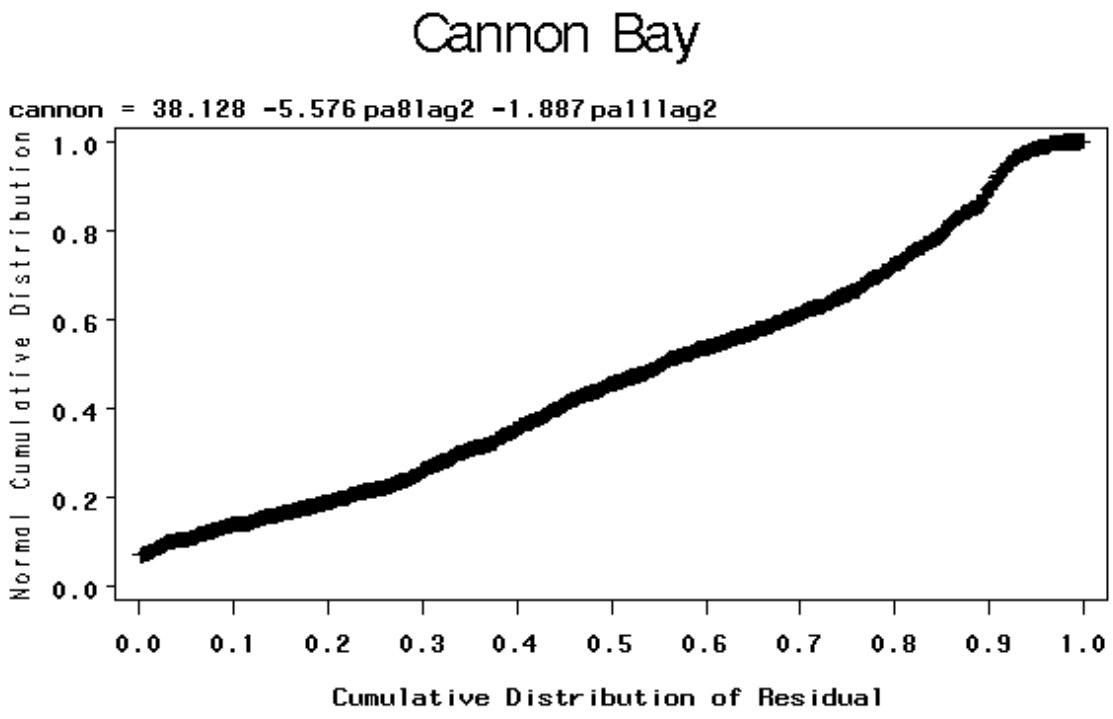
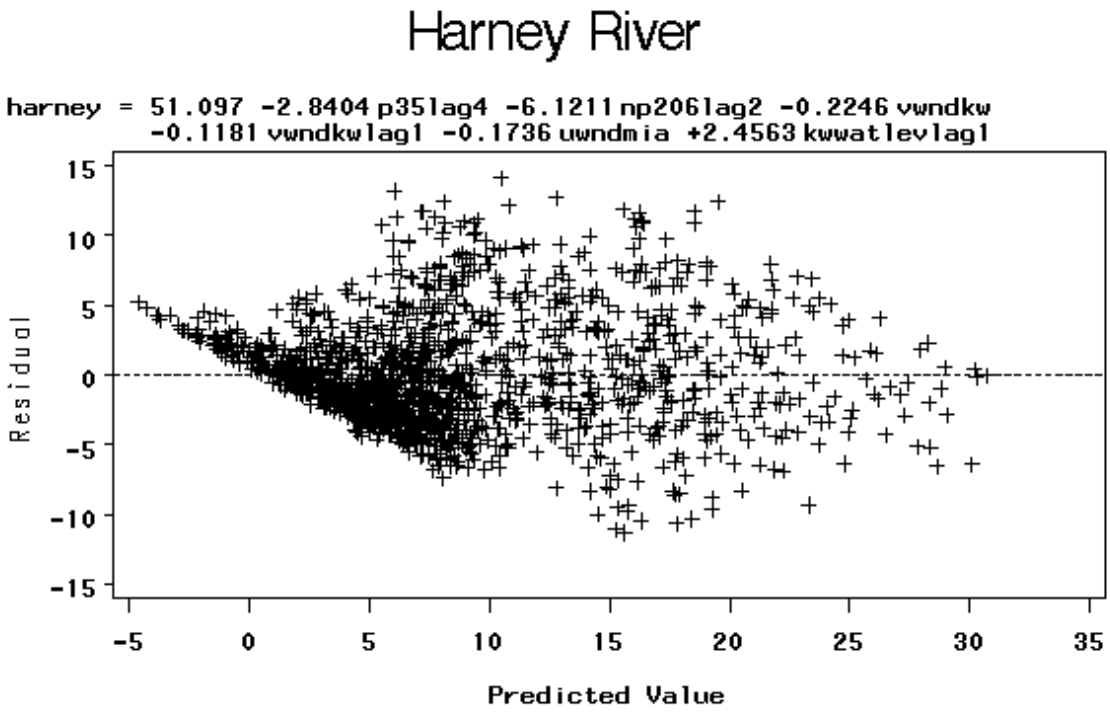
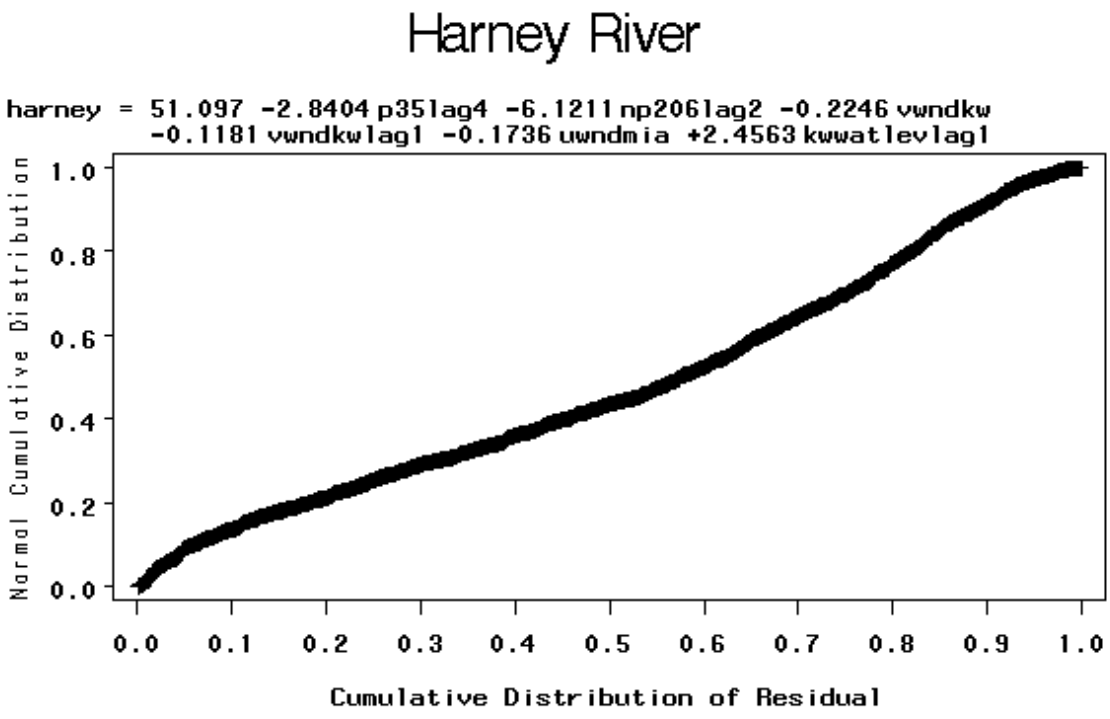
Residual
Predicted Value
25
20
15
10
5
0
-5
-10
5
10
15
20
25
30
35
40

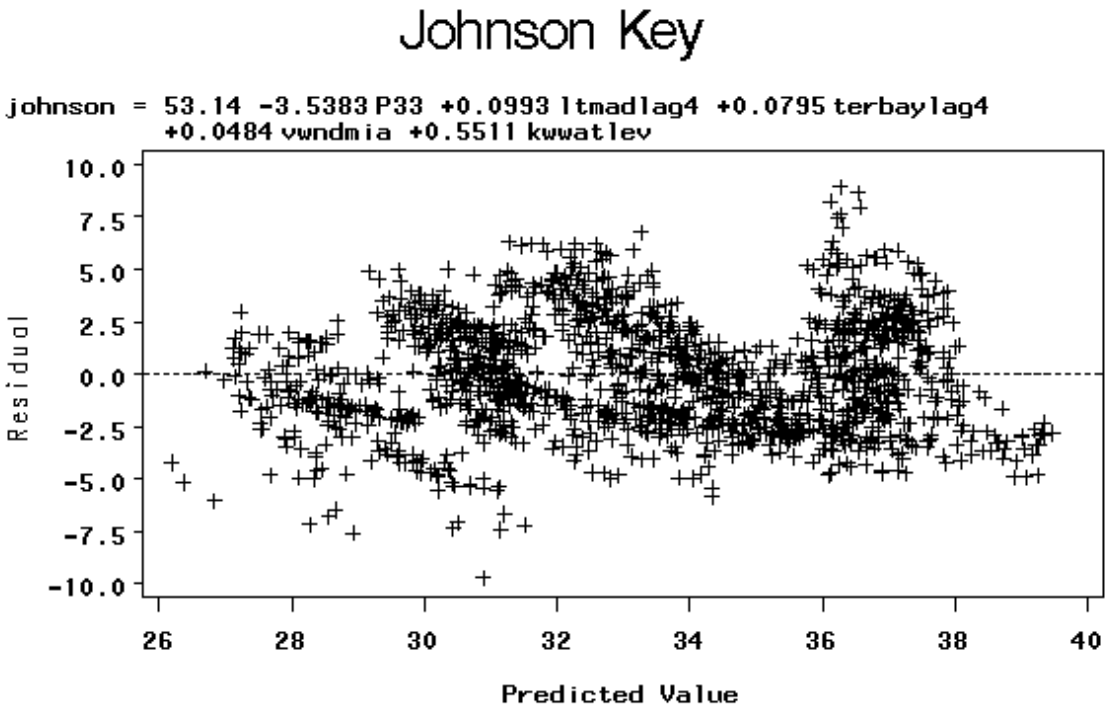

Cannon Bay
cannon = 38.128 -5.576 pa8lag2 -1.887 pa11lag2
Normal Cumulative Distribution
Cumulative Distribution of Residual
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

Harney River





Johnson Key


Johnson Key
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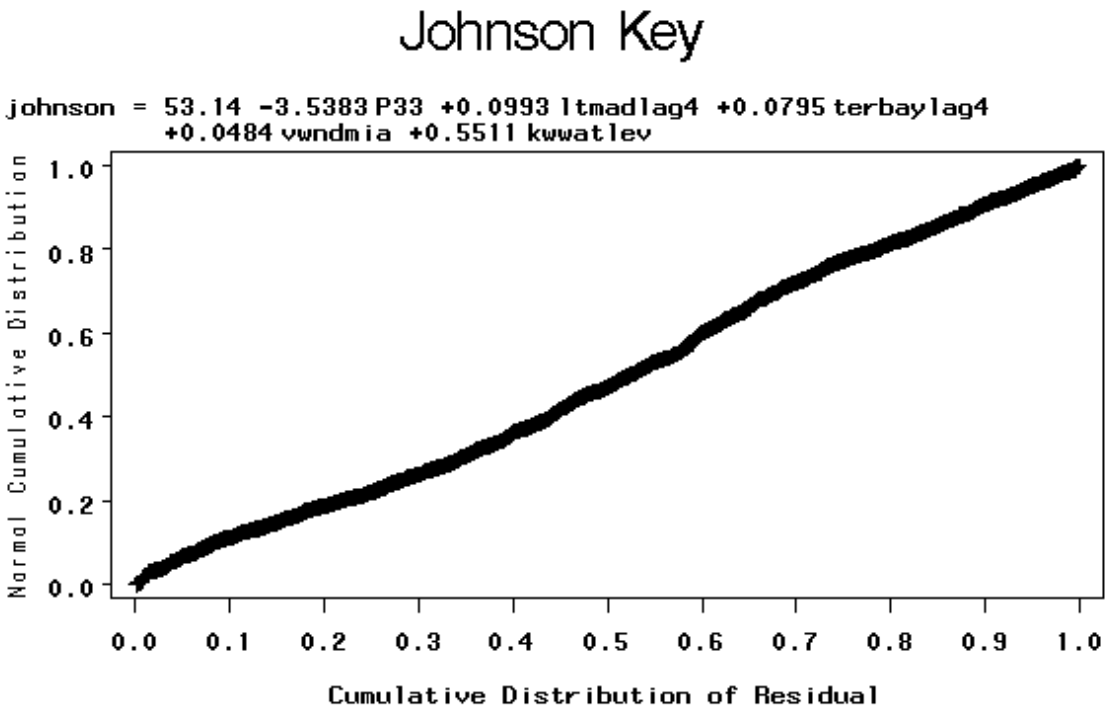
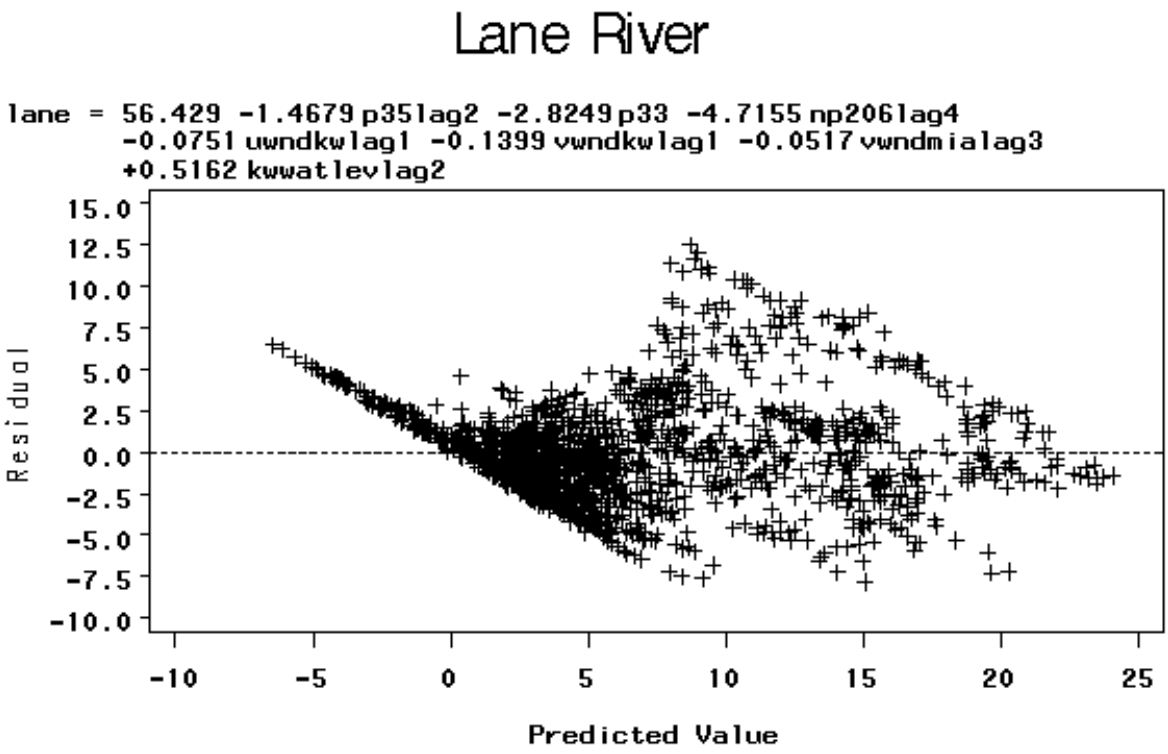
+0.0484 vwndmia +0.5511 kwwatlev
Residual
10.0
7.5
5.0
2.5
0.0
-2.5
-5.0
-7.5
-10.0
26
28
30
32
34
36
38
40
Predicted Value


Johnson Key
johnson = 53.14 -3.5383 P33 +0.0993 ltmadlag4 +0.0795 terbaylag4
+0.0484 vwndmia +0.5511 kwwatlev
Normal Cumulative Distribution
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Cumulative Distribution of Residual

Lane River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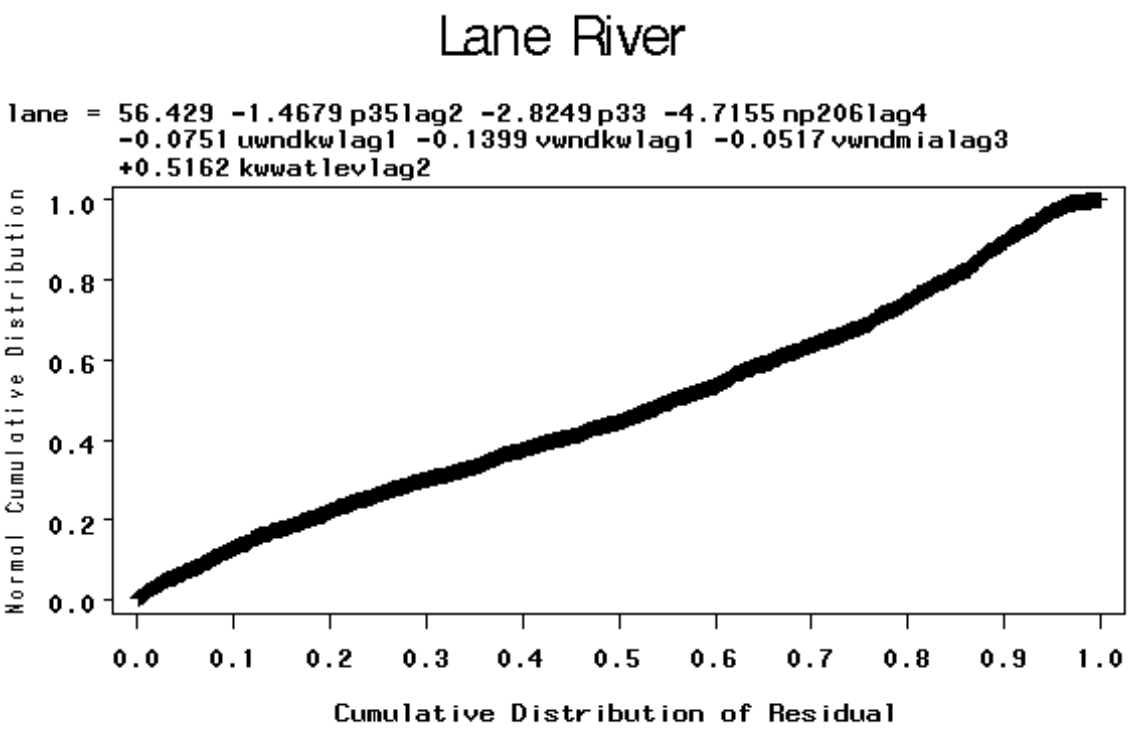
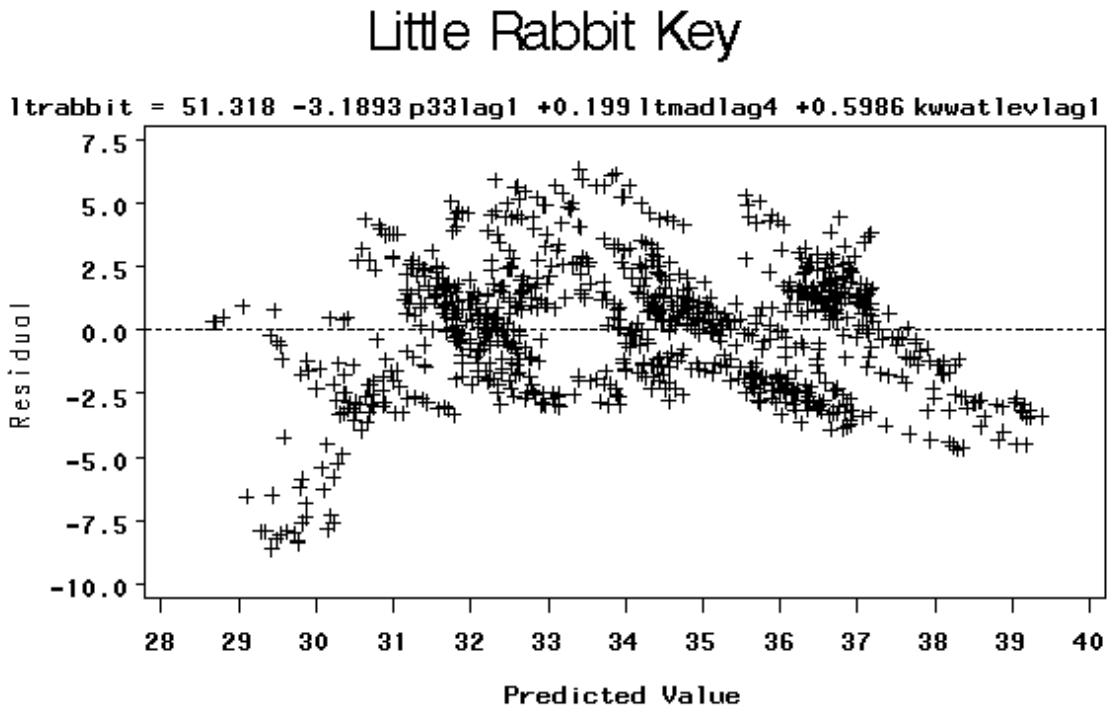
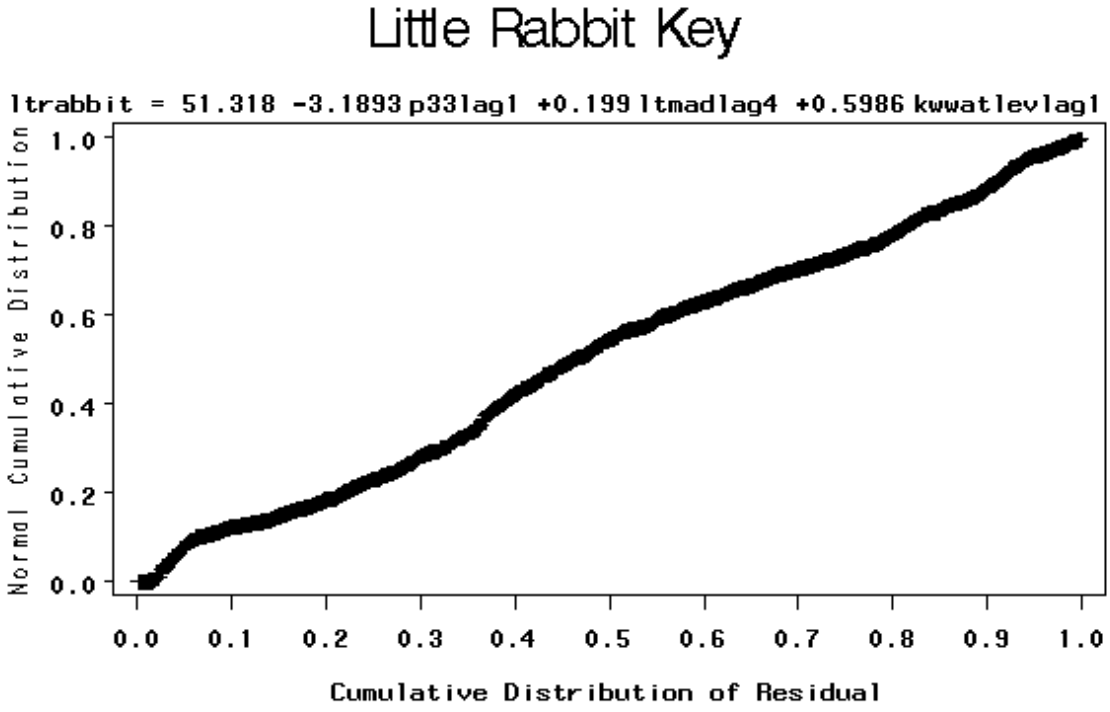
-0.0751 uwndkwlag1 -0.1399 vwndkwlag1 -0.0517 vwndmialag3
+0.5162 kwwatlevlag2
Residual
Predicted Value

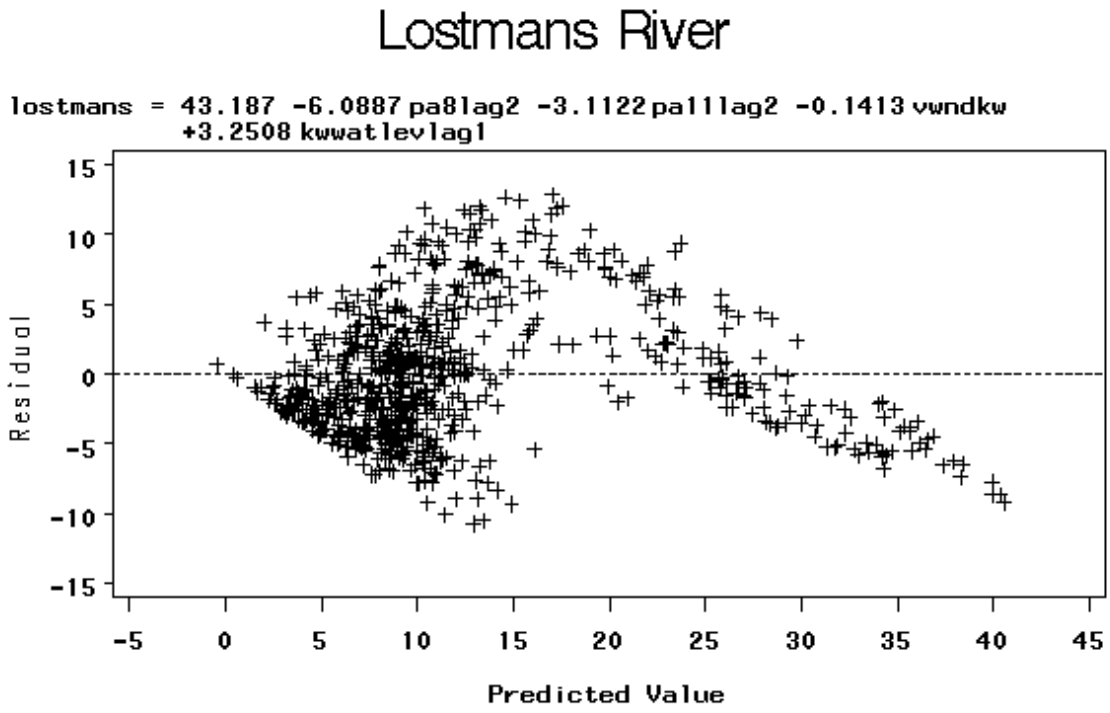

Lane River
lane = 56.429 -1.4679 p35lag2 -2.8249 p33 -4.7155 np206lag4
-0.0751 uwndkwlag1 -0.1399 vwndkwlag1 -0.0517 vwndmialag3
+0.5162 kwwatlevlag2
Normal Cumulative Distribution
Cumulative Distribution of Residual

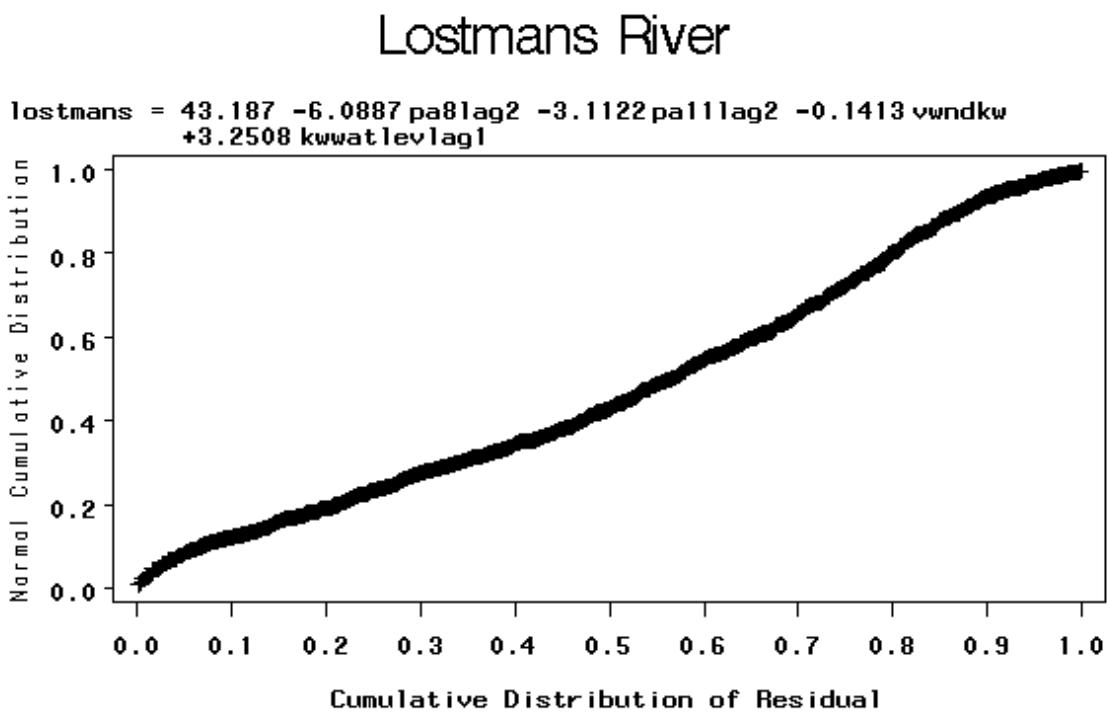
Little Rabbit Key



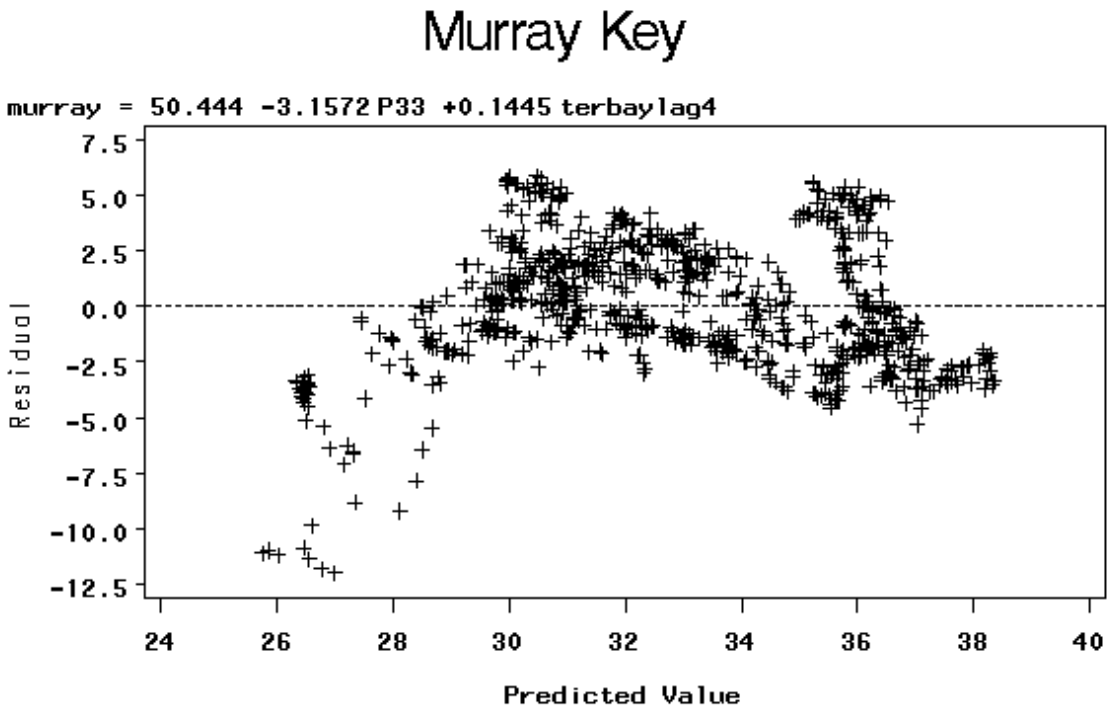


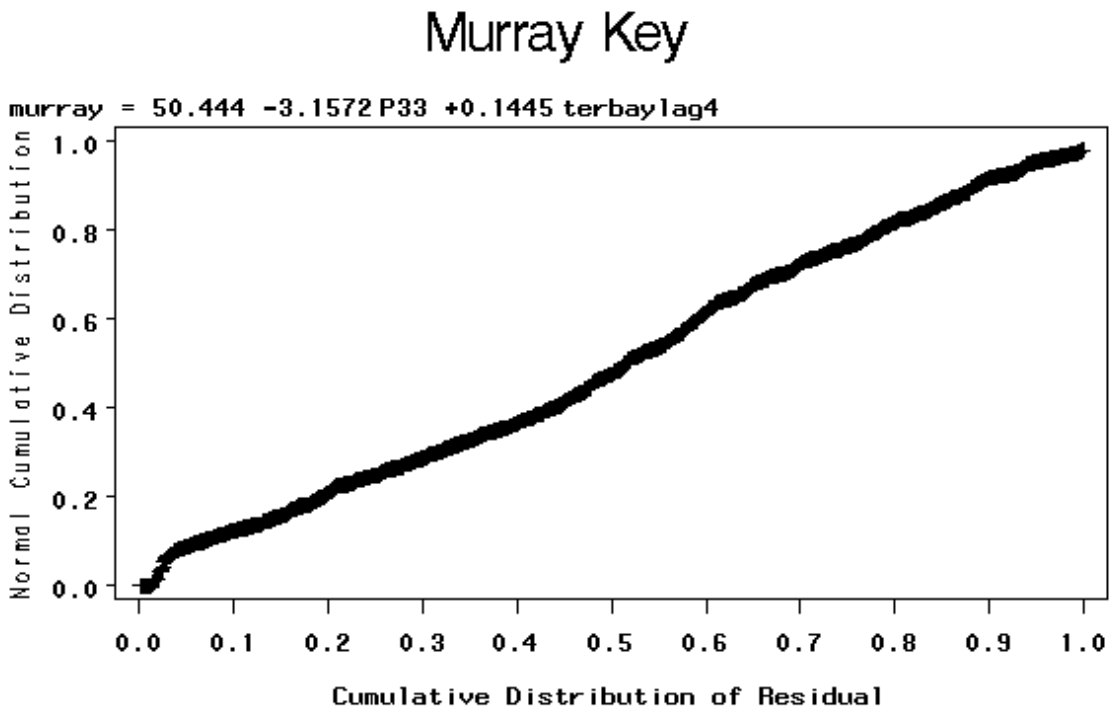
Lostmans River



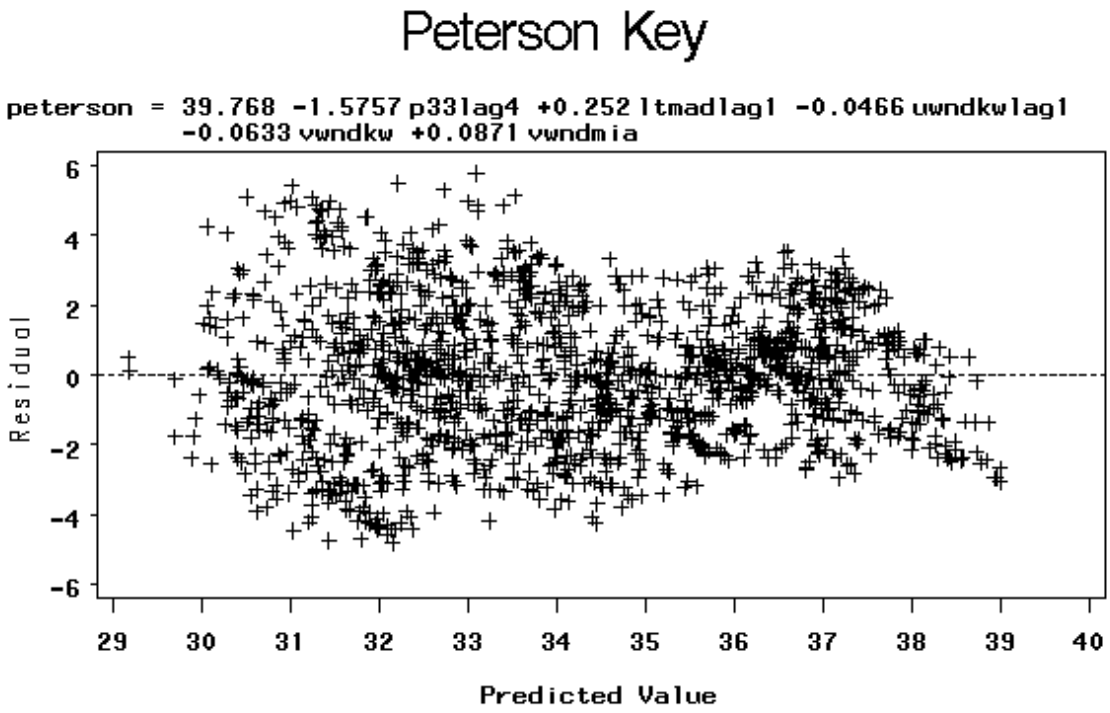


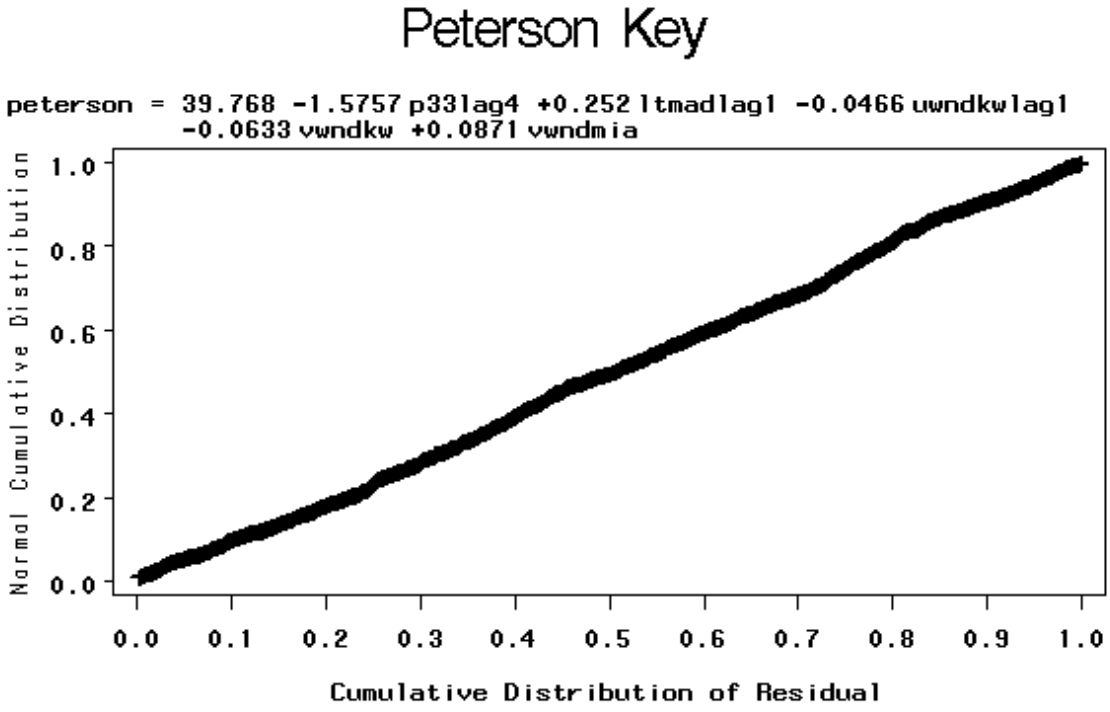
Murray Key


Murray Key
murray = 50.444 -3.1572 P33 +0.1445 terbaylag4
Residual
7.5
5.0
2.5
0.0
-2.5
-5.0
-7.5
-10.0
-12.5
24
26
28
30
32
34
36
38
40
Predicted Value

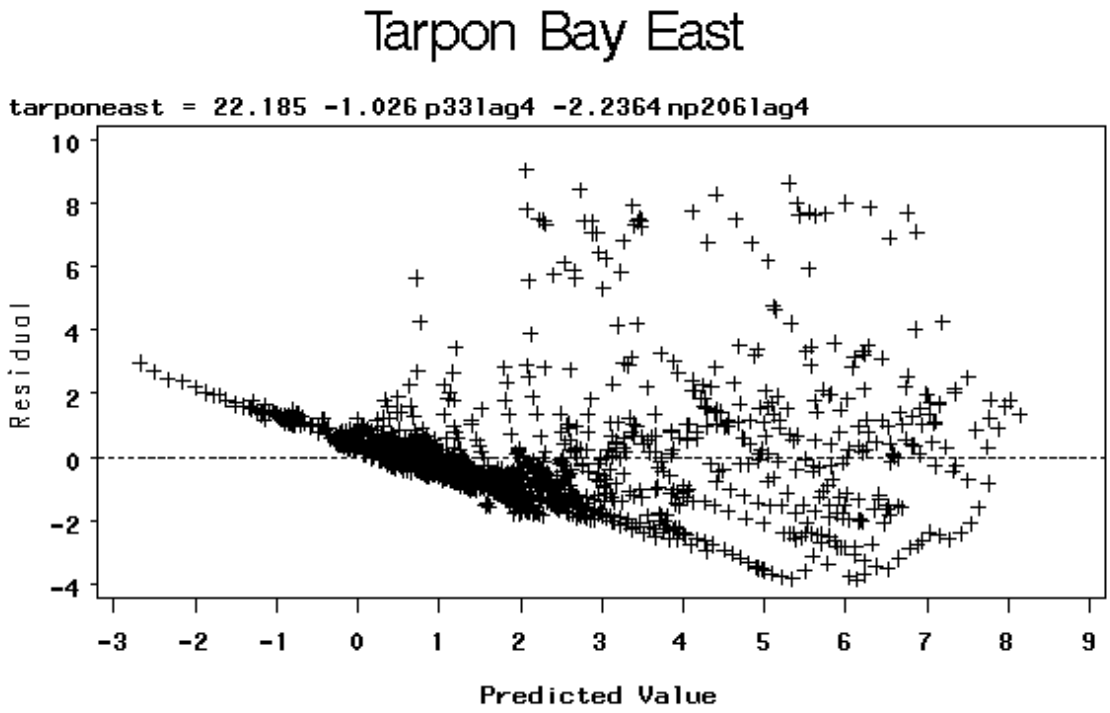

Murray Key
murray = 50.444 -3.1572 P33 +0.1445 terbaylag4
Normal Cumulative Distribution
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Cumulative Distribution of Residual

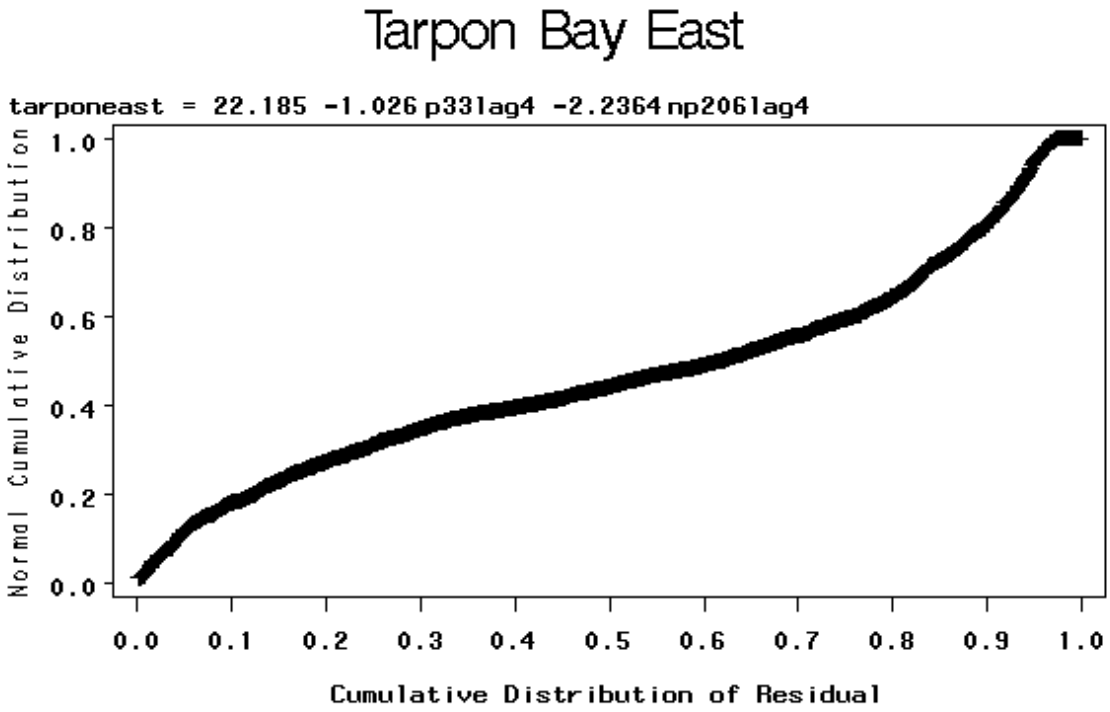
Peterson Key



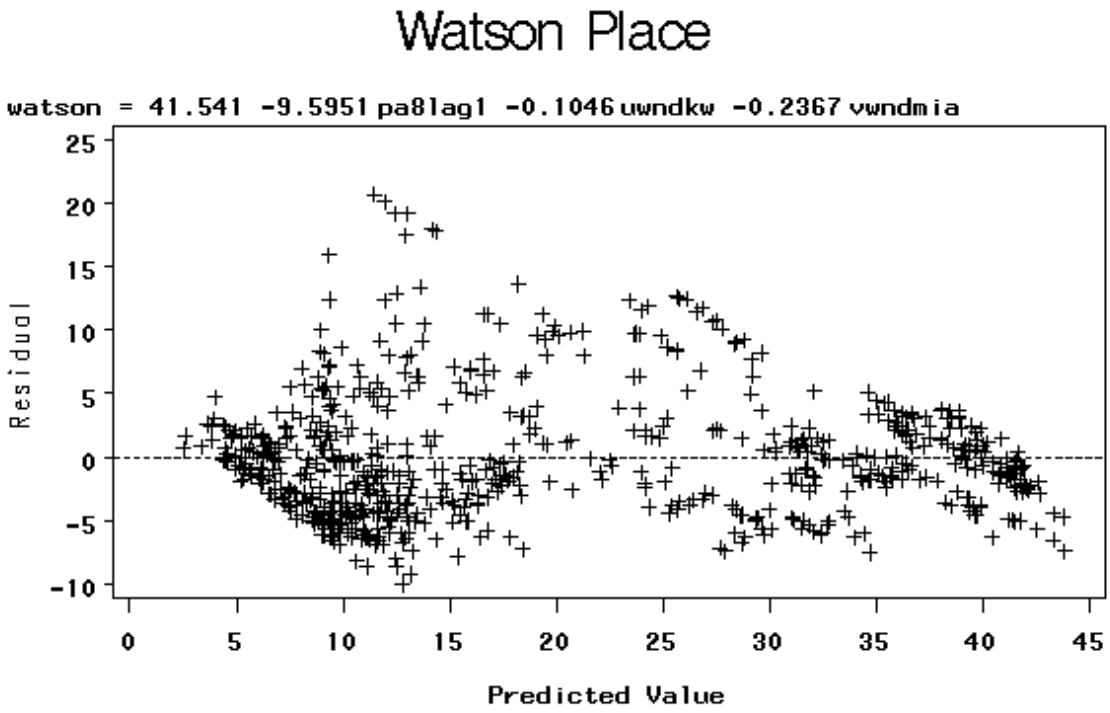


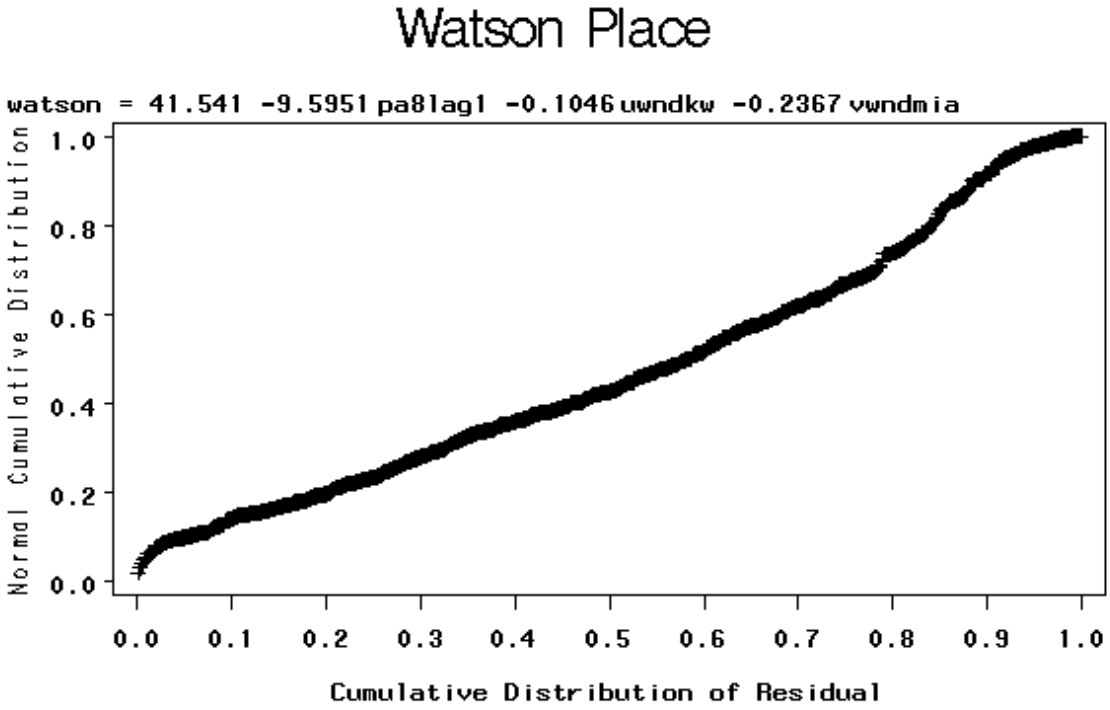
Tarpon Bay East



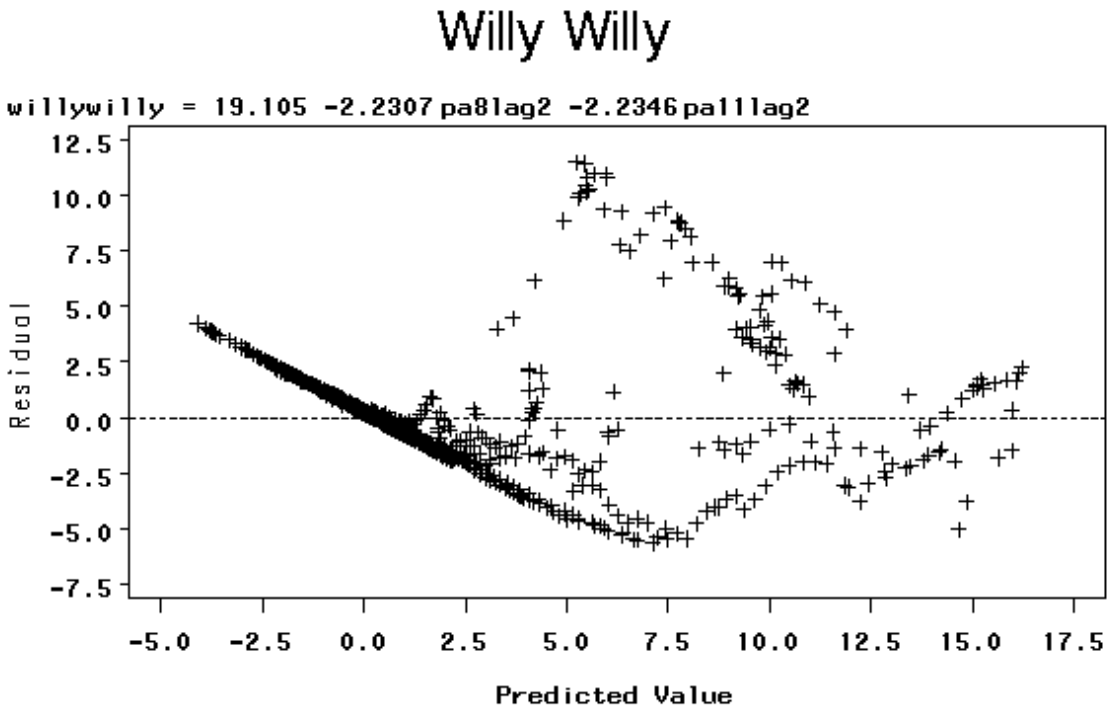


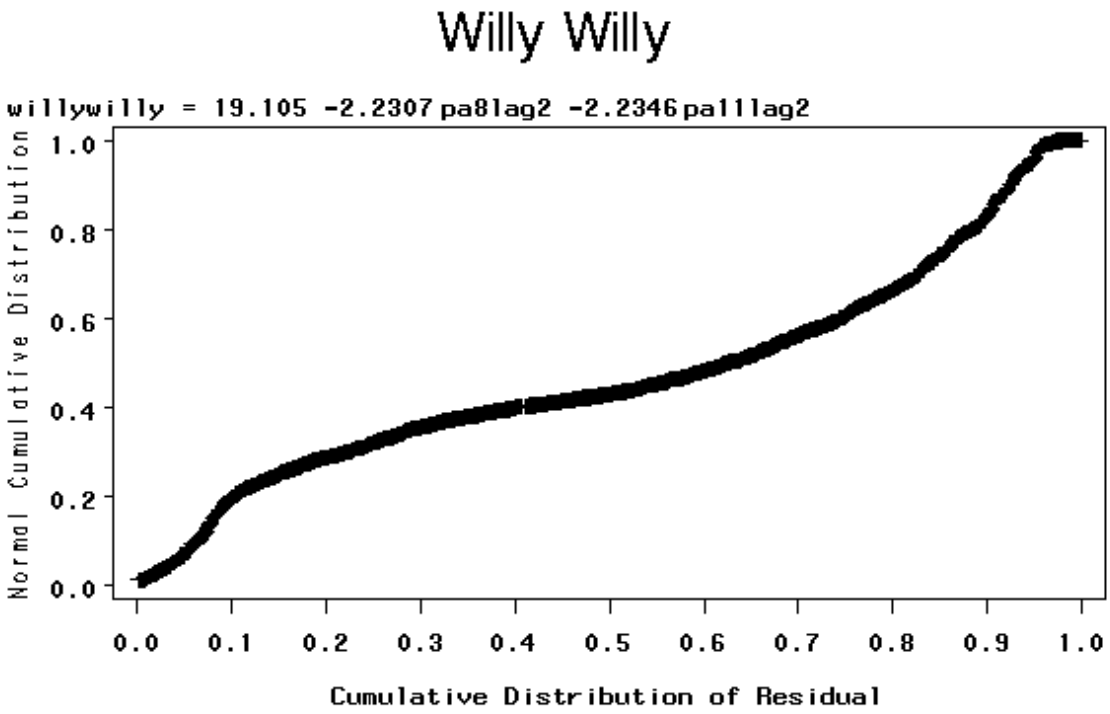
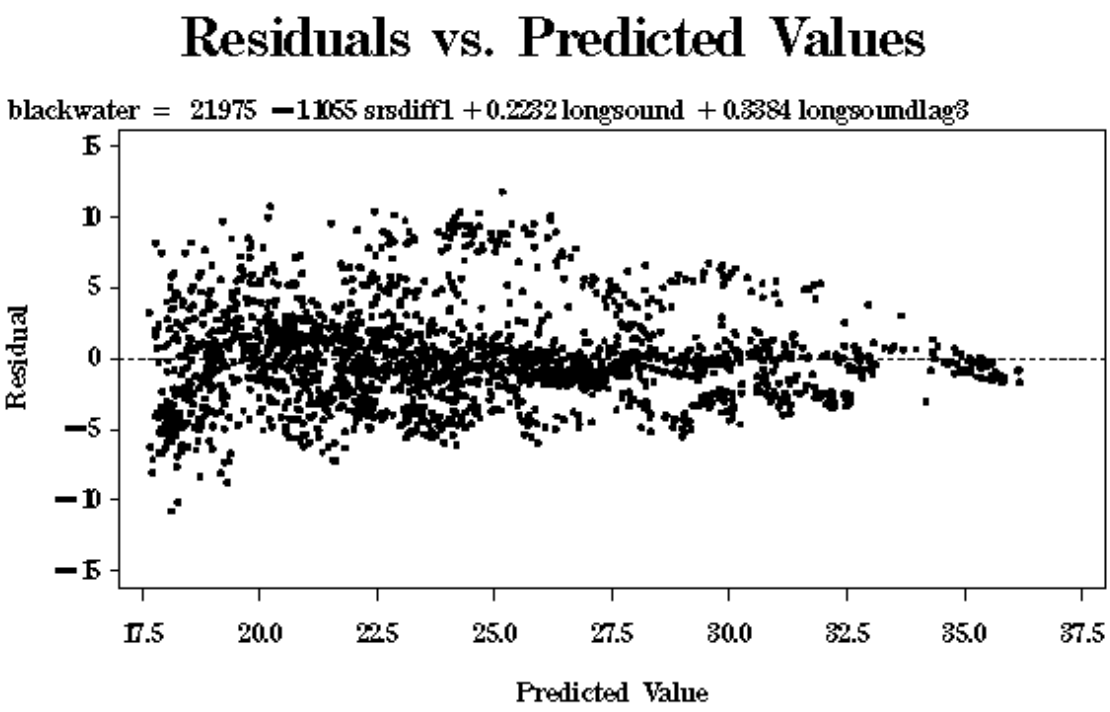
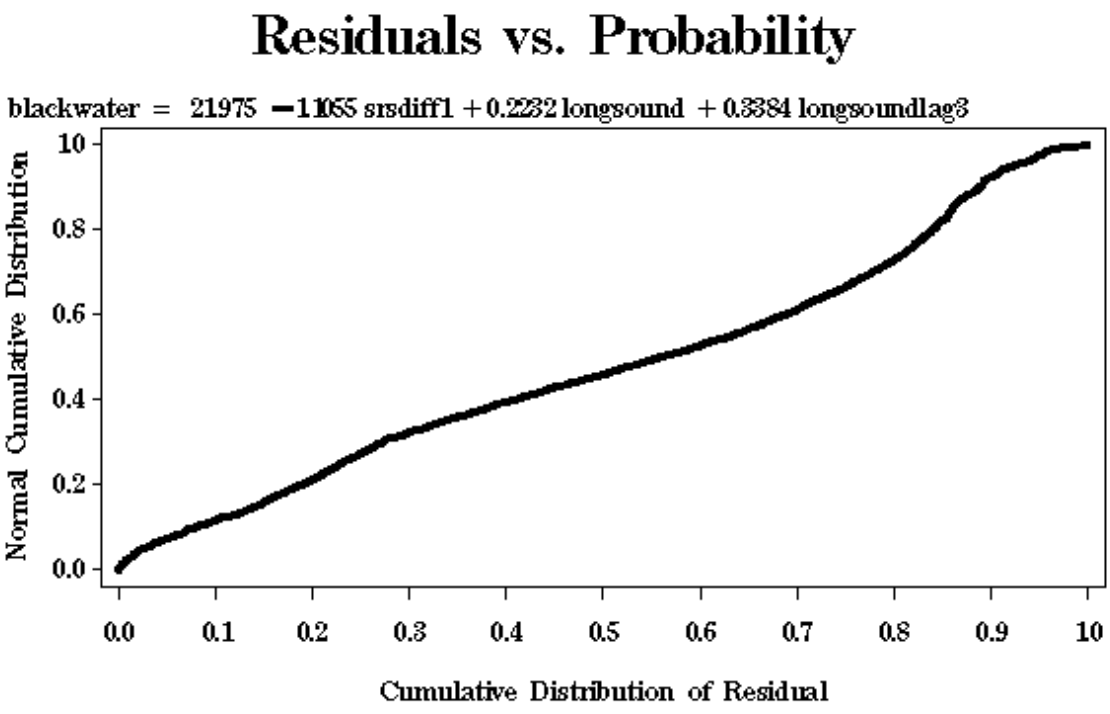
Watson Place





Willy Willy


Willy Willy
willywilly = 19.105 -2.2307 pa8lag2 -2.2346 pa11lag2
Residual
12.5
10.0
7.5
5.0
2.5
0.0
-2.5
-5.0
-7.5
-5.0
-2.5
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
Predicted Value


Willy Willy
willywilly = 19.105 -2.2307 pa8lag2 -2.2346 pa11lag2
Normal Cumulative Distribution
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Cumulative Distribution of Residual

Blackwater Sound