Development, Calibration, and Analysis of a Hydrologic and Water-Quality Model of the Delaware Inland Bays Watershed

Progress Report January 1– June 30, 2002

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Personnel

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Project Description

Problem

The Delaware Inland Bays (Figure 1) have experienced significant environmental degradation due to human activities over the past several decades. Excessive nutrients and sediment are among the most severe environmental stressors in the Inland Bays. The sources of nutrients, sediment, and other contaminants include point-source discharges from industries and wastewater-treatment plants, runoff and infiltration to ground water from agricultural fields and poultry operations, septic-system effluent, and atmospheric deposition.

In order to determine how best to approach restoration of the Inland Bays, it is necessary to understand the relative distribution and contribution of each of the potential sources of nutrients, sediment, and other contaminants. It is also important to understand the hydrology of the Inland Bays Watershed in order to effectively restore them. Understanding the complex interrelations and interactions between hydrology and the various water-quality inputs is a prerequisite to restoration.

Objective

This project is a cooperative effort involving the Delaware Department of Natural Resources and Environmental Control (DNREC), the Delaware Geological Survey (DGS), and the U.S. Geological Survey (USGS). The objective of this project is to develop a hydrologic and water-quality model of the Delaware Inland Bays Watershed that can be used as a water-resources planning and management tool. The water-quality constituents of concern will be suspended sediment and nutrients (nitrogen and phosphorus). A well-documented model, Hydrologic Simulation Program—FORTRAN (HSPF), will be applied by the USGS to meet the objective.

The USGS role in this cooperative project is to construct, calibrate, and demonstrate the use of the hydrologic and water-quality model for the portion of the Inland Bays Watershed discharging to the Bays themselves. The following tasks are included in this role: (1) compilation of existing hydrologic, climatological, water-quality, and ancillary data into model data sets; (2) construction and calibration of a hydrologic model; (3) construction and calibration of a water-quality model for suspended sediment, nitrogen, and phosphorus; (4) demonstration of the use of the model to simulate selected scenarios of the allocation of point and nonpoint sources; and (5) presentation of the model results to DNREC and DGS in the form of electronic model files, a written USGS report, and training in use of the model.

Background

The hydrologic and water-quality data needed to calibrate the model were collected during water year 1999 and the beginning of water year 2000. The USGS collected streamflow data at six stations in the

Delaware Inland Bays Watershed, and the University of Delaware and DGS collected water-quality data at the same six stations for the same time period. All the streams for which data were collected (except Munchy Branch, 01484668) are on Delaware's 303(d) list, and all six streams also were monitored as part of Delaware's water-quality monitoring program in water years 1999 and 2000.

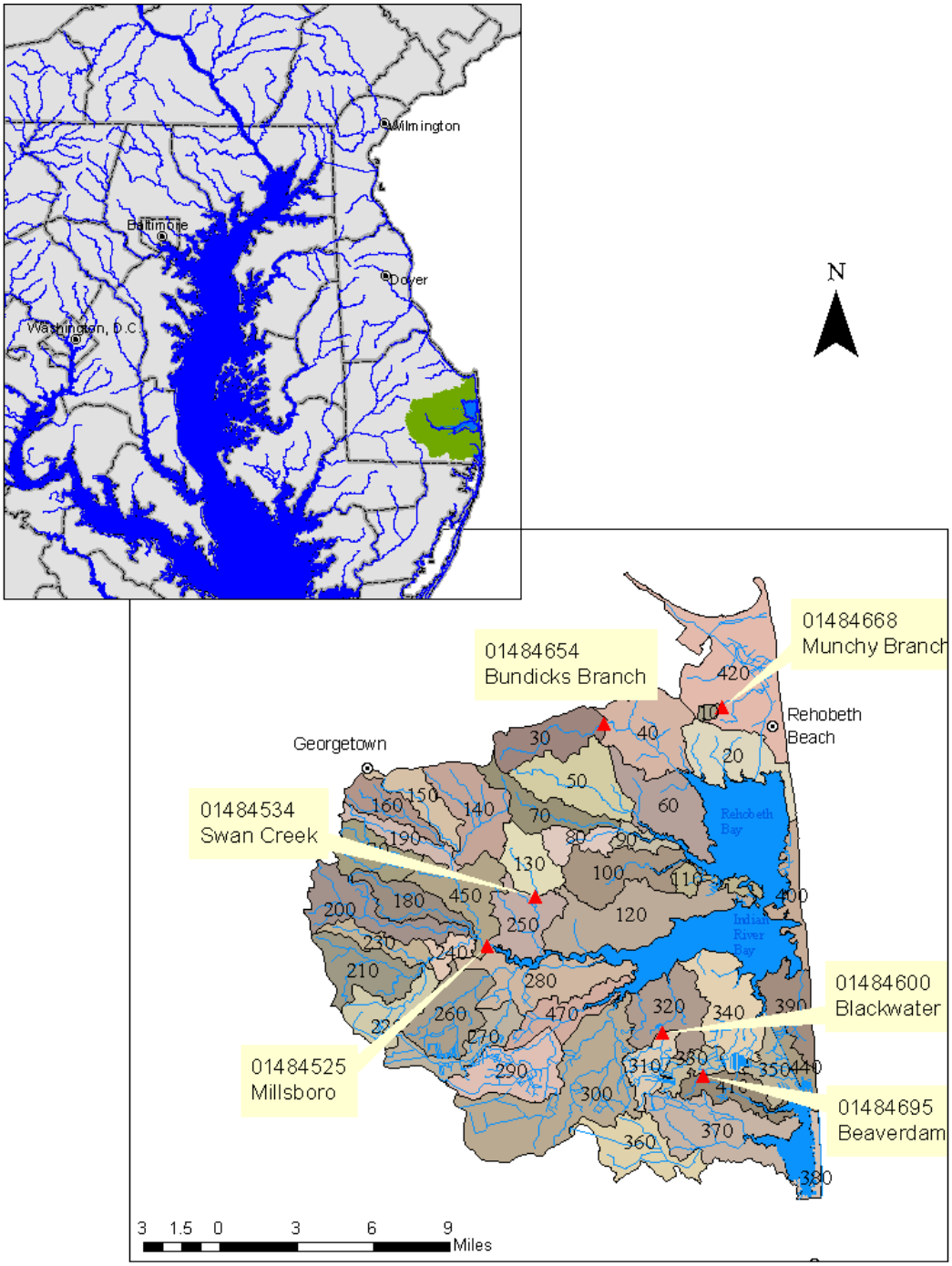


Figure 1. Location of the Delaware Inland Bays Watershed, calibration points, and HSPF model segment names.

Responsibilities

USGS is responsible for developing the HSPF model framework and for model calibration. The framework of the model is based on Geographic-Information-System (GIS) data in ARC/INFO format previously prepared by USGS for DGS, and supplemented by DNREC and other agencies as appropriate. GIS data include land use, geology, soils, digital-elevation-model (DEM) data, drainage basins, stream network, data-collection points, and point-source discharges. The data sets will be properly attributed and include critical information such as fertilizer application rates and timing for agricultural areas and lawns. USGS will use the GIS data to build the framework of the model and produce appropriate model segmentation. USGS will provide streamflow data and assemble climatological data for model operation.

DNREC is responsible for providing existing water-quality data including suspended-sediment, nitrogen, and phosphorus concentrations for calibration points and other model nodes of interest. These data will include all the water-quality data collected by the University of Delaware and DGS during 1999 and 2000 at the six established stream stations mentioned above, as well as any other pertinent water-quality data for the Inland Bays Watershed. DNREC will also provide quantity and quality data for point-source discharges to streams in the study area, and supply or facilitate the obtaining of other data needed for the model application, including stream hydraulic characteristics and fertilizer-application data.

DGS is responsible for supplying selected data that may enhance the model application, including analysis and interpretation of results. DGS provides coordination between USGS and DNREC as appropriate.

Progress

During the reporting period (January 1-June 30, 2002), the following tasks were completed by the USGS:

1. Assumptions in the development of nutrient application rates were modified as needed and validated during the calibration; additional improvements to various datasets were made.

2. Methods for hydrological and sediment (TSS) calibration using the parameter estimator PEST were developed and validated.

3. Hydrological calibration was completed for all basins, using PEST.

4. Sediment transport calibration was completed for all basins, using PEST.

5. Subjective calibration for nutrients, dissolved oxygen, and temperature was completed for all basins.

1. Modification of Model Assumptions and Other Dataset Improvements

A number of model assumptions detailed in the previous progress report (July 1-December 31, 2001) were revised following presentations at the DE Inland Bays STAC Meeting and discussions with DNREC, DGS, and staff at the University of Delaware and Delaware Center for Inland Bays.

1.1 Animal type

The modeled animal type for the development of nutrient applications from poultry was changed from layers to broilers. Nutrient production increased with the change in animal type (Table 1) and less mineral fertilizer was used to supplement fertilizer needs in the simulated crops.

Table 1. Manure constants for two poultry animal types.

Animal Type	Animals/Animal Unit	N per animal unit (lb/yr)	P per animal unit (lb/yr)
Layers	250	303	113
Broilers	500	402	125

1.2 Atmospheric nitrogen deposition rate

Atmospheric nitrogen deposition rates were changed to values obtained from the report by Joseph R. Scudlark and Thomas M. Church, "A Comprehensive Reexamination of the Input of Atmospheric Nitrogen to the Rehoboth and Indian River Estuaries". The application rates for dry and wet deposition are as follows:

- Wet deposition:
  - NO_3 = 20 µmoles/L
  - NH_4 = 17.1 µmoles/L
  - Organic N = 9.1 µmoles/L
- Dry deposition:
  - NO_3 = 1.08 kg N/ha/yr
  - NH_4 = 0.33 kg N/ha/yr
  - Organic N = 0.46 kg N/ha/yr

1.3 Precipitation data for the southern basins

A new time series of precipitation for the Blackwater Creek and Beaverdam Ditch sub-basins was developed using daily records provided by DNREC, and measured at the wastewater treatment plant at Selbyville, DE. Daily values were disaggregated to hourly values using hourly proportions from the recorded hourly precipitation at Georgetown, DE.

2. Methodology for Model Calibration Using the Parameter Estimator PEST

This progress report briefly documents the methodology used in the determination of parameter values for the simulation of hydrology and sediments, using a parameter estimator (PEST). The model was calibrated for the 1999 water year, over which time continuous (hourly) flow measurements and sporadic TSS measurements were available. Figure 2 shows flow and observed TSS for the Swan Creek sub-basin. Hourly flow data were carefully inspected; Figure 2 shows lengthy flat (baseflow) portions followed by sudden changes (events). This "flashiness" presented a challenge in the overall calibration. Daily flow data as well as hourly flow data (Figure 3) were used in calibration.

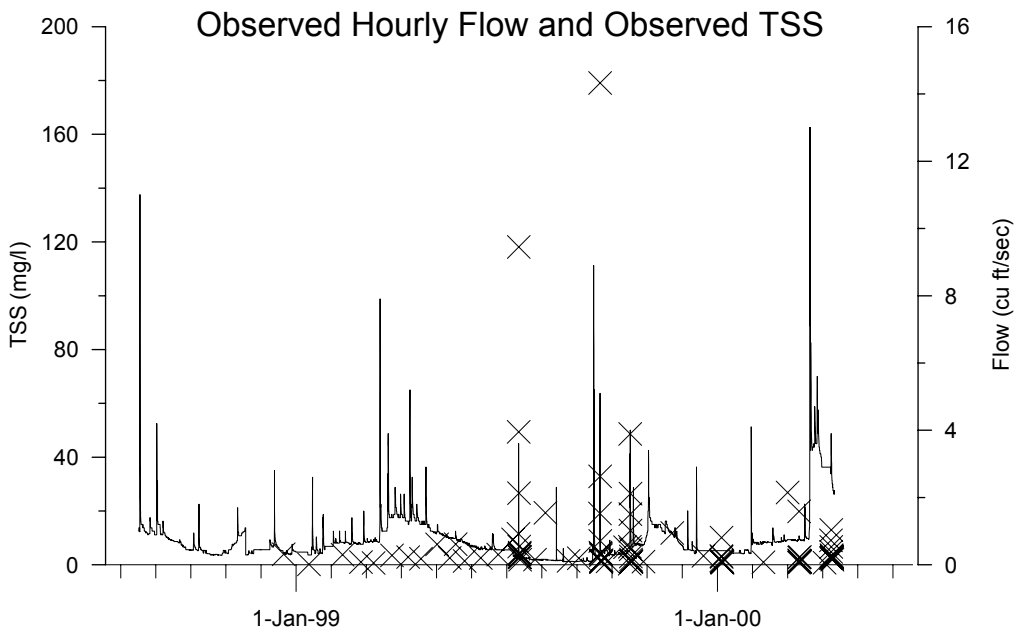


Figure 2. Flow (dark line) and TSS (crosses) over the calibration period for the Swan Creek gaging station.

2.1 Hydrologic characteristics and data analysis

The "flashy" nature of the stream flow is observed in Figure 3, and a flow event is shown in greater detail in Figure 4; in this figure major tick marks are in days while minor tick marks are in hours. The sharp nature of the runoff response as observed in Figure 4 had repercussions for the design of the RCHRES FTABLE which links RCHRES flow to volume, and thus governs routing of water within the creek draining the watershed. An analysis of Figure 4 showed that the RCHRES was able to fill and rapidly drain in the period of only a few hours. F-tables were initially developed using measured cross-sections as well as data from the indirect measurement files from the USGS; a trapezoidal channel of constant and uniform width was assumed when developing the initial F-tables. Due to the uncertainty of the results in volumes and discharge using this assumption, and the importance of F-table entries in determining hydrologic response, it was decided to estimate (using PEST) the surface areas contained in the F-tables. The surface area times the depth of the water will produce the total volume at a particular water depth.

The flashy nature of the stream led to additional questions during the calibration. It was apparent, particularly from Figure 2, that the magnitude of the small events was directly related to the impervious area (which is linked to the PERLND). If the impervious area is too large, then no amount of adjustment of PERLND or IMPLND hydrologic parameters will allow a fit between simulated and modeled RCHRES to take place. It thus became apparent that in addition to the hydrologic parameters of the PERLNDS and IMPLNDS modules, the IMPLND area was an important parameter requiring adjustment during the calibration process.

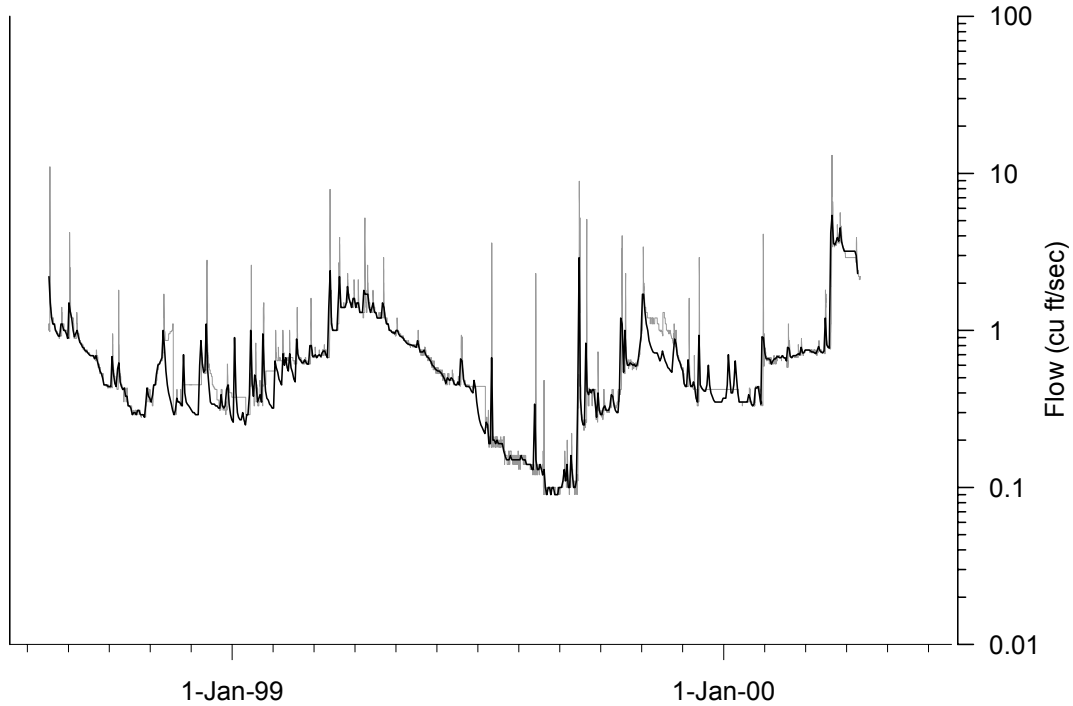


Figure 3. Hourly (grey) and daily (dark) flow observed at the Swan Creek gaging station.

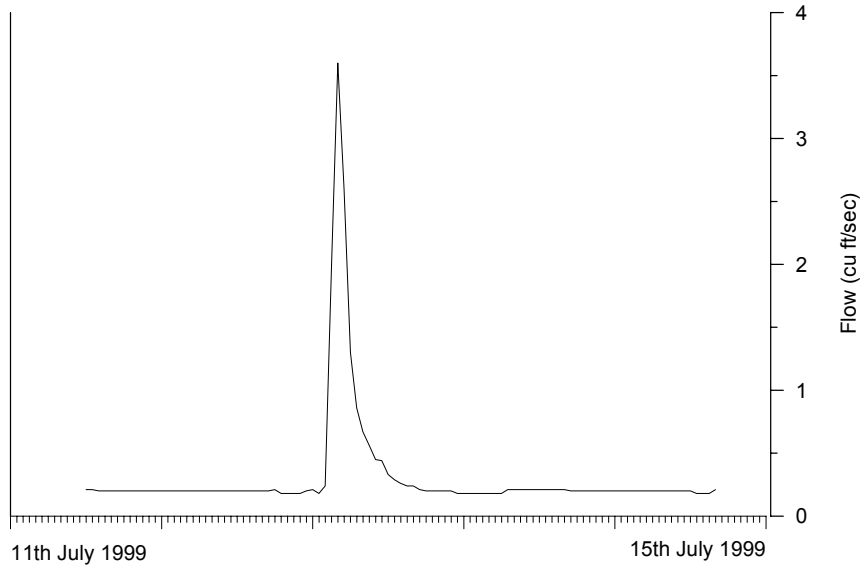


Figure 4. Details of a major flow event observed at the Swan Creek gaging station.

2.2 TSS data

An analysis of TSS data was performed in all basins, however Swan Creek data was selected as an example of the applied methodology. Figure 2 shows TSS data together with flow over the calibration period. An inspection of the TSS data revealed that a number of flow events were sampled for TSS.

Figure 5, Figure 6, Figure 7, Figure 8, Figure 9, and Figure 10 show these events in detail. In all cases, flows are depicted with a black line whereas TSS data is depicted in gray. The fact that gray lines join TSS samples is not meant to convey continuity of TSS; it is simply a device to make these graphs more readable.

A sediment-rating curve was developed using the measured data for all basins. The sediment-rating curve computed using the Swan Creek data is shown in Figure 11. The dark line represents the equation:

$$\ln(\mathbf{TSS}) = 1.0579 + 0.8796\ln(\mathbf{FLOW}) + 0.21184[\ln(\mathbf{FLOW}) - 0.87117]^2$$

The sediment-rating curve was calculated using TSPROC (a utility used with PEST) as both the model and the model pre-processor, and the methodology was as follows:

- Hourly flow data were used because, as is apparent from Figure 3, hourly flow rates were generally higher for event peaks than daily flow rates, and were more likely to approach true flow rates and therefore runoff intensities.

- Hourly flows were time-interpolated to the times at which TSS samples were taken before being used in the sediment-rating curve to estimate TSS load.

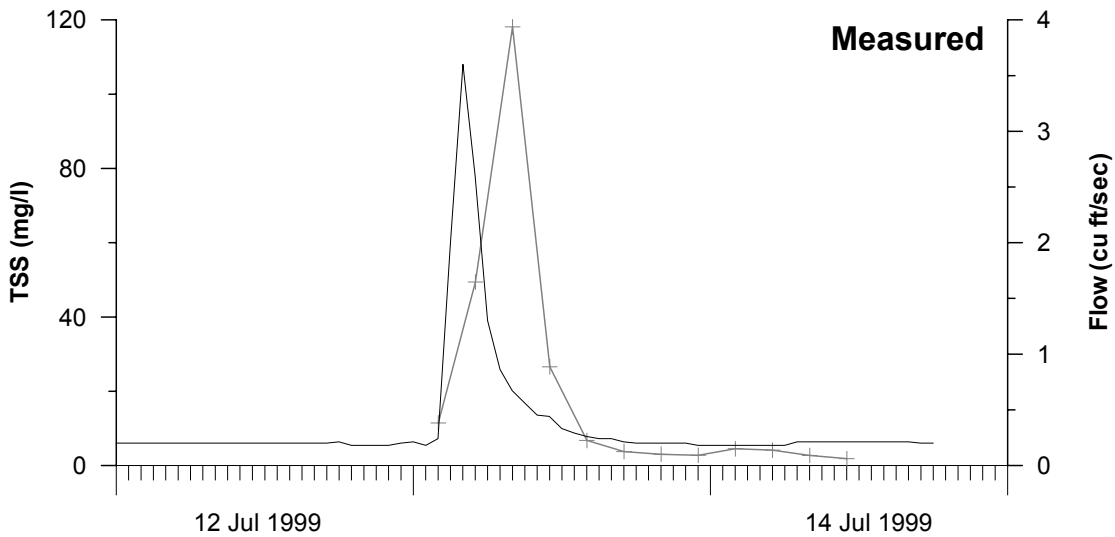


Figure 5. Flow and TSS during part of July 1999 at the Swan Creek gaging station.

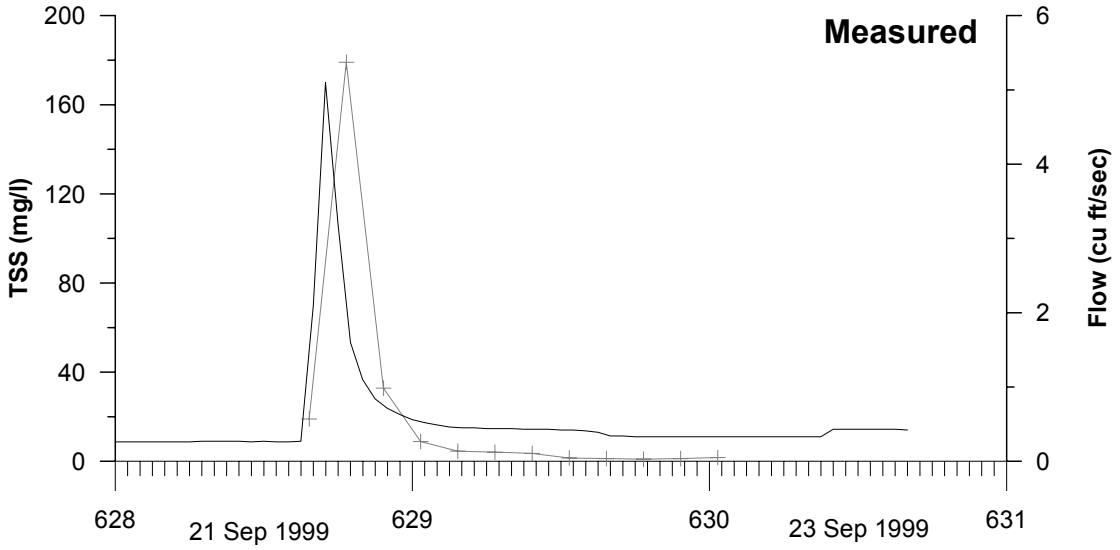


Figure 6. Flow and TSS during part of September 1999 at the Swan Creek gaging station.

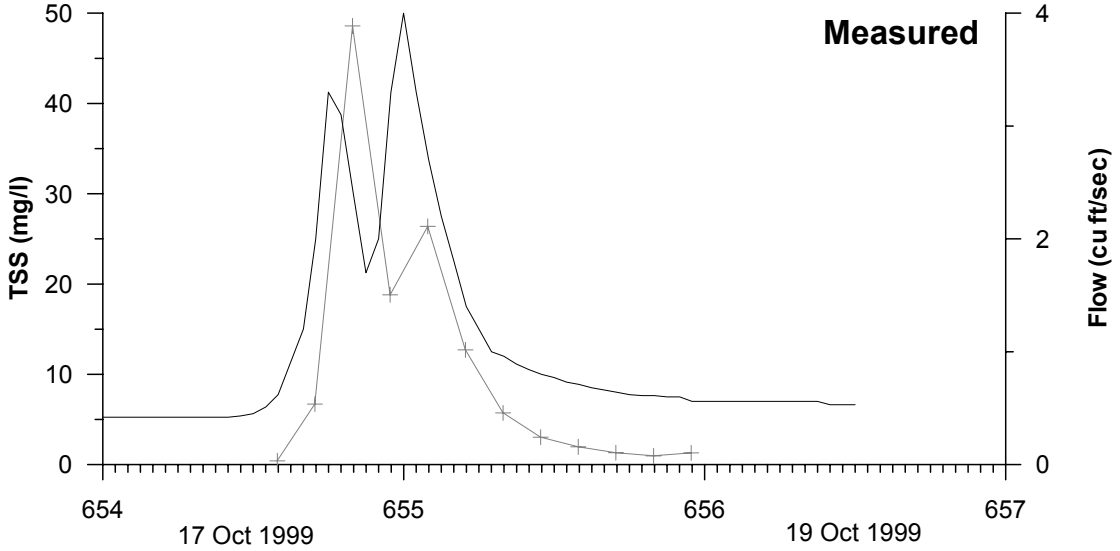


Figure 7. Flow and TSS during part of October 1999 at the Swan Creek gaging station.

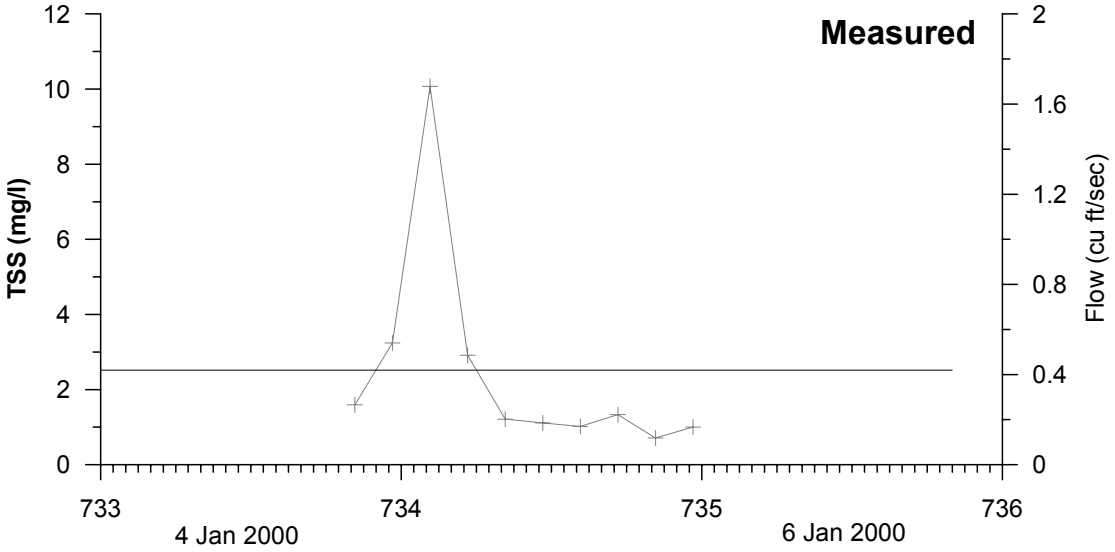


Figure 8. Flow and TSS during part of January 2000 at the Swan Creek gaging station.

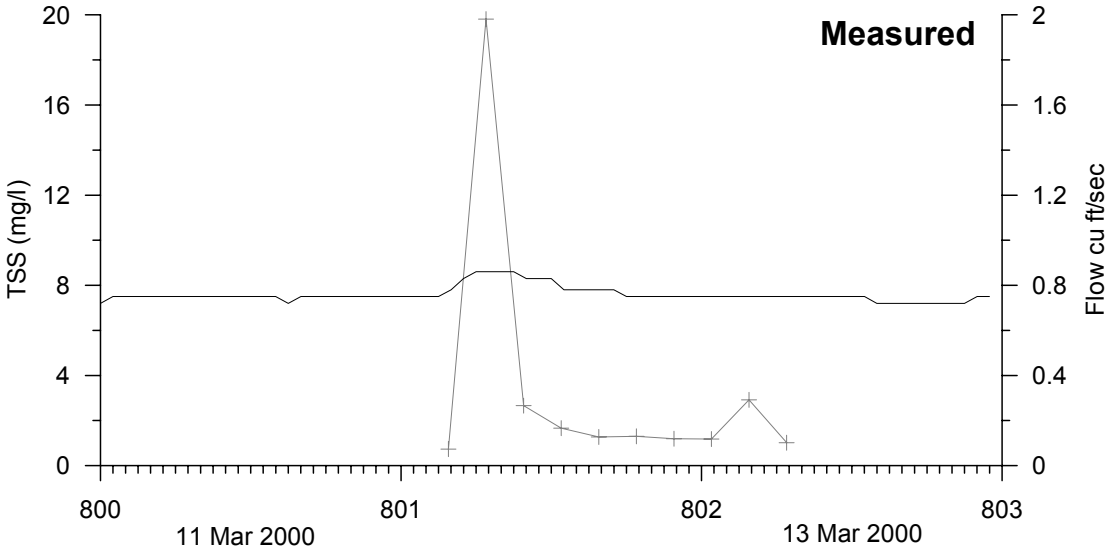


Figure 9. Flow and TSS during part of March 2000 at the Swan Creek gaging station.

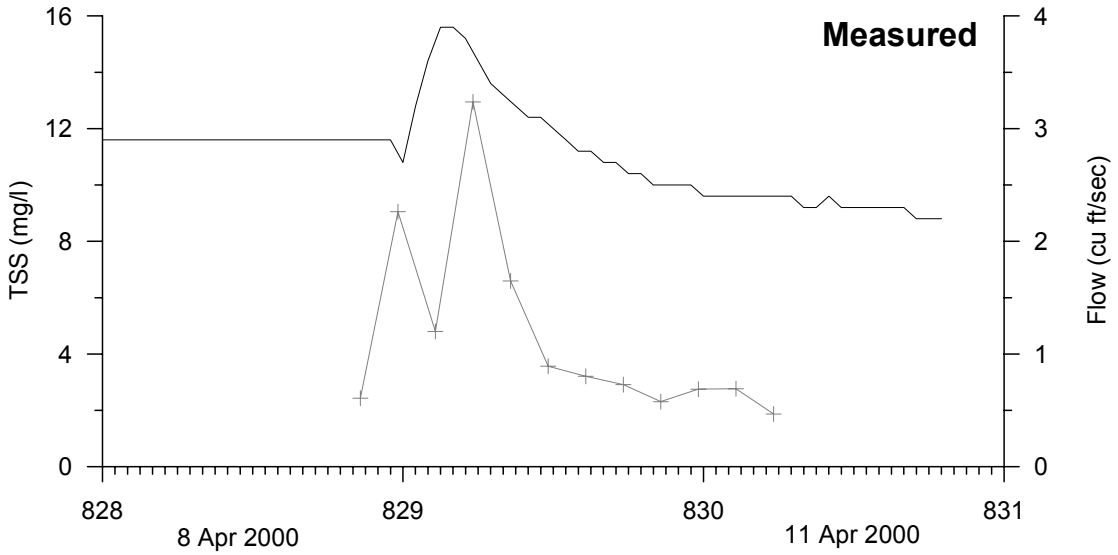


Figure 10. Flow and TSS during part of April 2000 at the Swan Creek gaging station.

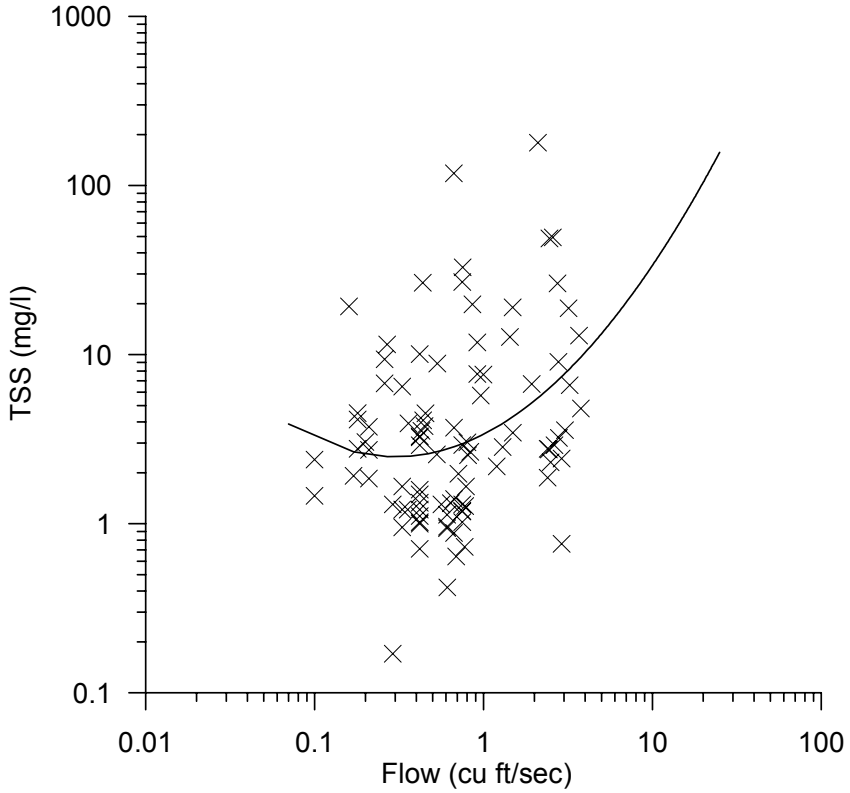


Figure 11. Sediment-rating curve calculated over the calibration period.

3. Calibration of Hydrology

3.1 Parameters

3.1.1 Separation of PERLNDS

During the calibration process, it was decided to select the largest PERLND or land use acreage for the parameter estimation. Parameter values for other land uses were tied to those being estimated by a ratio, and the following land uses were selected to be estimated:

Munchy Branch: Pervious Urban

Bundicks Branch, Black Water Creek, and Beaver Dam Ditch: Forest

Swan Creek: Forest and Urban

Millsboro: Forest and Corn

3.1.2 Monthly parameters

HSPF allows certain parameters to vary month by month, or to remain constant throughout the year. When monthly parameters were estimated, the maximum and minimum value of the parameter were selected for the estimation, and included in an equation which would imitate the annual seasonality of the estimated parameter as observed in the equation for the Manning's *n* parameter NSUR:

$$\text{NSUR(I)} = \text{NSURMIN} + (\text{NSURMAX-NSURMIN})*\text{RATIO(I)}$$

where NSUR(I) is the parameter value for the *i*th month, RATIO(I) is a monthly parameter value ratio pertaining to the *i*th month (taken from the supplied UCI file) and NSURMIN and NSURMAX are the parameters estimated by PEST.

As is briefly discussed below, an improved fit between model outputs and measured flows was obtained through using monthly parameters instead of long-term parameters.

3.1.3 Characteristics of the RCHRES

The importance of estimating RCHRES F-table characteristics was discussed above. Four F-table parameters were estimated: f_a, f_b, f_u, and f_v. The first two of these are used in the filling of the flow column of the F-table whereas the last two are used for filling the area column. Using these parameters, flows and areas corresponding to each RCHRES volume are calculated and written directly to the UCI file.

The relationship between flow and volume in a RCHRES is assumed to take the form:

$$volume = f_a \times flow + f_b \times flow^2$$

The relationship between area and volume is a RCHRES is assumed to take the form:

$$area = f_u \times flow^{f_v}$$

Note that in the second of these equations, f_v is assumed to be less than 1.0. These equations are provided for each flow cited in the F-table. Flows were added to this table in excess of that provided in the original UCI file in order to forestall premature termination of HSPF execution if a parameter set was supplied to HSPF by PEST which resulted in transient high flows. Erroneous F-table entries at

these high flows are of no concern because the parameter estimation process assures that such flows will cease to exist once parameters have been adjusted in such a way as to ensure a good fit between model output and field data.

3.2 Observations and the objective function

A multiple-criterion objective function was used in the calibration process. These criteria are briefly discussed.

3.2.1 Flows

Part of the objective function was comprised of residuals calculated by subtracting model-generated daily flows from their measured counterparts. Daily rather than hourly flows were used for this purpose because of the potential for timing errors as a result of the fact that the precipitation supplied to the model was measured at a rain gage situated at some distance from the watershed.

3.2.2 Flow differences

It is suggested in some studies that the "model output" should consist of a time series in which the entry for a particular day consists of the flow measured that day, minus part of the flow measured on the previous day. This is then matched to on "observation time series" which is calculated in the same way. See for example Kuczera (1983). In the present instance a similar, though not identical, procedure was undertaken. Using TSPROC, a "partial model output" comprised of hourly flow differences was calculated for both the model and the observed flow time series. These were then matched. Experience demonstrated that this helped to preserve the "flashy" nature of the hydrologic record in the Swan Creek watershed for example, as the discrepancy between model outputs and field measurements was reduced through the calibration process.

3.2.3 Monthly flow volumes

Model-calculated and monthly flow volumes were used in the calibration process.

3.2.4 Exceedence times

Times of flow exceedence at various flow thresholds were included in the calibration process.

3.2.5 SURO/PERO ratio

The ratio of overland flow to total flow for all PERLNDS was calculated for two of the calibrated basins, Swan Creek and Munchy Branch, because of the characteristics of these basins. This is matched to a preferred value of 10% in formulating a single observation comprising the sole member of volume for the observation group.

Calibration plots are presented in the Appendix.

4. Calibration of Total Suspended Sediments

Attempts were made to estimate TSS parameters simultaneously with hydrologic parameters. It was hoped that this strategy might help to remove some of the non-uniqueness associated with hydrologic parameters. However these attempts were unsuccessful in that PEST was not able to achieve an objective function as low as if hydrologic calibration was carried out first, and then sediment-related parameters were estimated after that.

4.2 Estimated parameters

At first, only PERLND SEDMNT parameters and RCHRES SEDTRN parameters for each basin were estimated through the calibration process. However because of the contribution made to small flow events by runoff from impervious areas, IMPLND SOLIDS parameters were also estimated (a plot of surface flow from the 109 IMPLND superimposed on surface flows from all other sources – not presented herein – reveals the extent of the contribution from this source to small flow events). It is acknowledged that hopes of parameter uniqueness are entirely misplaced. For simplicity, all SEDMNT parameters in all PERLNDS were assigned the same value.

4.3 Observations and the objective function

Components of the objective function used in the estimation of sediment-related parameters are outlined in the following sections.

4.3.1 TSS concentrations

Using TSPROC, model-generated TSS values were time-interpolated to TSS measurement times and compared with actual measurements. Weighted residuals were added to form one component of the objective function.

4.3.2 The sediment-rating curve

Model generated TSS values were time-interpolated to TSS measurement times. These were then compared with notional TSS values calculated from model-generated flows at the same times. Differences between the two formed a residual at each measurement time. Weighted residuals were summed to form a component of the objective function.

4.3.3 Bed sediments

It is important when calibrating a model that simulates movement of sediments that bed sediments are not ignored. Unless caution is exercised it is very easy to estimate a parameter set that matches stream TSS concentrations well, but which erodes the bed or deposits to the bed over time. In the present instance "observations" were included in the parameter estimation process that bed sand, silt, and clay storage did not change over the calibration period.

Over any simulation time, some bed deposition and erosion will occur. In the present instance it was assumed that this took place to a minimal extent. The standard deviation of bed sand, silt, and clay storage was evaluated by TSPROC, and matched to an "observed value" of zero. From analysis of the simulation output, it appears that the flowing creek might continue to erode bed sediments for a while after a flow event, with the depleted bed storage re-deposited during the next event.

4.3.5 TSS variation over time

In an attempt to capture some of the "character" of the TSS time-series, the standard deviation of the log of this series was calculated. Model-generated TSS values were time-interpolated to TSS measurement times and the log standard deviation of this time series was calculated as well. The observed and model generated quantities were compared and a residual was calculated and added to the objective function.

Figure 12 through Figure 17 show the match between modeled and observed flow and TSS data. Some of the model-generated TSS curves appear to be too large (over-simulation) during some of the small flow events depicted in these figures. It should be noted that smaller responses were obtained on calibration runs in which the sediment-rating curve was omitted from the calibration process. Additional calibration plots are presented in the Appendix.

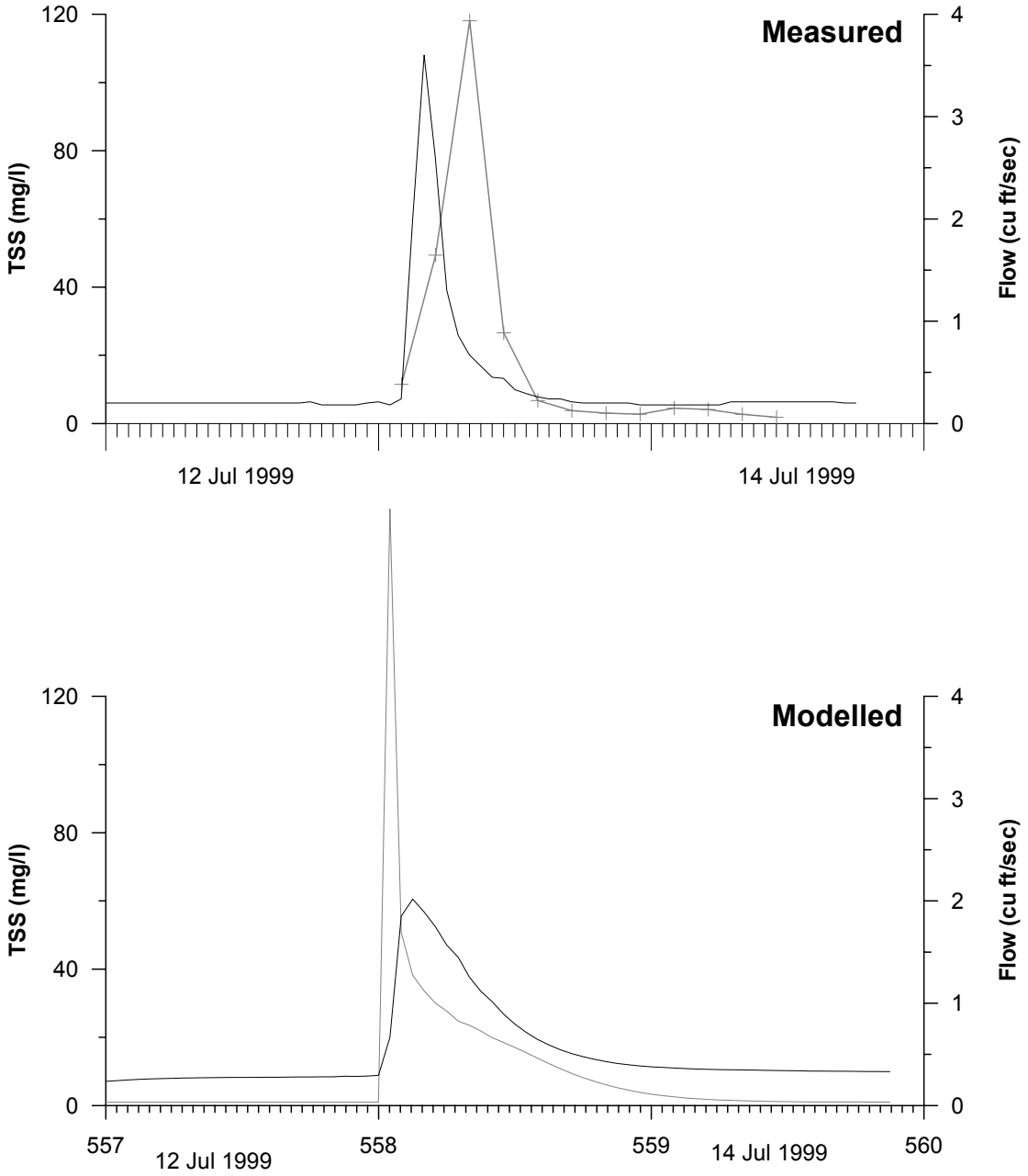
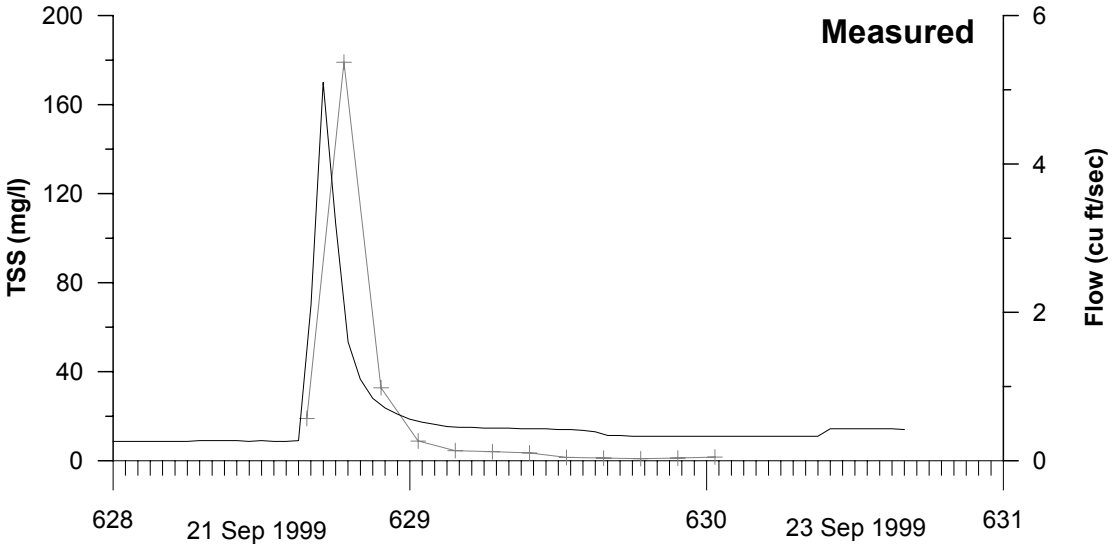


Figure 12. Measured (top) and modeled (bottom) flow and TSS during part of July 1999 at the Swan Creek gaging station.



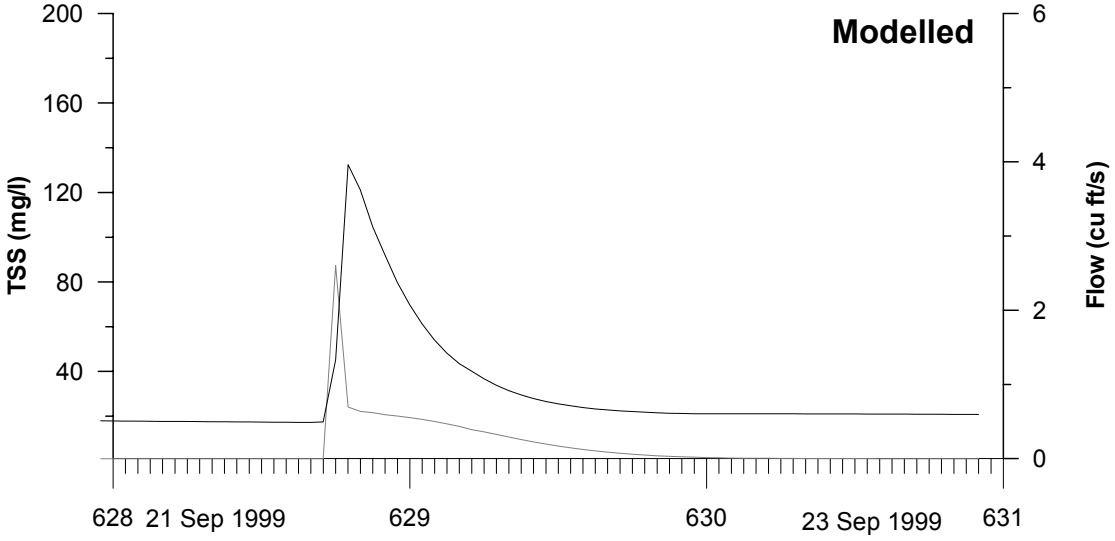


Figure 13. Measured (top) and modeled (bottom) flow and TSS during part of September 1999 at the Swan Creek gaging station.

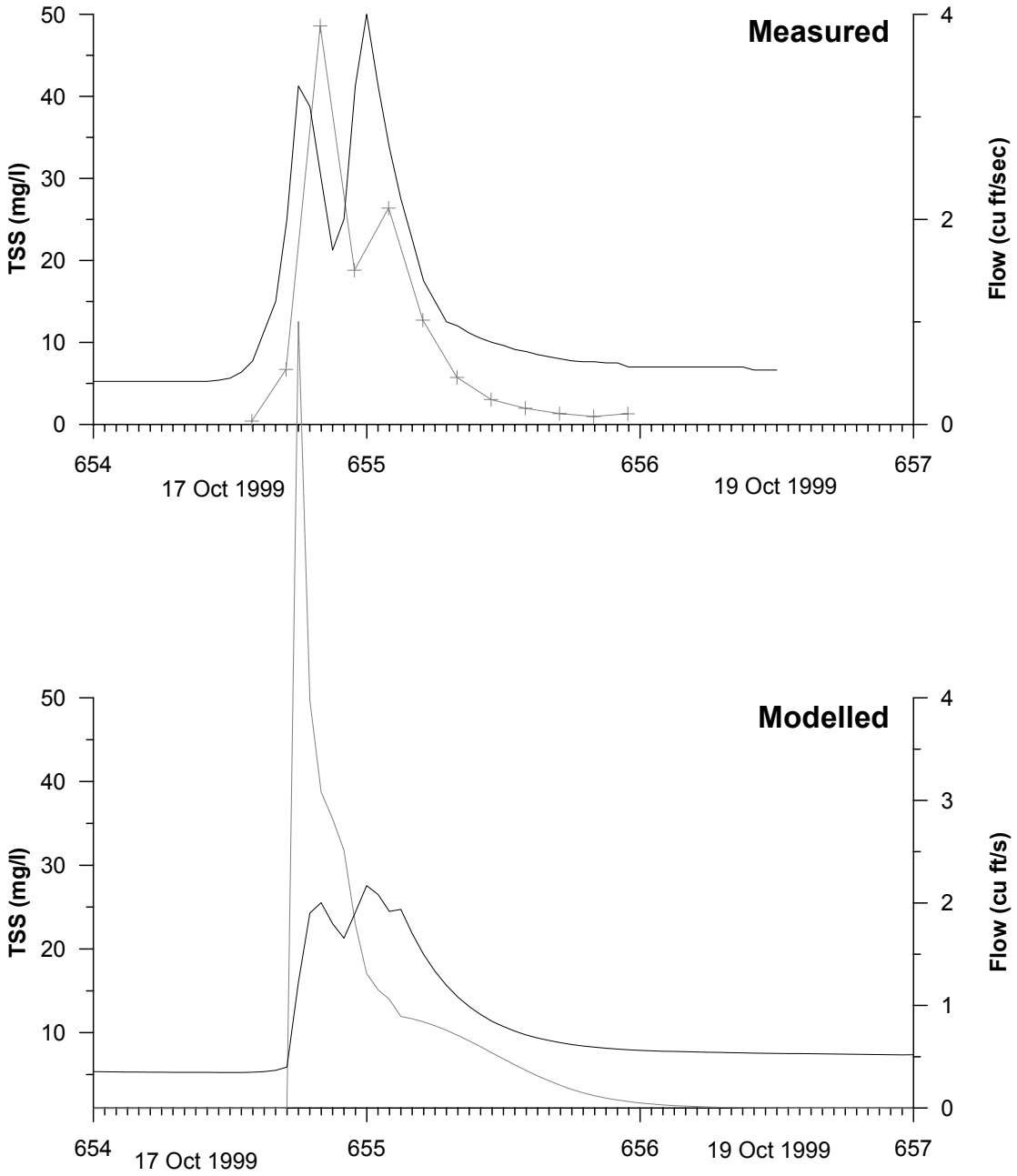


Figure 14. Measured (top) and modeled (bottom) flow and TSS during part of October 1999 at the Swan Creek gaging station.

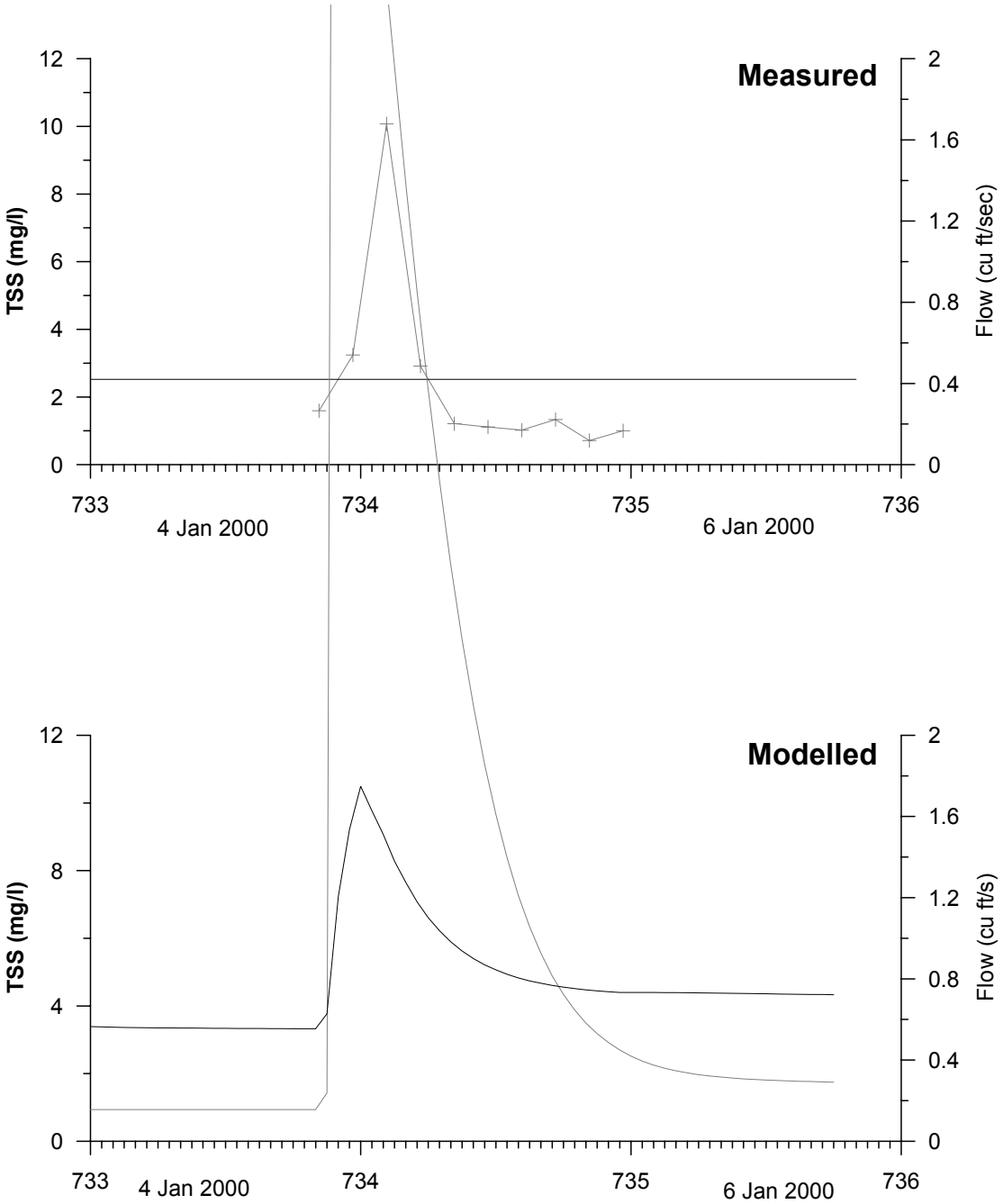
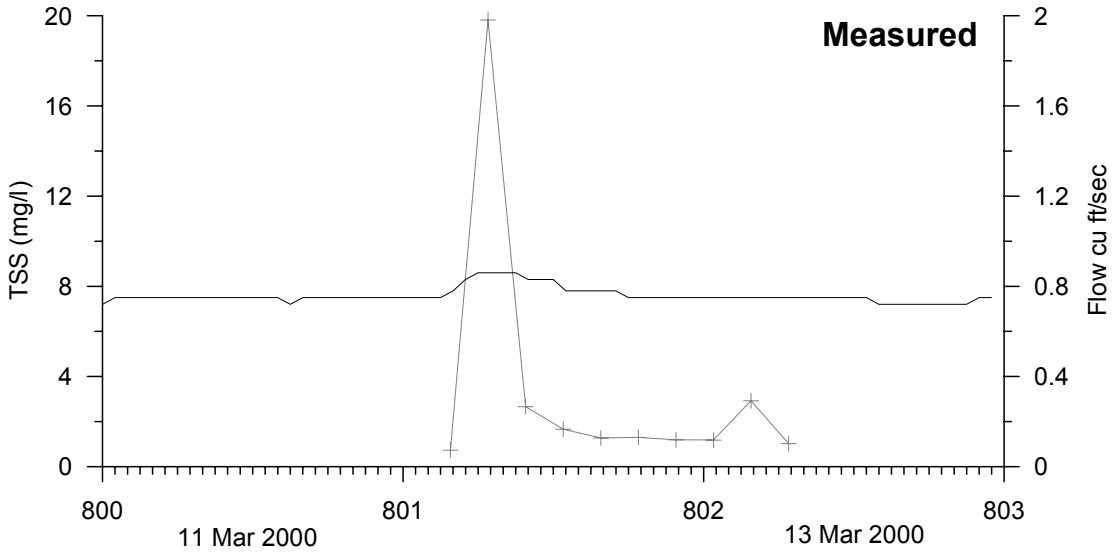


Figure 15. Measured (top) and modeled (bottom) flow and TSS during part of January 2000 at the Swan Creek gaging station.



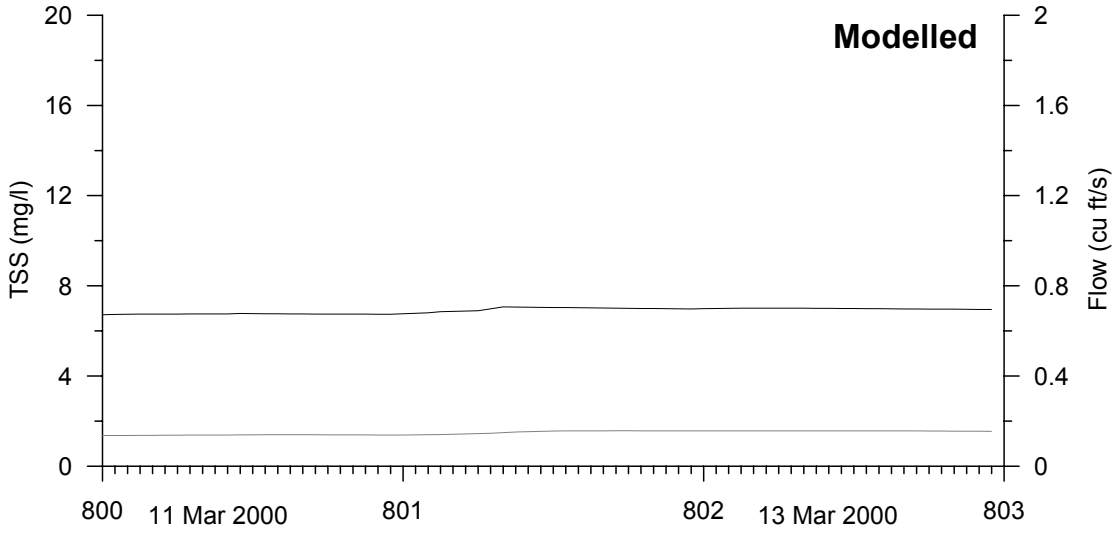


Figure 16. Measured (top) and modeled (bottom) flow and TSS during part of March 2000 at the Swan Creek gaging station.

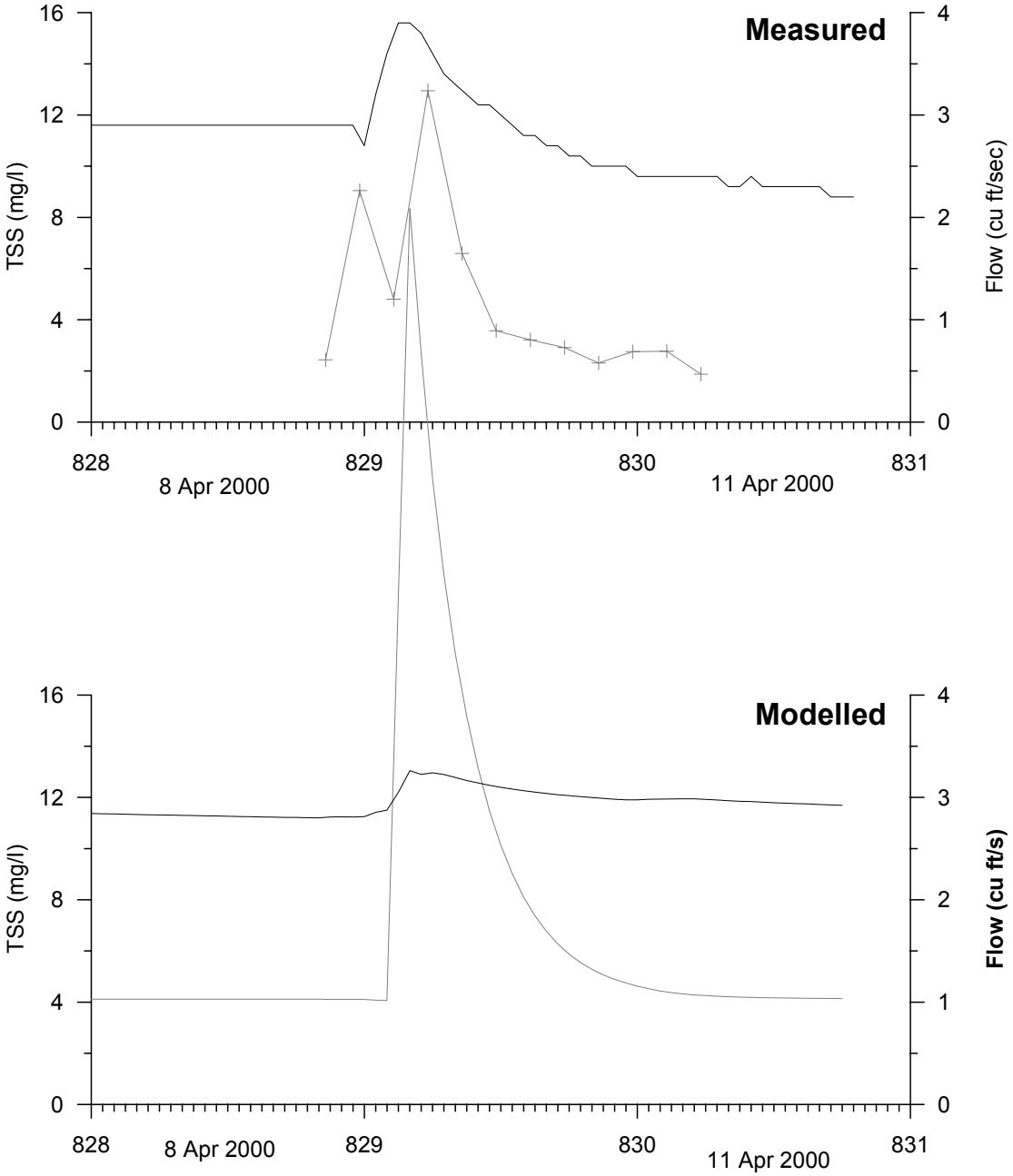


Figure 17. Measured (top) and modeled (bottom) flow and TSS during part of April 2000 at the Swan Creek gaging station.

5. Calibration of Nutrients

The calibration of nutrients was performed in two parts: (1) edge of stream loads, and (2) in-stream concentrations. For the calibration of edge of stream nitrogen and phosphorous loads, first-order reaction parameters for the surface, upper, lower, and active ground-water layers, as well as initial values, were obtained from the HSPF model developed by the Chesapeake Bay Program office for the Choptank River on the Maryland Eastern Shore. The final average values for nitrogen processes are presented in Table 2 while average values for phosphorous are presented in Table 3.

Table 2. Nitrogen first-order reaction parameters. Units: 1/day

SOIL LAYER	LAND USE	KIMNI	KAM	KDNI	KNI	KIMAN
Surface	Forest	0.00	0.02	0.0	10.0	5.0
	other	0.00	0.01	0.0	10.0	5.0
Upper	Forest	0.00	0.01	0.0	5.0	2.0
	other	0.00	0.001	0.0	5.0	2.0
Lower	Forest	0.00	0.005	0.0	3.0	0.5
	other	0.00	0.001	0.0	3.0	0.5
Active ground water	Forest	0.00	0.0015	0.02	1.0	0.0
	other	0.00	0.0005	0.02	1.0	0.0

Key: KIMNI Nitrate immobilization (only relevant if NUPTFG = 0 or 1)
KAM Organic N ammonification
KDNI Denitrification of NO_3
KNI Nitrification
KIMAM Ammonium immobilization (only relevant if NUPTFG = 0 or 1)

Table 3. Phosphorous first-order reaction parameters. Units: 1/day

SOIL LAYER	LAND USE	KIMP	KMP
Surface	All	2.00	0.002
Upper	All	0.50	0.001
Lower	All	0.05	0.0002
Active ground water	All	0.00	0.00

Key: KIMP Phosphate immobilization
KMP Organic P mineralization

Nutrient applications varied in amount and time during the year (described in the previous progress report). Phosphorous, more so than nitrogen, is strongly associated with the soil, thereby appearing in low concentrations in water but in high concentrations on soil particles. For both elements, it was found that the amount of nutrient fixed to the soil increased with depth.

Once the edge of stream load was determined, the in-stream parameter estimation was initiated. The in-stream simulation included the primary processes that determined the balance of inorganic nitrogen and phosphorus in natural waters. The processes are:

1. Longitudinal advection of dissolved NO_3, NO_2, NH_3, and PO_4

2. Benthal release of inorganic nitrogen (NH_3) and PO_4

3. Ammonia ionization (NH_3/NH_4^+ equilibrium)

4. Ammonia vaporization

5. Nitrification of NH_3 and NO_2

6. Denitrification of NO_3

7. Ammonification due to degradation of BOD materials

8. Adsorption/desorption of NH_3 and PO_4 to inorganic sediment in the water column

9. Deposition/scour and longitudinal advection of adsorbed NH_3 and PO_4

Additional sources and sinks of NO_3, NH_3, and PO_4 were simulated adding phytoplankton and benthic algae. Phytoplankton (free floating photosynthetic algae), and benthic algae (the state variable for algae attached to the benthal surface) were included in the simulation after the analysis of measured data for ammonia and phosphate. During anaerobic conditions/dry periods, high releases of ammonia were observed in the measured data. Through the simulation was determined to be a release from the benthic algae during anaerobic conditions (1.0 mg/L).

Calibration plots are presented in the Appendix.

Plans for Next Six Months

1. Calibrated model files will be modified to be used with the scenario generator GENSCN.

2. Draft of final report ready for colleague review will be completed.

3. Once final calibration is complete, all files required for HSPF model simulation (including GENSCN scenario generation and evaluation) will be delivered to DNREC.

References

Andres, A.S., Savidge, K.S., Scudlark, J., and Ullman, W.J., 2001, IBTMDL612 database: Delaware Geological Survey Digital data product No.02-001.

Ullman, W.J., Scudlark, J., and Andres, A.S., 2001, Storm-water sampling and analysis in the Inland Bays: final report to the Delaware Department of Natural Resources and Environmental Control under Contract No. 939519: Delaware Geological Survey Final Report of Research.

Appendix: Calibration Plots

A variety of SAS scripts, FORTRAN programs, and other tools were developed over the course of this project to provide detailed statistics on the behavior of the model. The following plots are directly from the SAS scripts for hydrology, TSS, and nutrient calibration. At the top of each plot are the segment number and name (refer to Figure 1), plot type, and other information. Summary statistics (such as the correlation coefficient and standard error) are sometimes presented in the lower right corner of the plot. Plots for segments 30 (Bundicks Branch), 310 (Blackwater Creek), and 330 (Beaver Dam Ditch) are presented and were chosen as being representative of the variety of simulations and goodness-of-fit that was achieved in the calibrated model simulations.

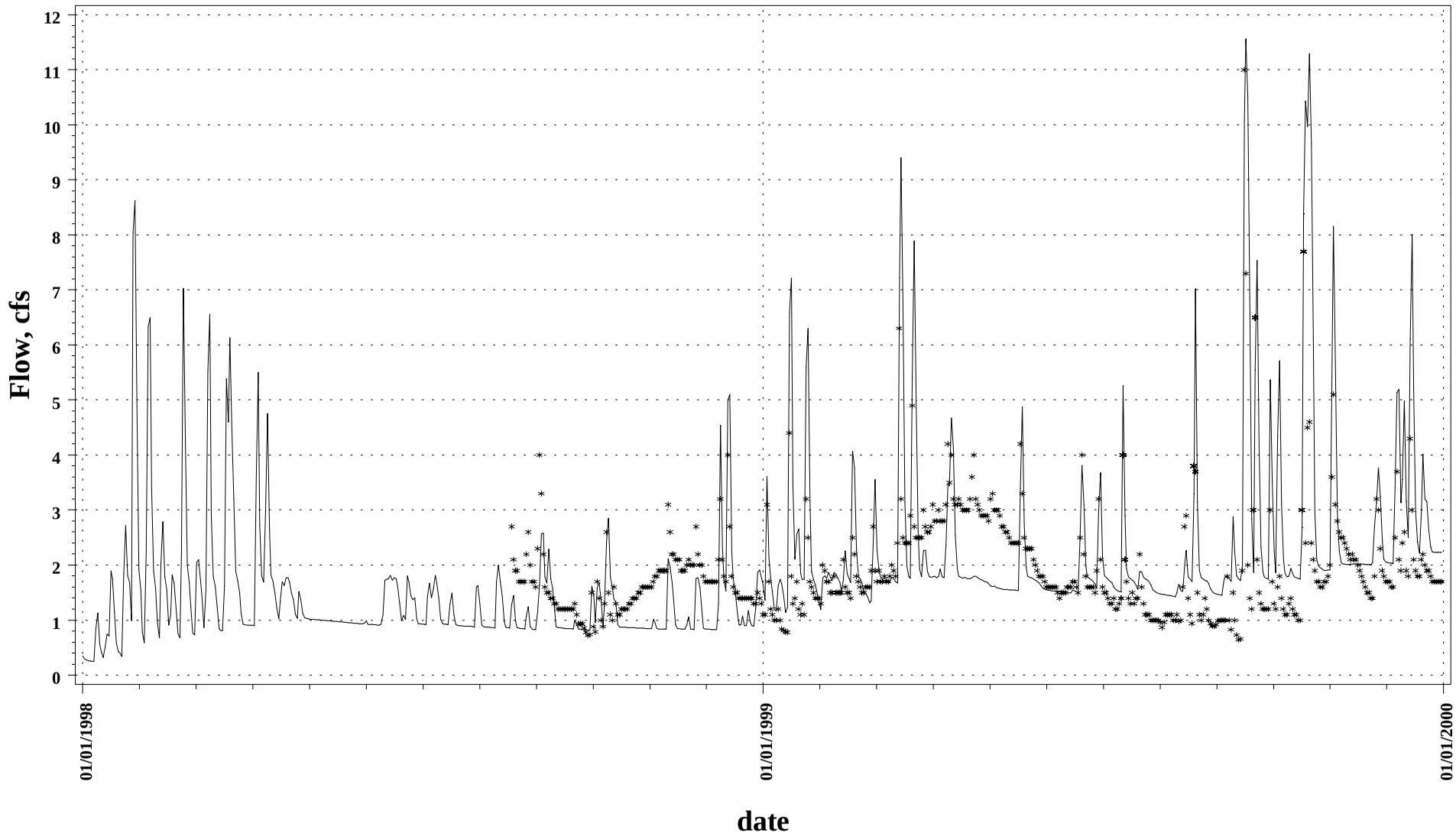
There are 22 plots for each sub-basin or segment:

1. Observed and simulated **daily discharge** time series.
2. A log-log plot of simulated and observed **daily discharge**.
3. Observed and simulated **ammonia** time series.
4. A log-log plot of simulated and observed **ammonia** concentrations.
5. Observed and simulated **nitrate plus nitrite** time series.
6. A log-log plot of simulated and observed **nitrate plus nitrite** concentrations.
7. Observed and simulated **total organic nitrogen** time series.
8. A log-log plot of simulated and observed **total organic nitrogen** concentrations.
9. Observed and simulated **total nitrogen** time series.
10. A log-log plot of simulated and observed **total nitrogen** concentrations.
11. Observed and simulated **dissolved oxygen** time series.
12. A log-log plot of simulated and observed **dissolved oxygen** concentrations.
13. Observed and simulated **orthophosphate** time series.
14. A log-log plot of simulated and observed **orthophosphate** concentrations.
15. Observed and simulated **organic phosphorus** time series.
16. A log-log plot of simulated and observed **organic phosphorus** concentrations.
17. Observed and simulated **total phosphorus** time series.
18. A log-log plot of simulated and observed **total phosphorus** concentrations.
19. Observed and simulated **total suspended sediment (TSS)** time series.
20. A log-log plot of simulated and observed **total suspended sediment (TSS)** concentrations.
21. Observed and simulated **water temperature** time series.
22. A log-log plot of simulated and observed **water temperature**.

Inland/ Segment 30 - Bundicks Branch: Calibration Run Flow

Observed and Simulated versus Time

(* =Observed, - =Simulated)

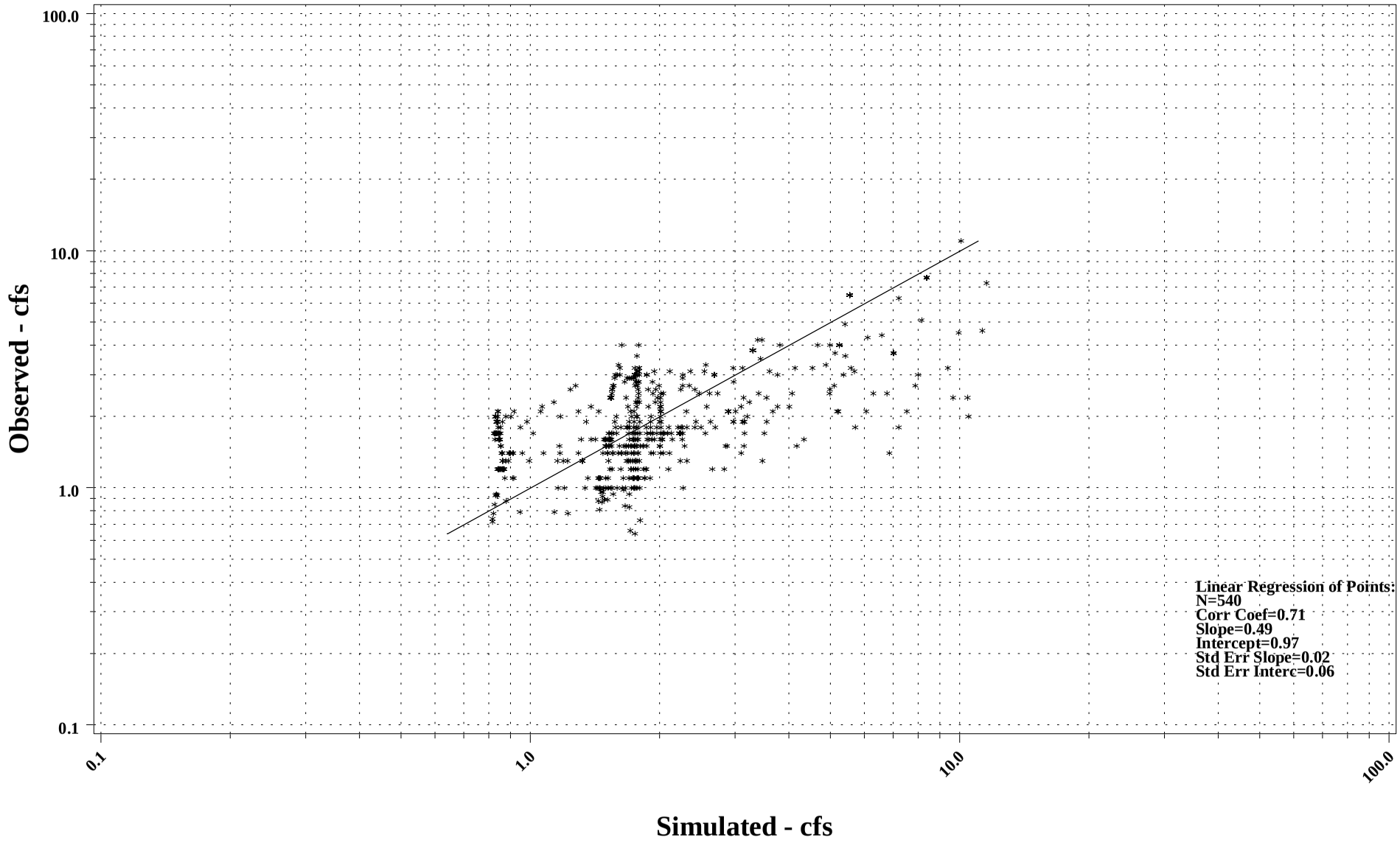


(10SEP02 13:14)
(plot.sas, omtime)

Inland/ Segment 30 - Bundicks Branch: Calibration Run

Scatter Plot and Regression of Simulated versus Observed with Ideal Line

Flow: 01JAN98 - 01JAN00

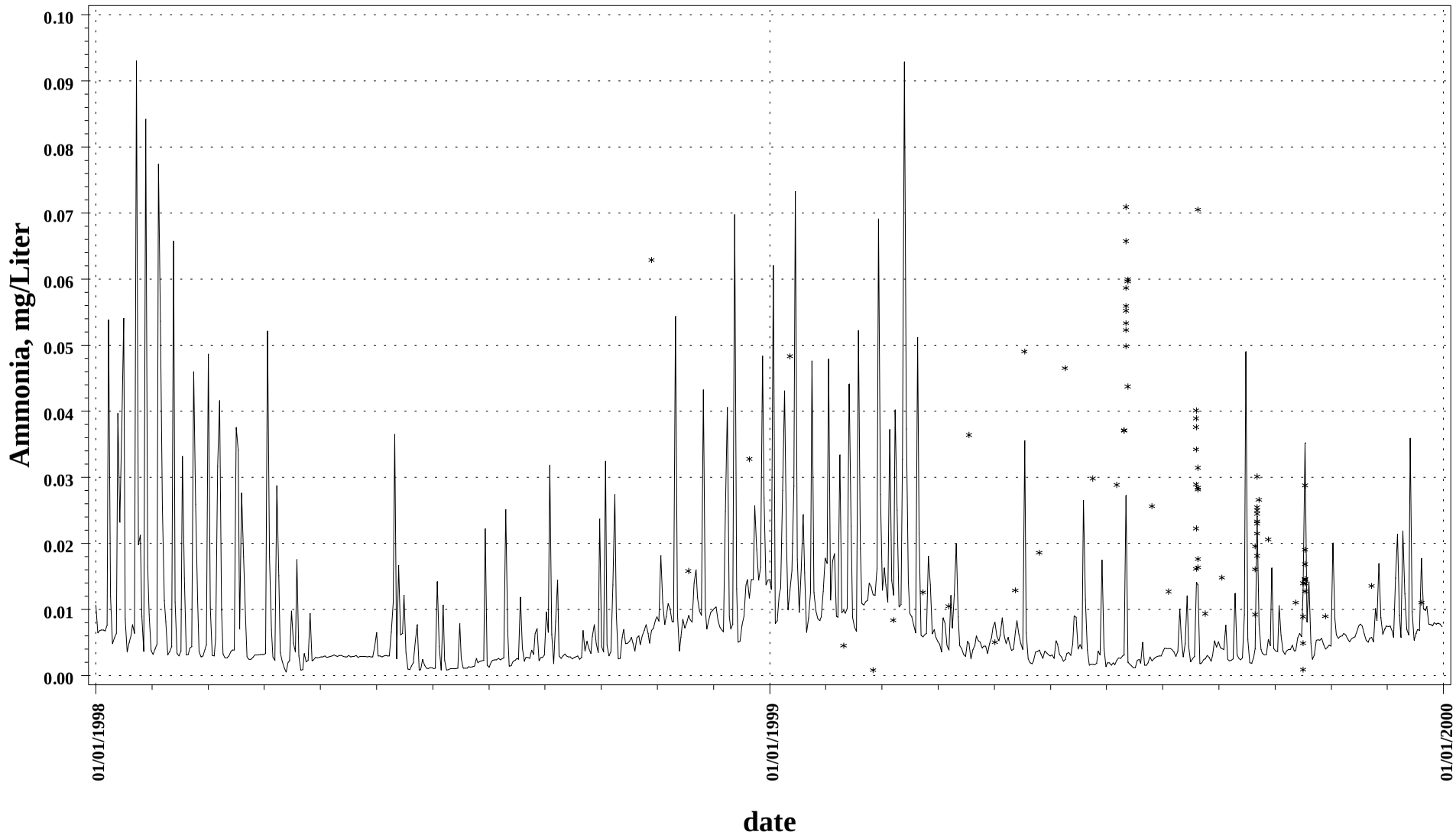


(10SEP02 13:14)
(plot.sas, llomregr.sas)

Inland/ Segment 30 - Bundicks Branch: Calibration Run Ammonia

Observed and Simulated versus Time

(* =Observed, - =Simulated)

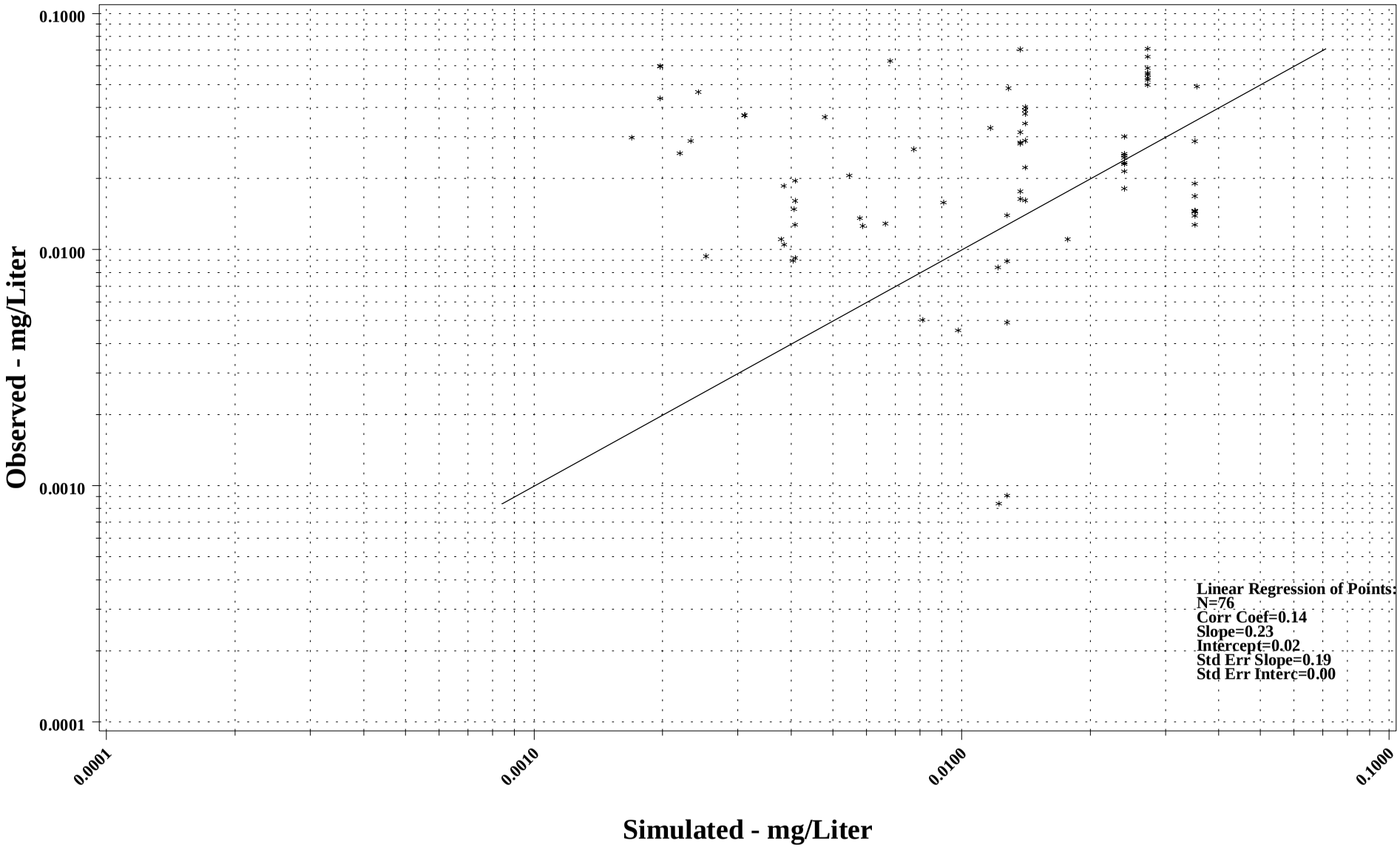


(10SEP02 13:14)
(plot.sas, omtime)

Inland/ Segment 30 - Bundicks Branch: Calibration Run

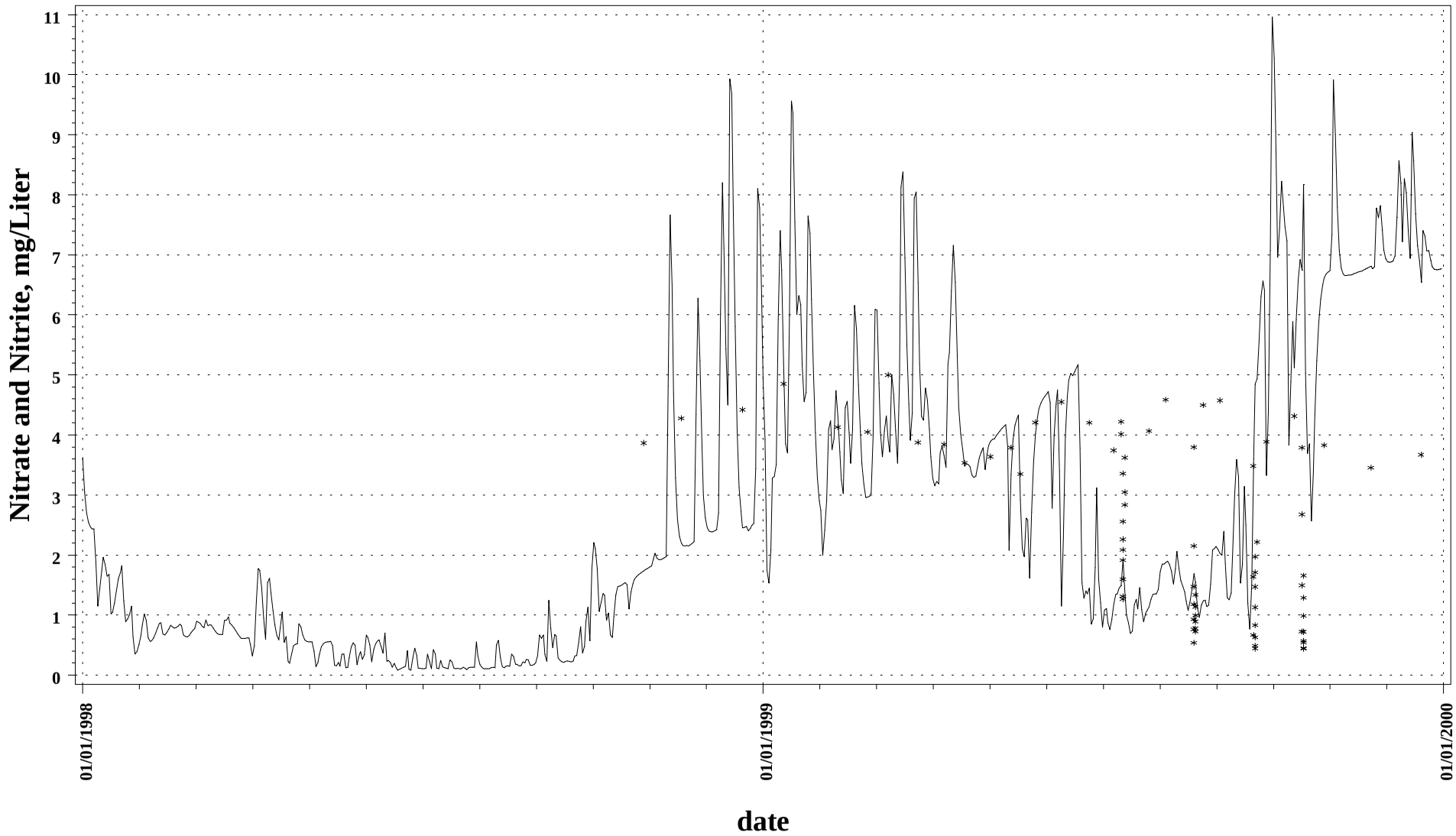
Scatter Plot and Regression of Simulated versus Observed with Ideal Line

Ammonia: 01JAN98 - 01JAN00



(10SEP02 13:14)
(plot.sas, llomregr.sas)

Inland/ Segment 30 - Bundicks Branch: Calibration Run
Nitrate and Nitrite
Observed and Simulated versus Time
(* =Observed, - =Simulated)

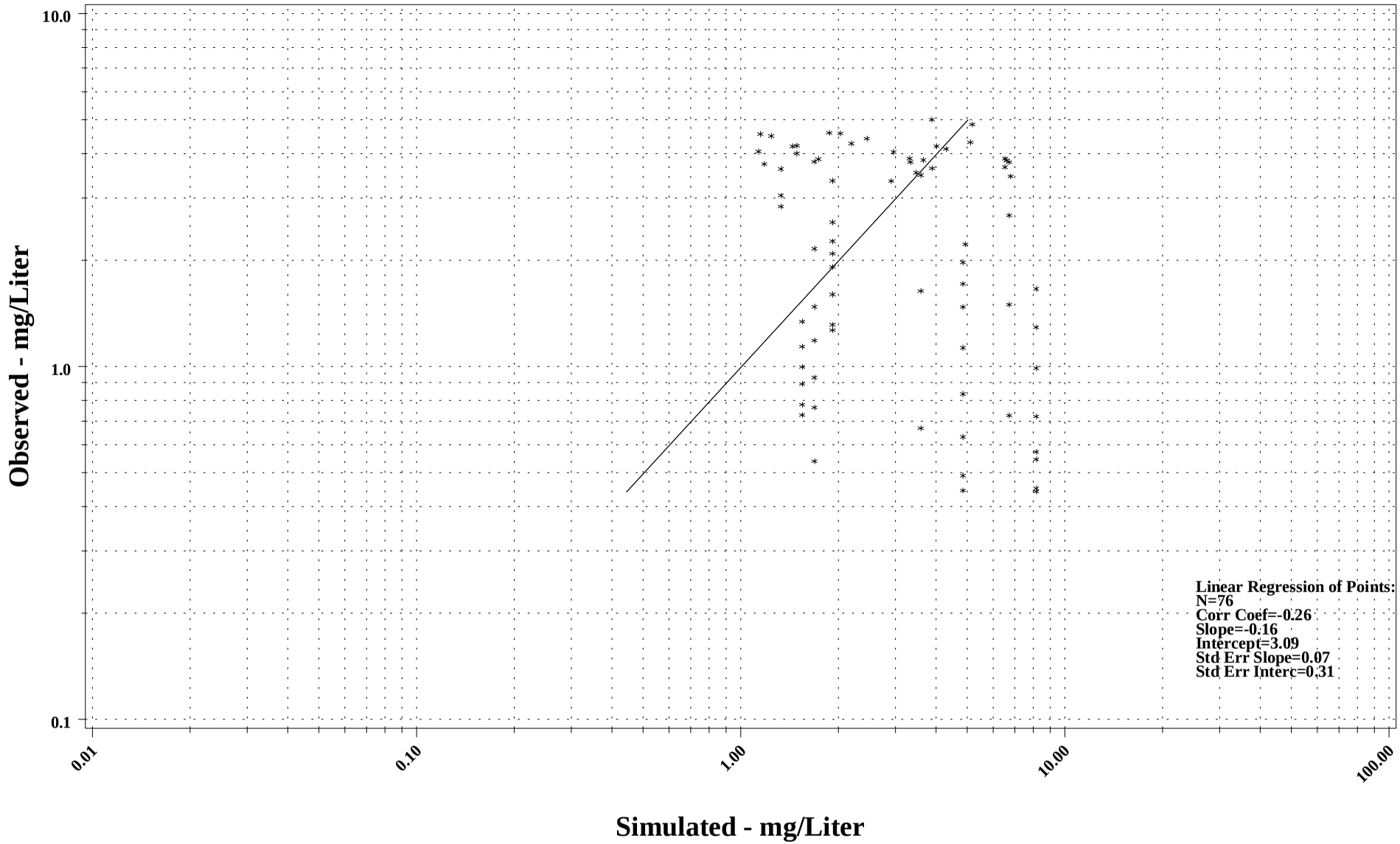


(10SEP02 13:14)
(plot.sas, omtime)

Inland/ Segment 30 - Bundicks Branch: Calibration Run

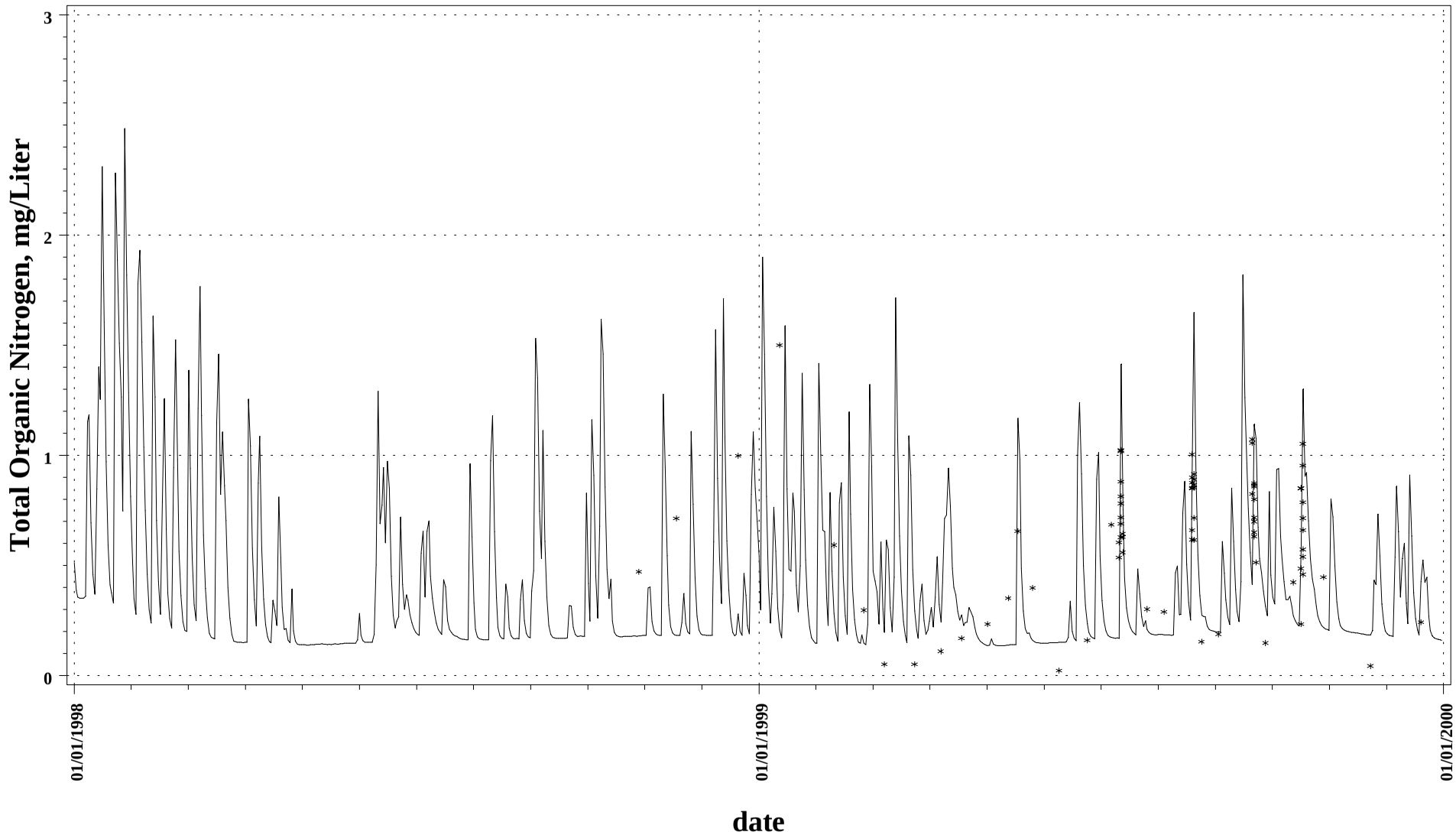
Scatter Plot and Regression of Simulated versus Observed with Ideal Line

Nitrate and Nitrite: 01JAN98 - 01JAN00



(10SEP02 13:14)
(plot.sas, llomregr.sas)

Inland/ Segment 30 - Bundicks Branch: Calibration Run
Total Organic Nitrogen
Observed and Simulated versus Time
(* =Observed, - =Simulated)

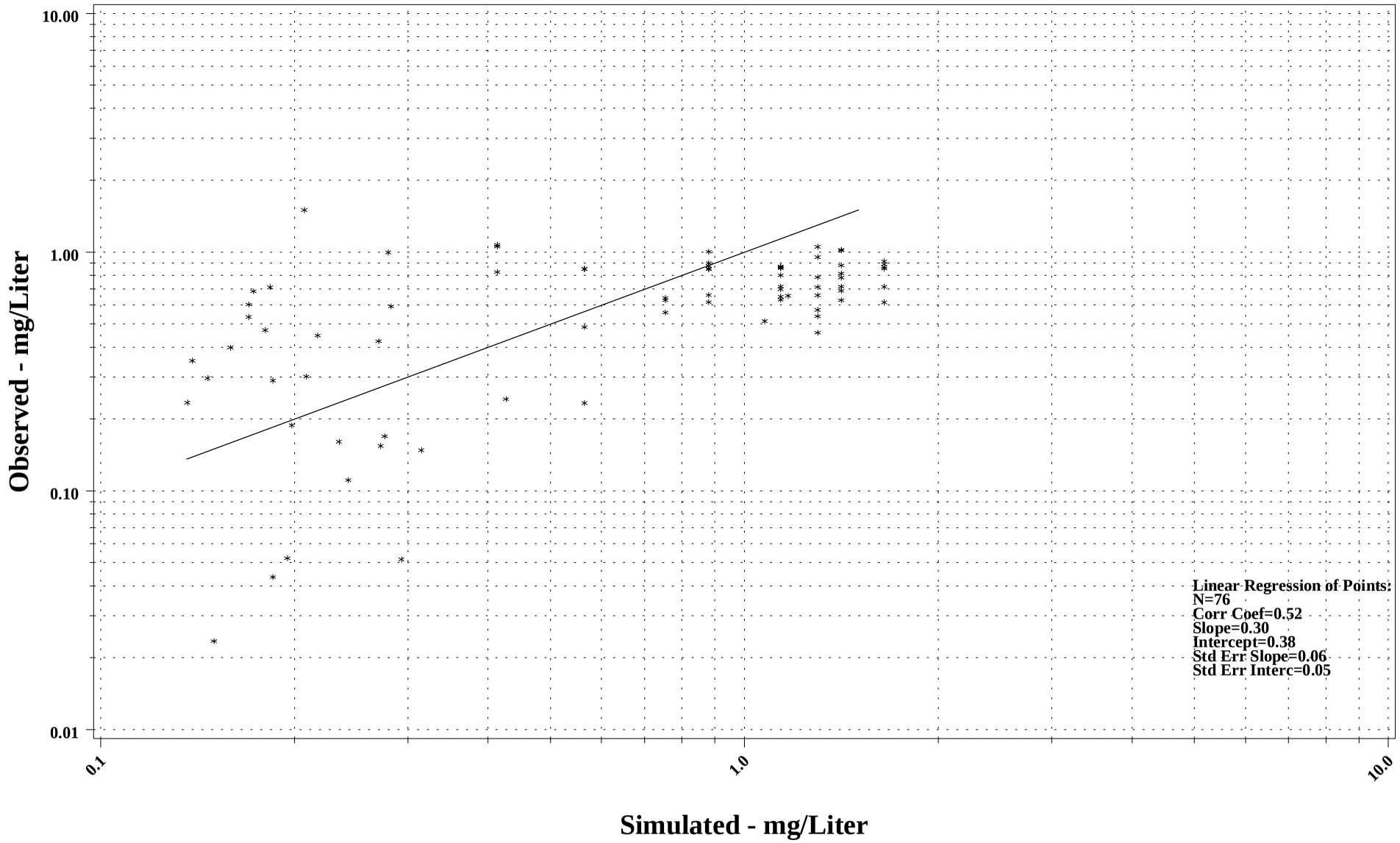


(10SEP02 13:14)
(plot.sas, omtime)

Inland/ Segment 30 - Bundicks Branch: Calibration Run

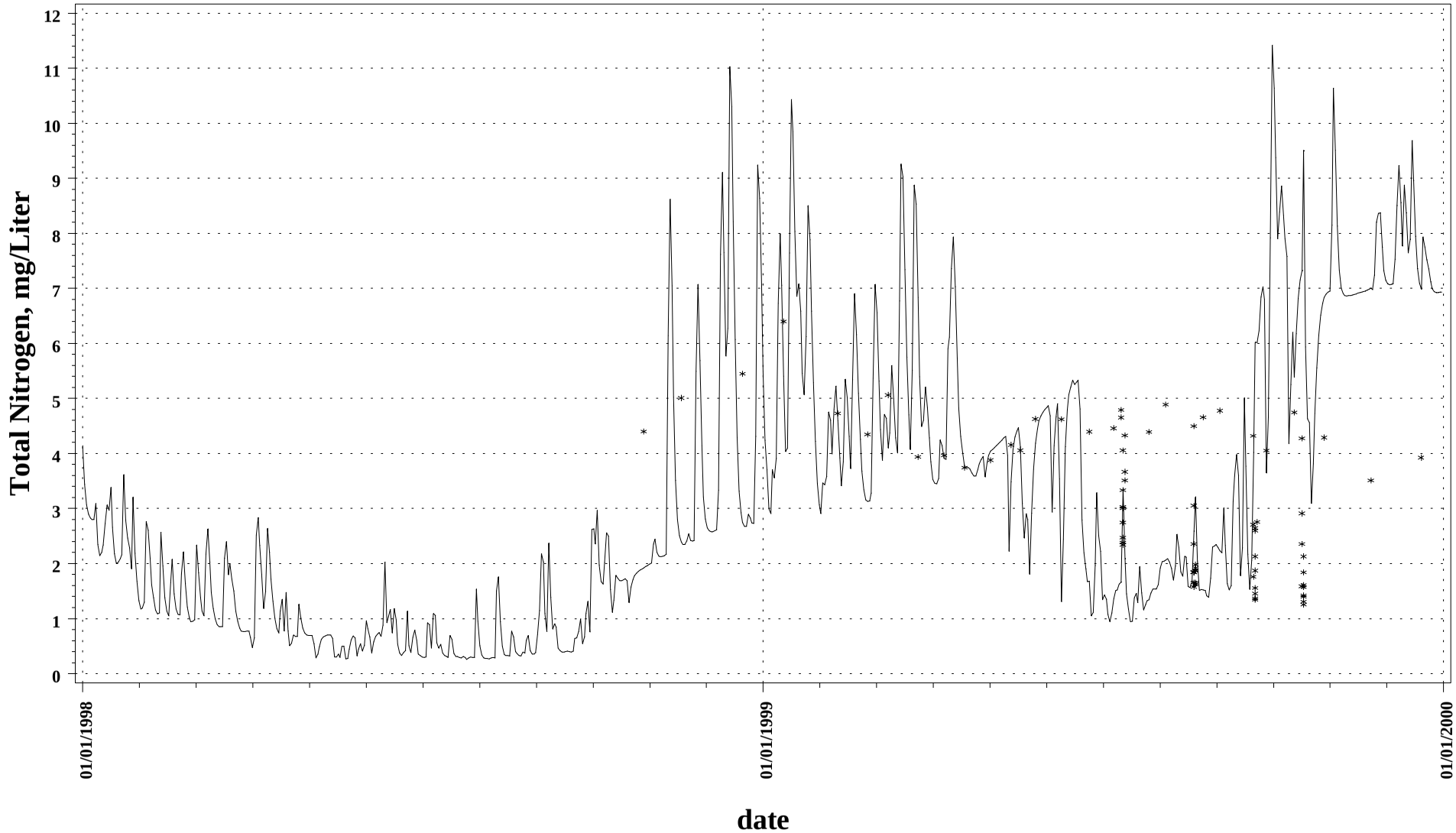
Scatter Plot and Regression of Simulated versus Observed with Ideal Line

Total Organic Nitrogen: 01JAN98 - 01JAN00



(10SEP02 13:14)
(plot.sas, llomregr.sas)

Inland/ Segment 30 - Bundicks Branch: Calibration Run
Total Nitrogen
Observed and Simulated versus Time
(* =Observed, - =Simulated)

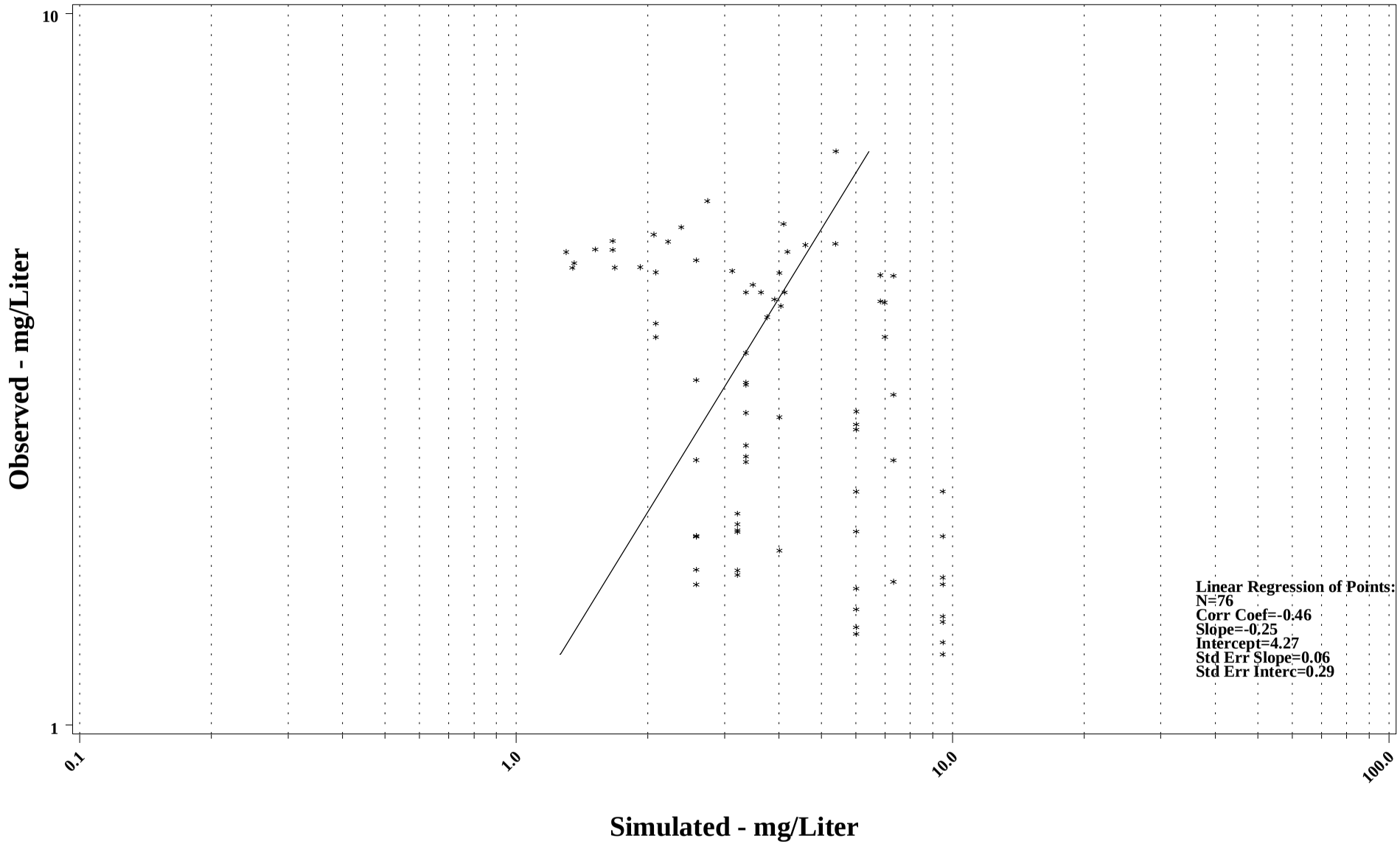


(10SEP02 13:14)
(plot.sas, omtime)

Inland/ Segment 30 - Bundicks Branch: Calibration Run

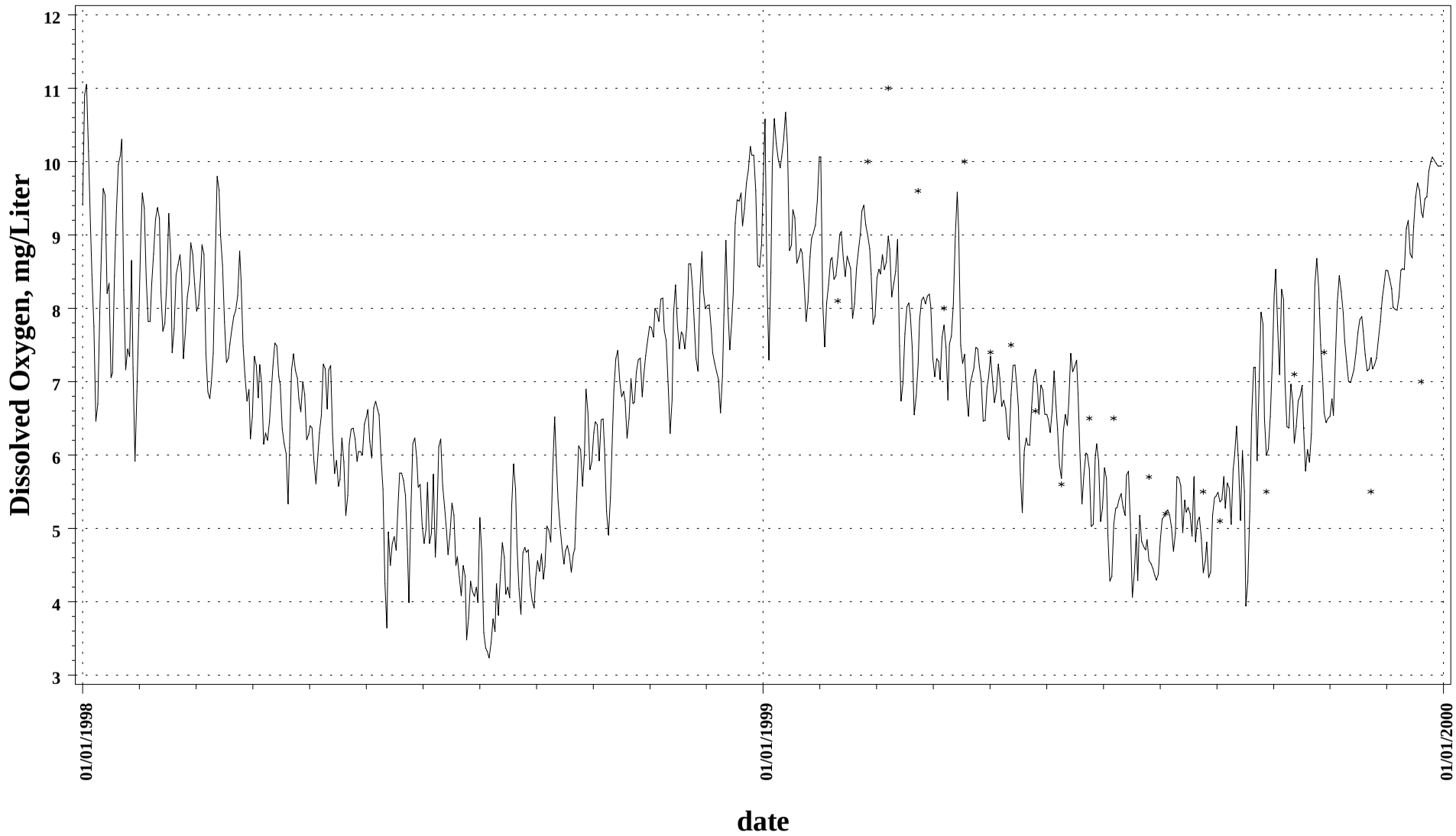
Scatter Plot and Regression of Simulated versus Observed with Ideal Line

Total Nitrogen: 01JAN98 - 01JAN00



(10SEP02 13:14)
(plot.sas, llomregr.sas)

Inland/ Segment 30 - Bundicks Branch: Calibration Run
Dissolved Oxygen
Observed and Simulated versus Time
(* =Observed, - =Simulated)

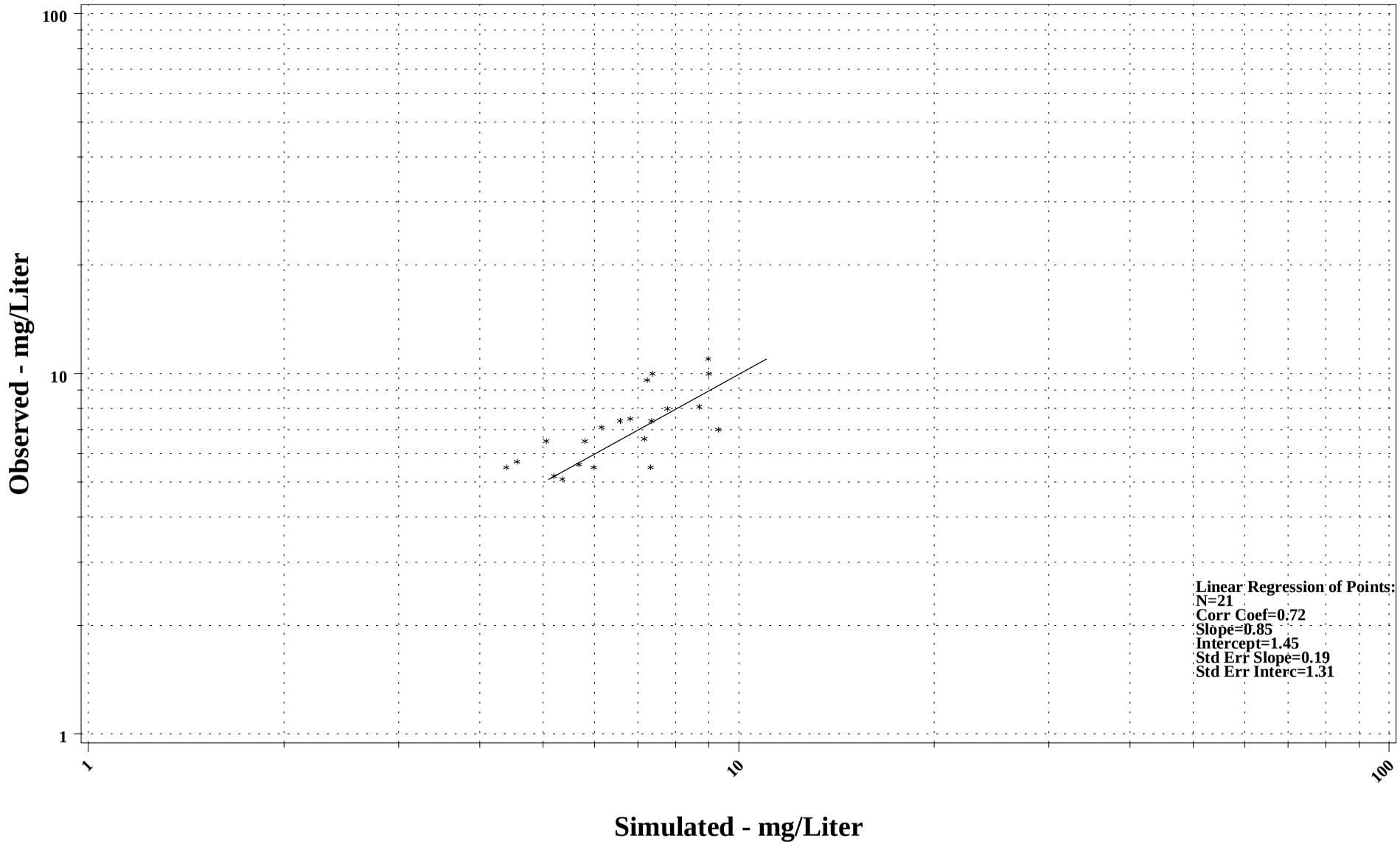


(10SEP02 13:14)
(plot.sas, omtime)

Inland/ Segment 30 - Bundicks Branch: Calibration Run

Scatter Plot and Regression of Simulated versus Observed with Ideal Line

Dissolved Oxygen: 01JAN98 - 01JAN00

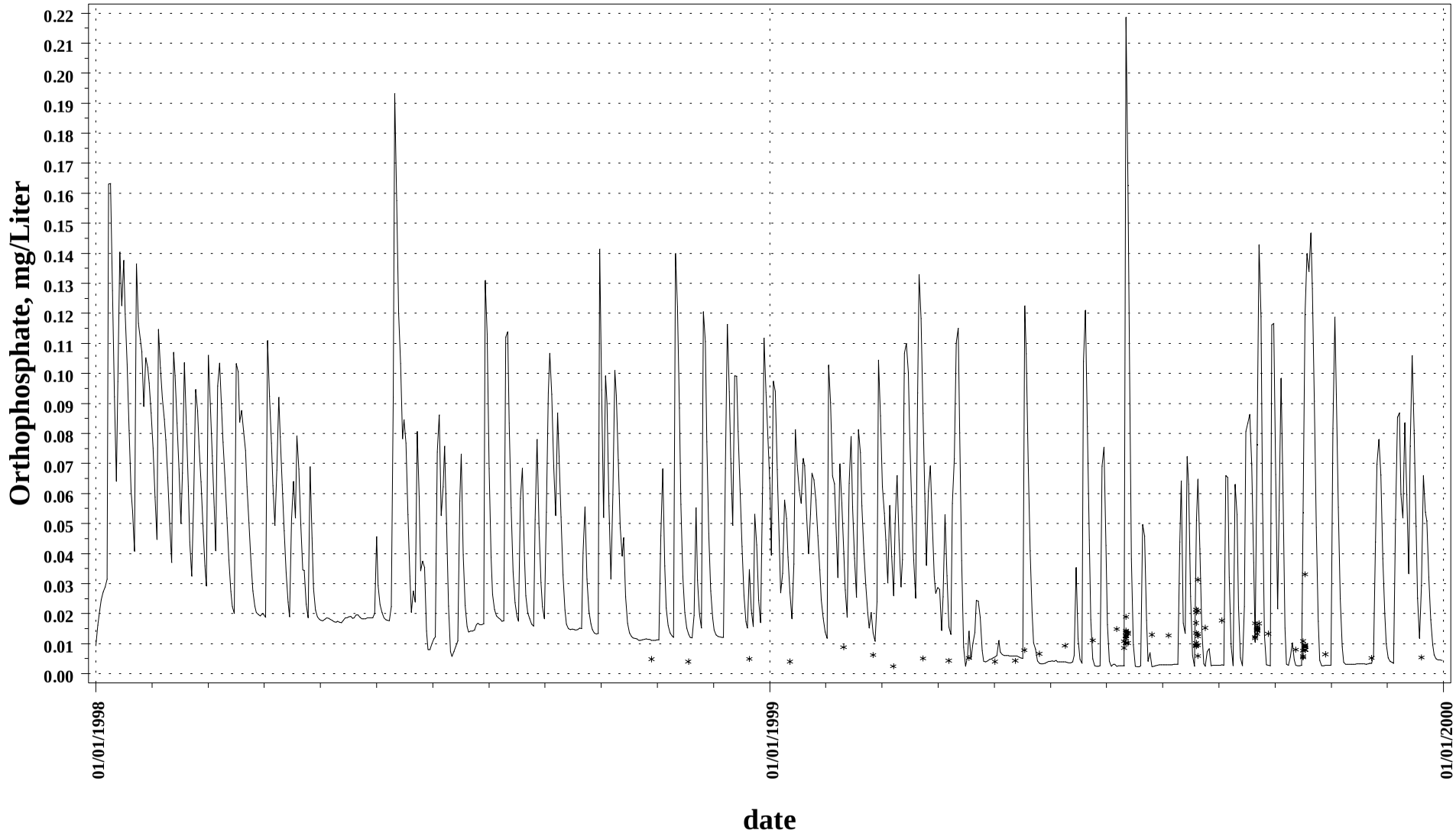


(10SEP02 13:14)
(plot.sas, llomregr.sas)

Inland/ Segment 30 - Bundicks Branch: Calibration Run Orthophosphate

Observed and Simulated versus Time

(* =Observed, - =Simulated)

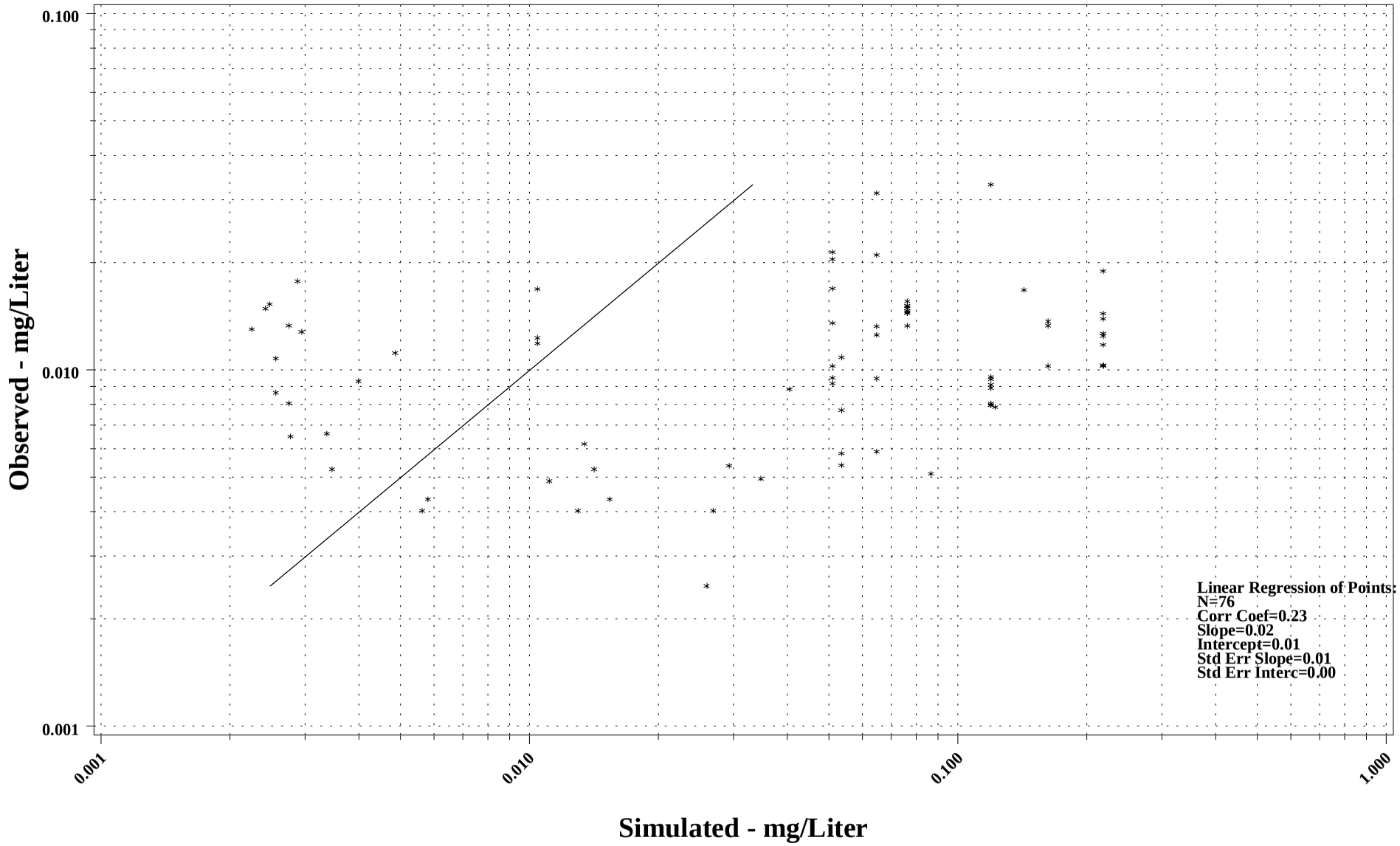


(10SEP02 13:14)
(plot.sas, omtime)

Inland/ Segment 30 - Bundicks Branch: Calibration Run

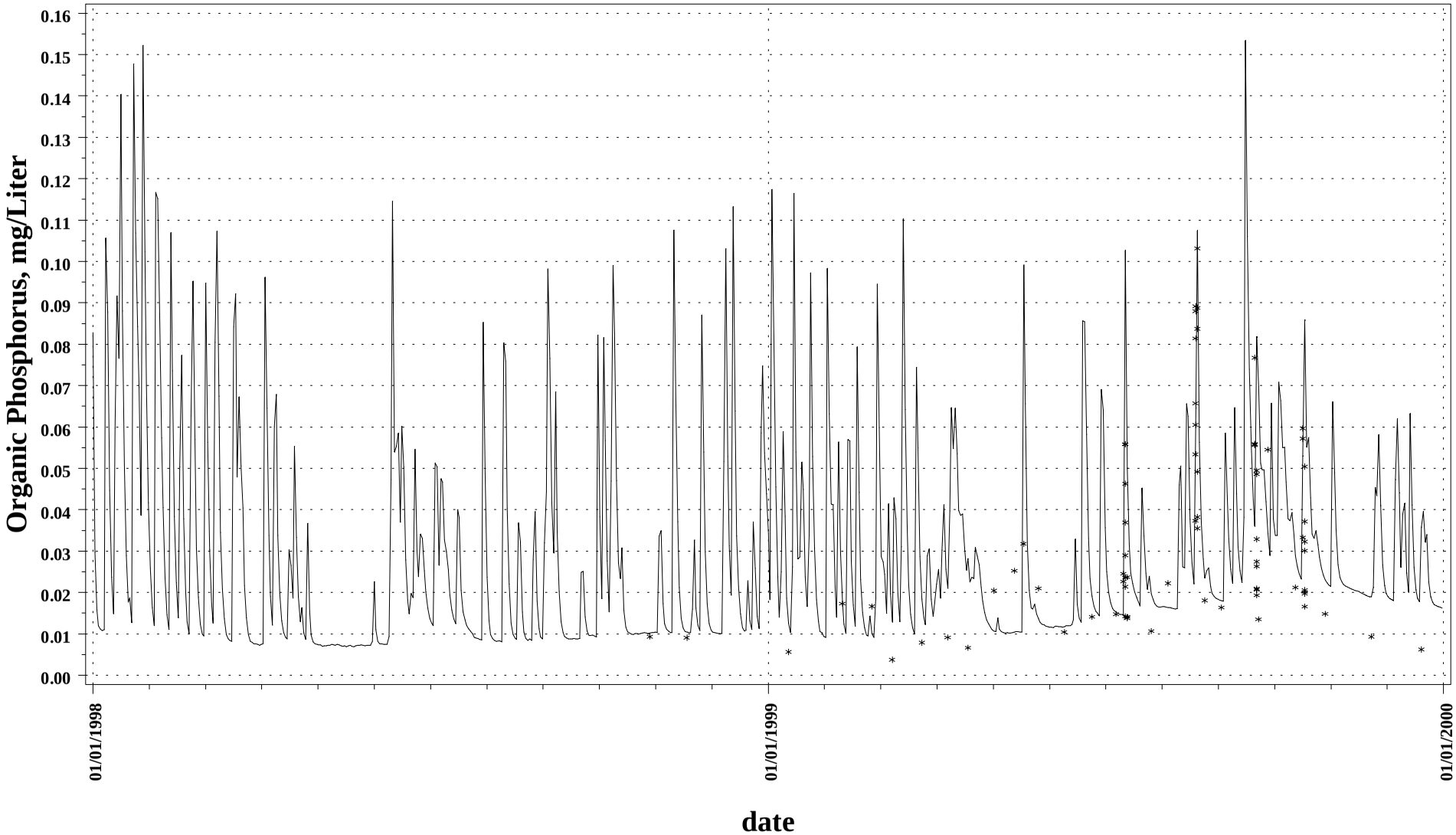
Scatter Plot and Regression of Simulated versus Observed with Ideal Line

Orthophosphate: 01JAN98 - 01JAN00



(10SEP02 13:14)
(plot.sas, llomregr.sas)

Inland/ Segment 30 - Bundicks Branch: Calibration Run
Organic Phosphorus
Observed and Simulated versus Time
(* =Observed, - =Simulated)

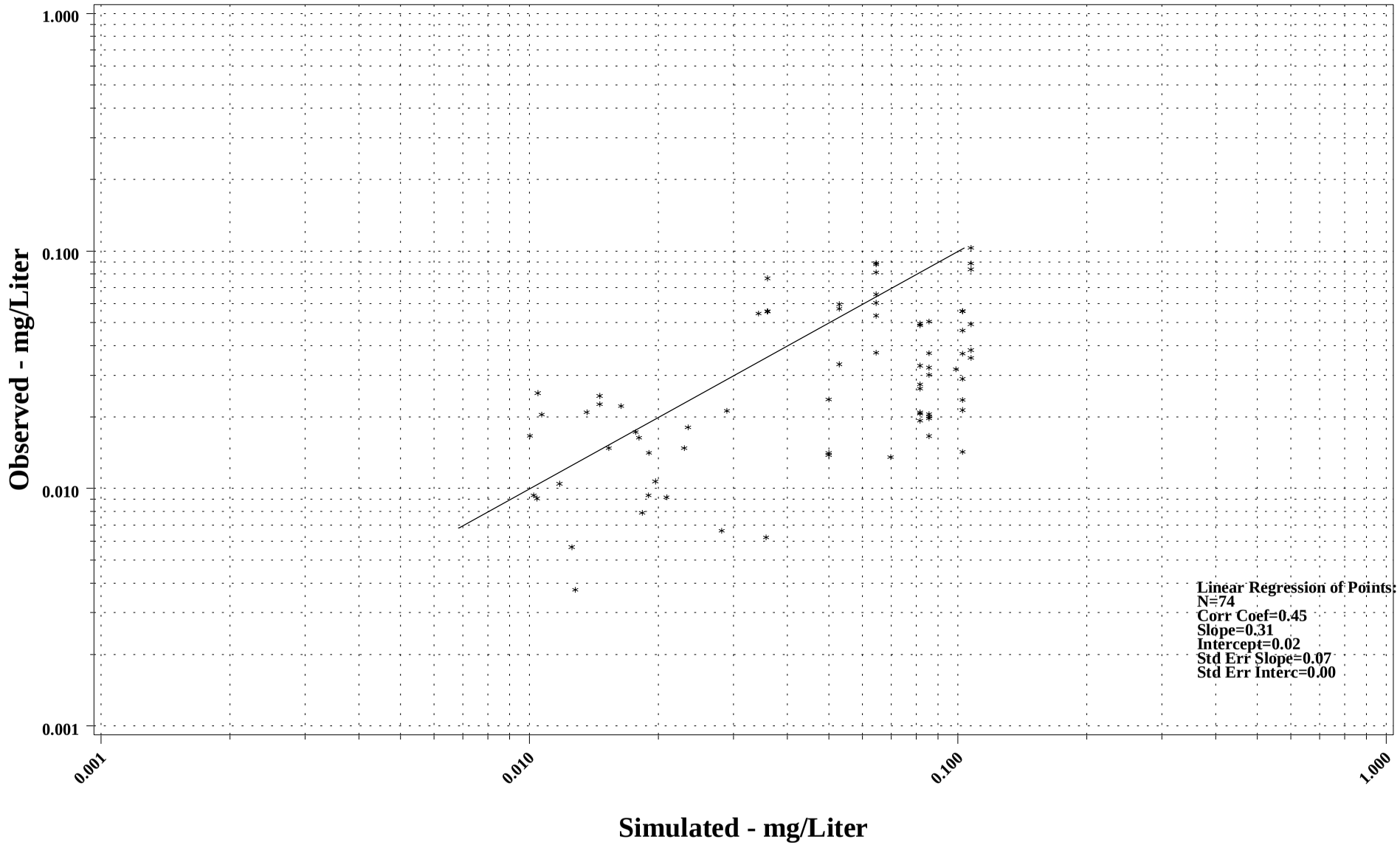


(10SEP02 13:14)
(plot.sas, omtime)

Inland/ Segment 30 - Bundicks Branch: Calibration Run

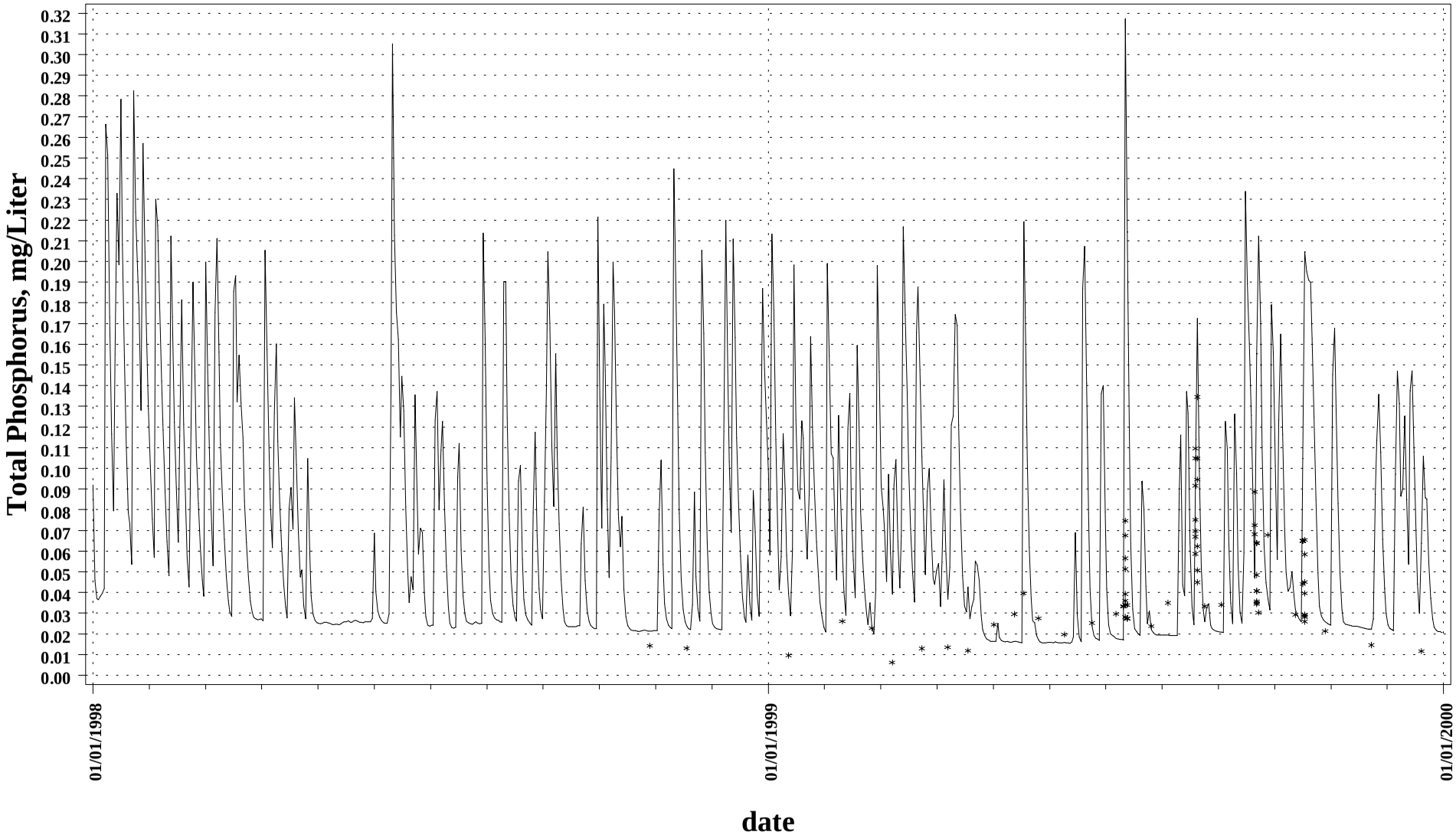
Scatter Plot and Regression of Simulated versus Observed with Ideal Line

Organic Phosphorus: 01JAN98 - 01JAN00



(10SEP02 13:14)
(plot.sas, llomregr.sas)

Inland/ Segment 30 - Bundicks Branch: Calibration Run
Total Phosphorus
Observed and Simulated versus Time
(* =Observed, - =Simulated)

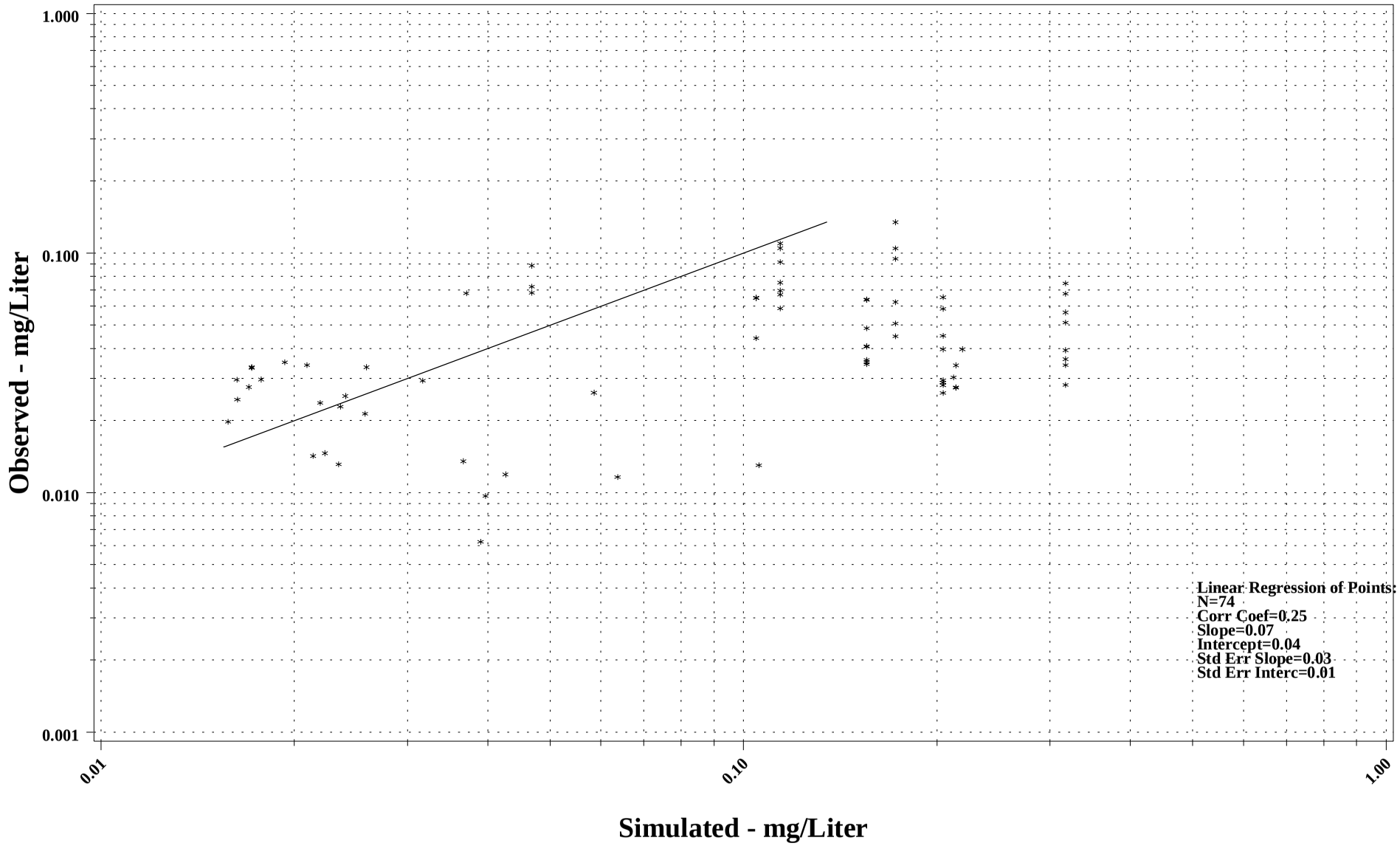


(10SEP02 13:14)
(plot.sas, omtime)

Inland/ Segment 30 - Bundicks Branch: Calibration Run

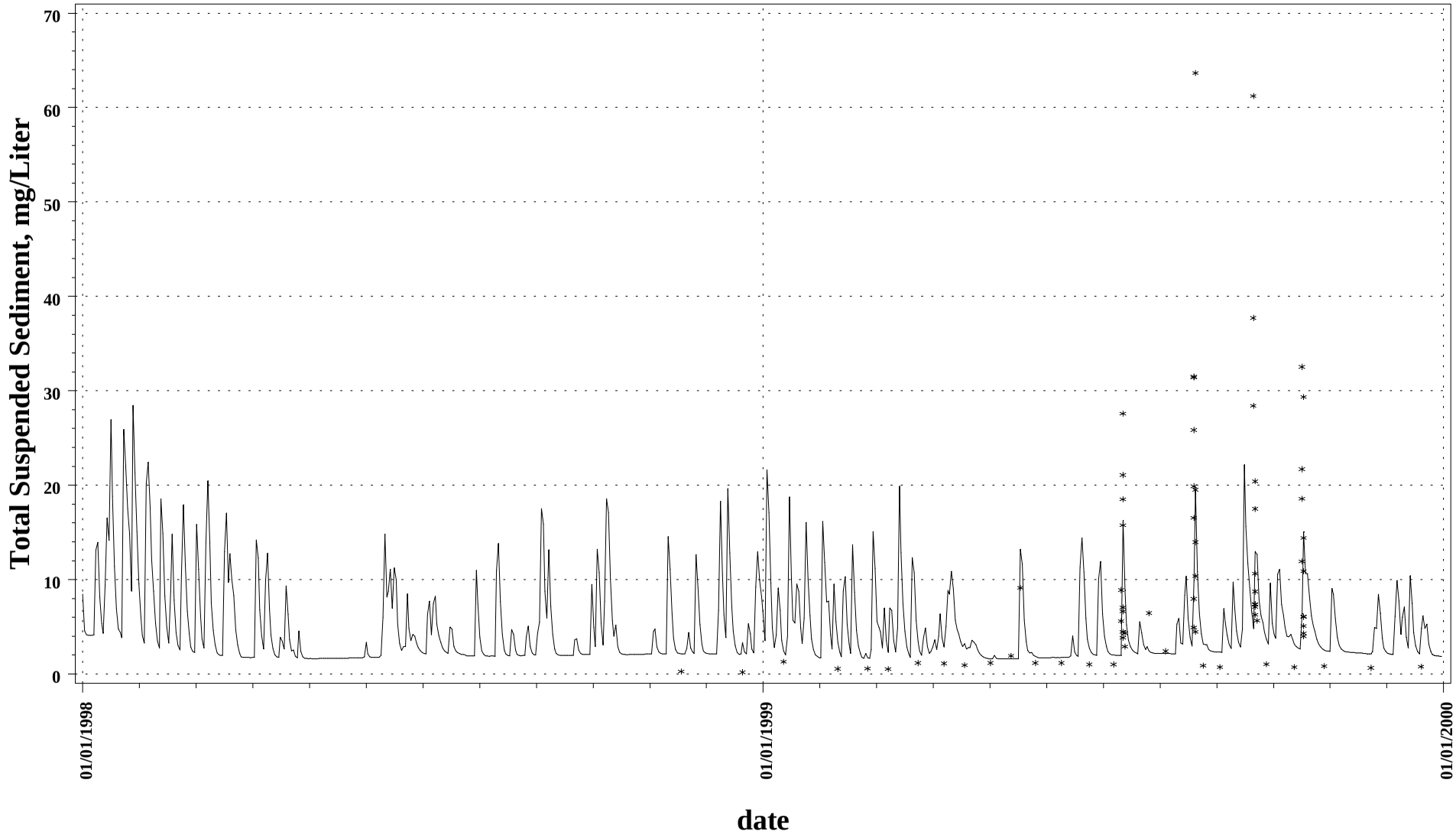
Scatter Plot and Regression of Simulated versus Observed with Ideal Line

Total Phosphorus: 01JAN98 - 01JAN00



(10SEP02 13:14)
(plot.sas, llomregr.sas)

Inland/ Segment 30 - Bundicks Branch: Calibration Run
Total Suspended Sediment
Observed and Simulated versus Time
(* =Observed, - =Simulated)

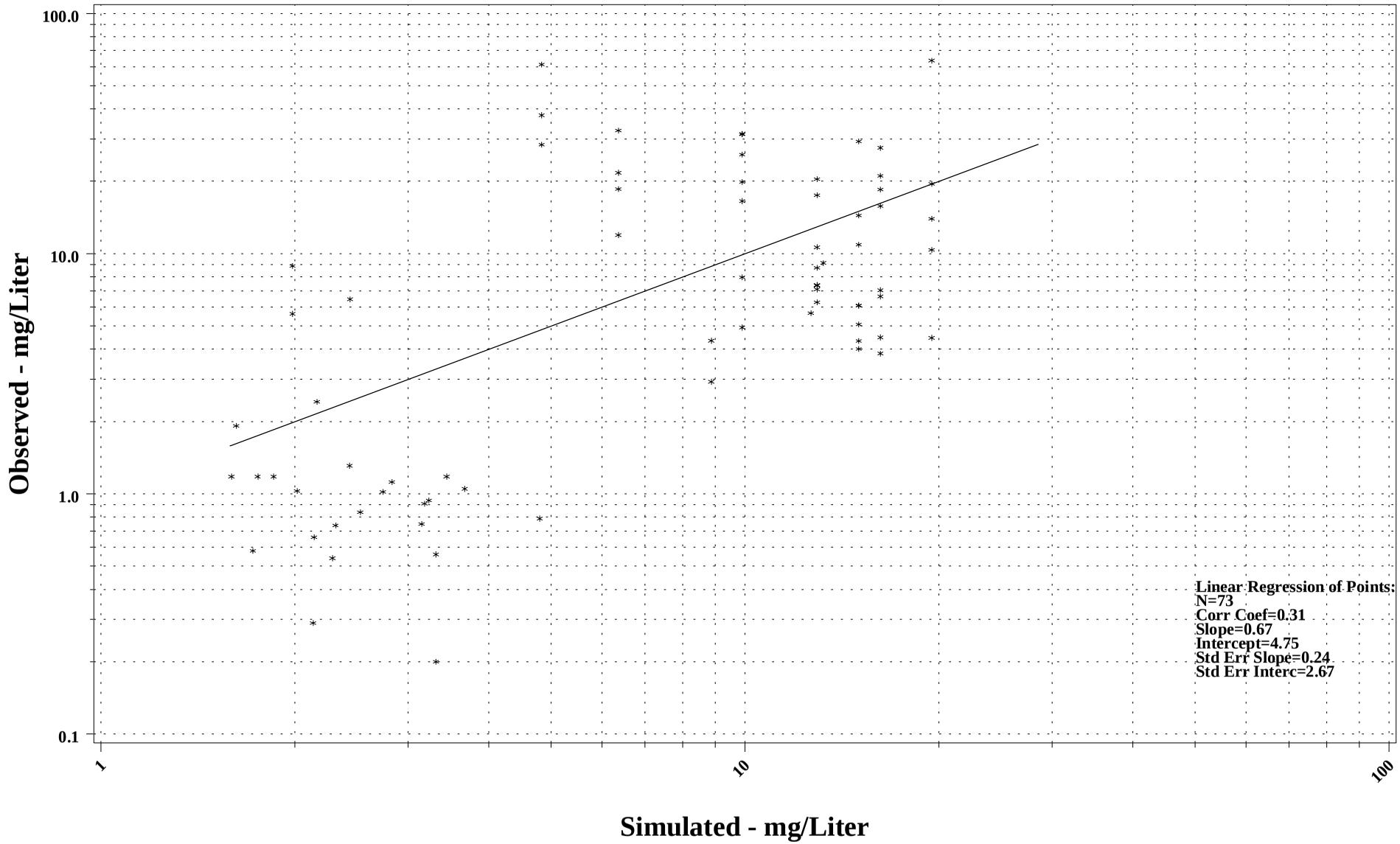


(10SEP02 13:14)
(plot.sas, omtime)

Inland/ Segment 30 - Bundicks Branch: Calibration Run

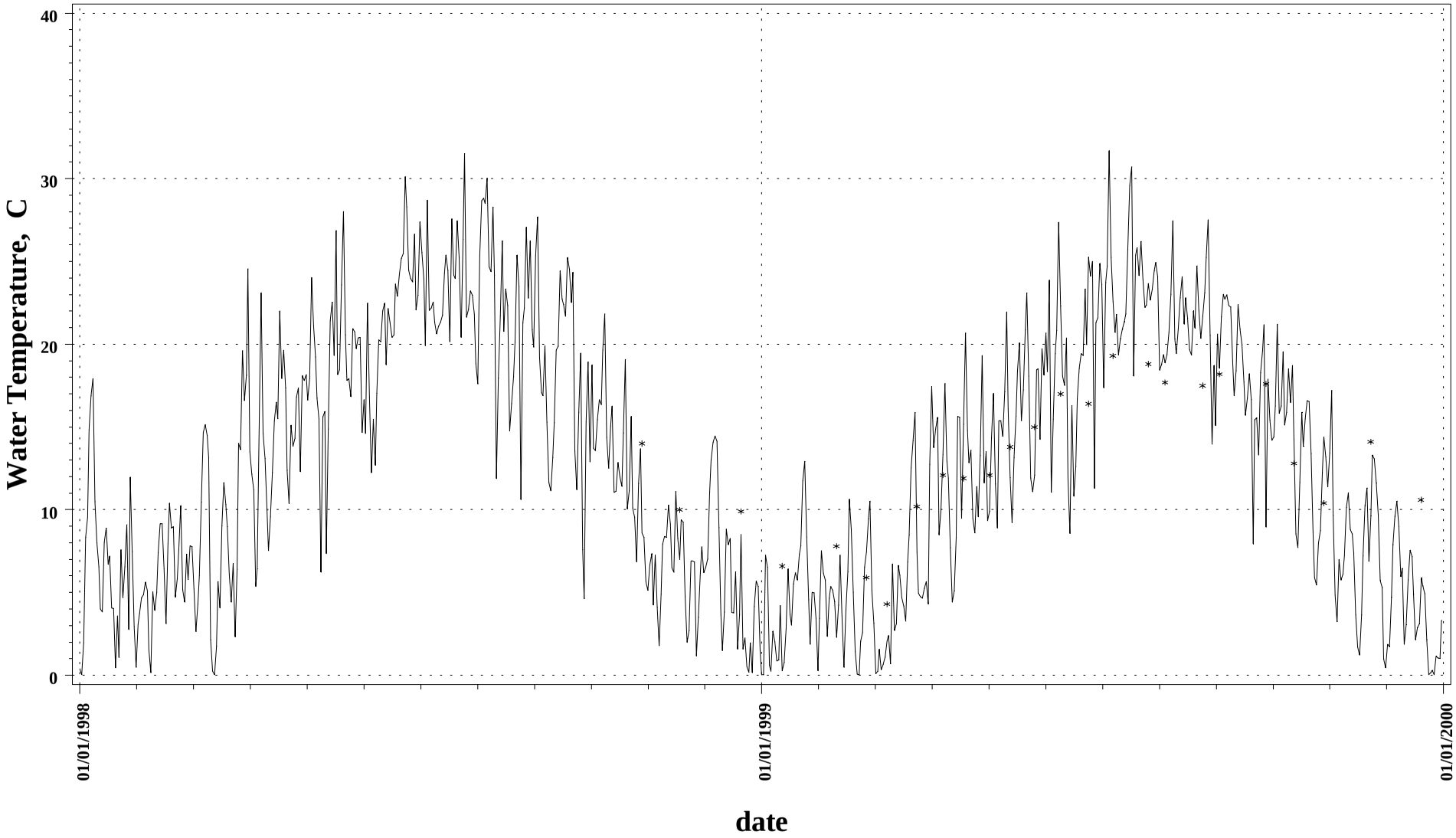
Scatter Plot and Regression of Simulated versus Observed with Ideal Line

Total Suspended Sediment: 01JAN98 - 01JAN00



(10SEP02 13:14)
(plot.sas, llomregr.sas)

Inland/ Segment 30 - Bundicks Branch: Calibration Run
Water Temperature
Observed and Simulated versus Time
(* =Observed, - =Simulated)

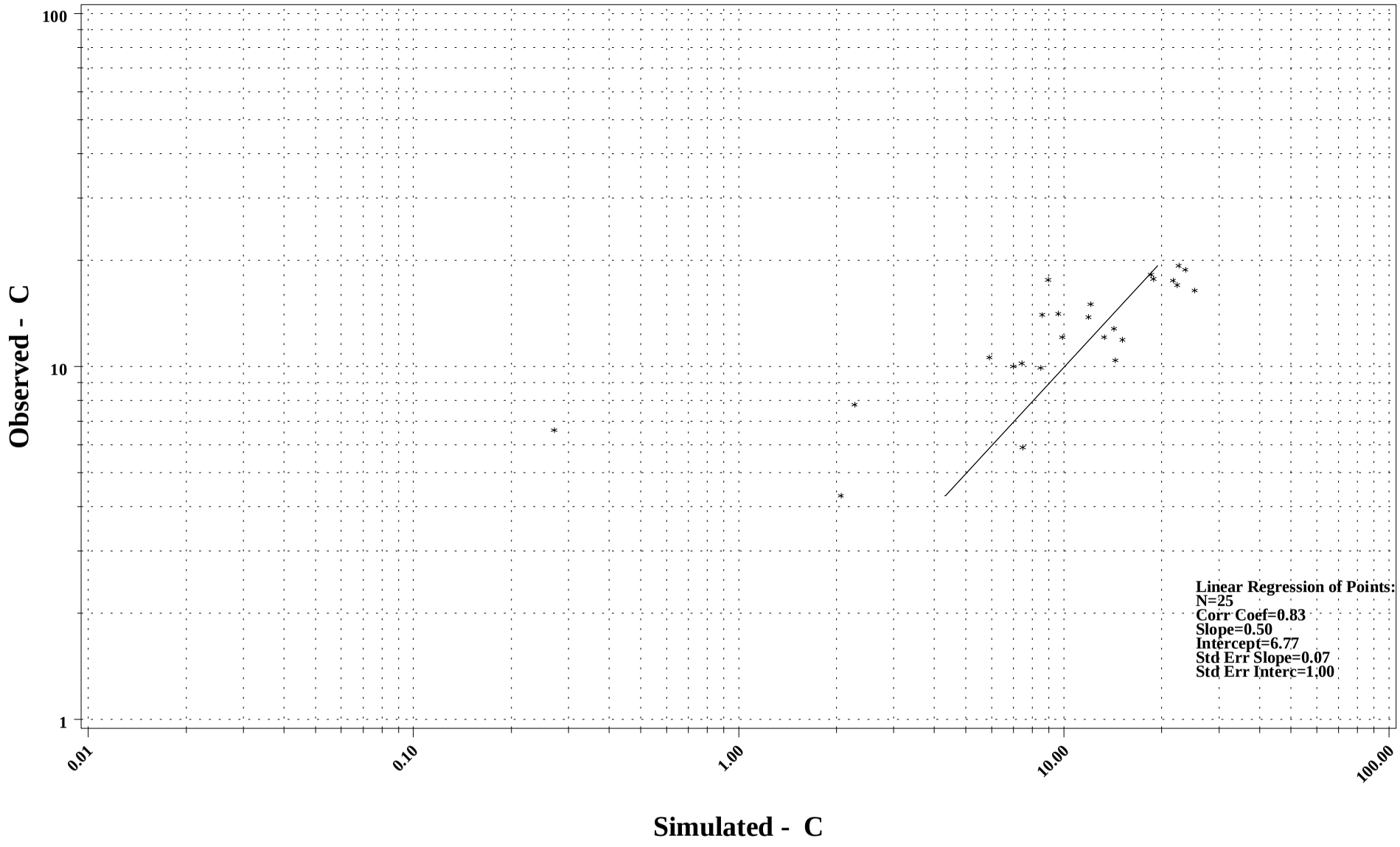


(10SEP02 13:14)
(plot.sas, omtime)

Inland/ Segment 30 - Bundicks Branch: Calibration Run

Scatter Plot and Regression of Simulated versus Observed with Ideal Line

Water Temperature: 01JAN98 - 01JAN00

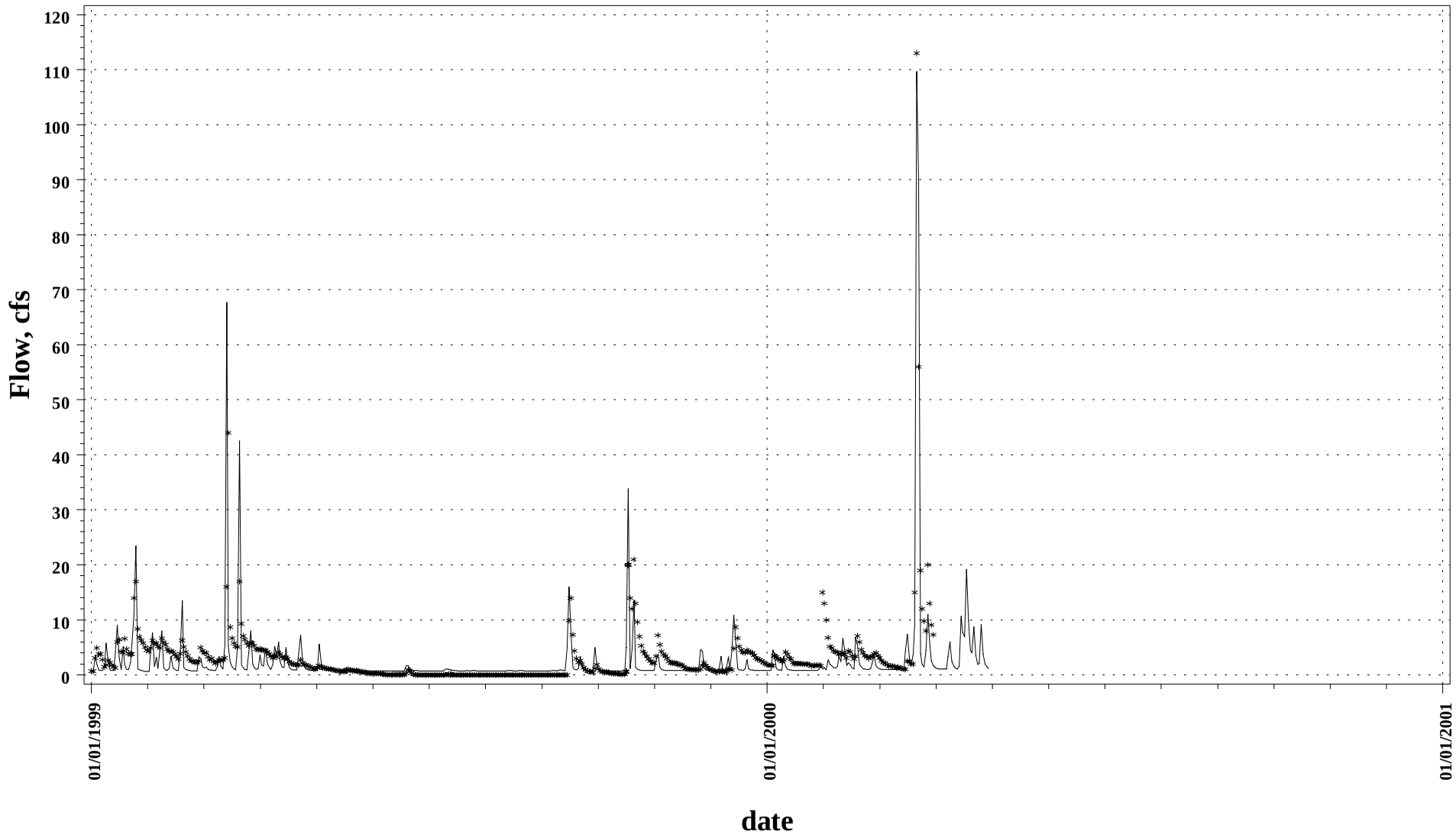


(10SEP02 13:14)
(plot.sas, llomregr.sas)

Inland/ Segment 310 - Blackwater Creek: Calibration Run Flow

Observed and Simulated versus Time

(* =Observed, - =Simulated)

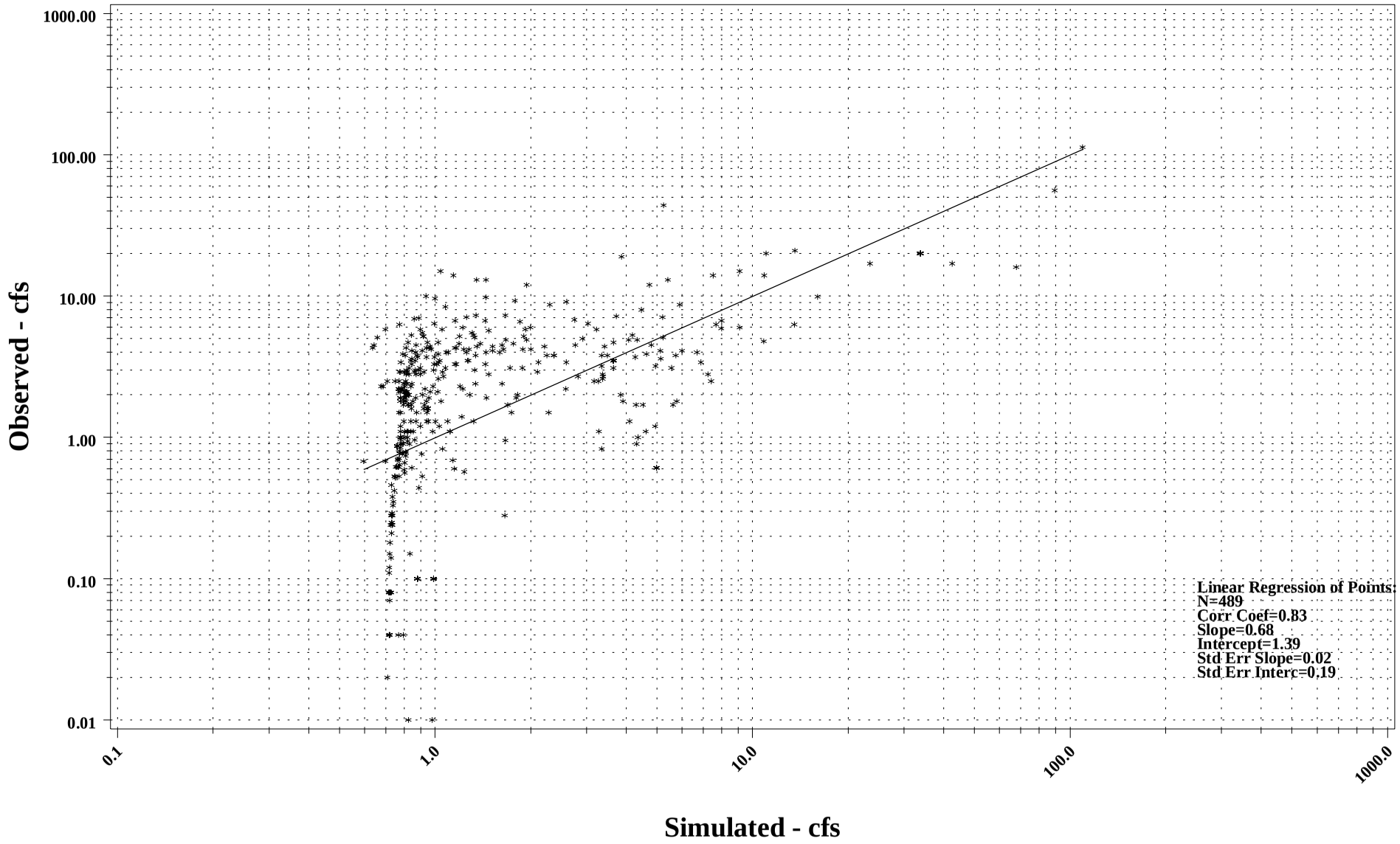


(10SEP02 13:14)
(plot.sas, omtime)

Inland/ Segment 310 - Blackwater Creek: Calibration Run

Scatter Plot and Regression of Simulated versus Observed with Ideal Line

Flow: 01JAN99 - 01JAN01

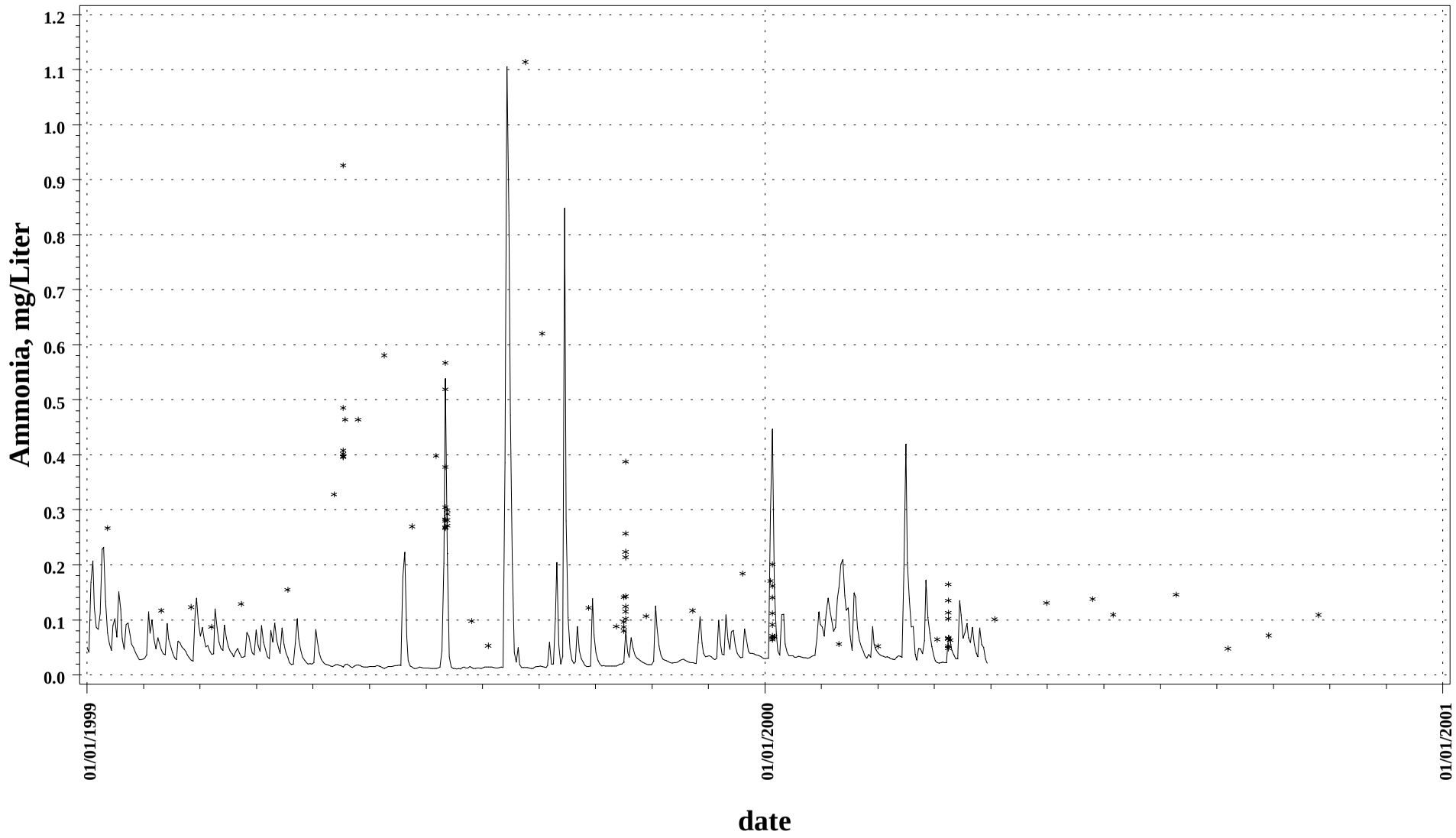


(10SEP02 13:14)
(plot.sas, llomregr.sas)

Inland/ Segment 310 - Blackwater Creek: Calibration Run Ammonia

Observed and Simulated versus Time

(* =Observed, - =Simulated)

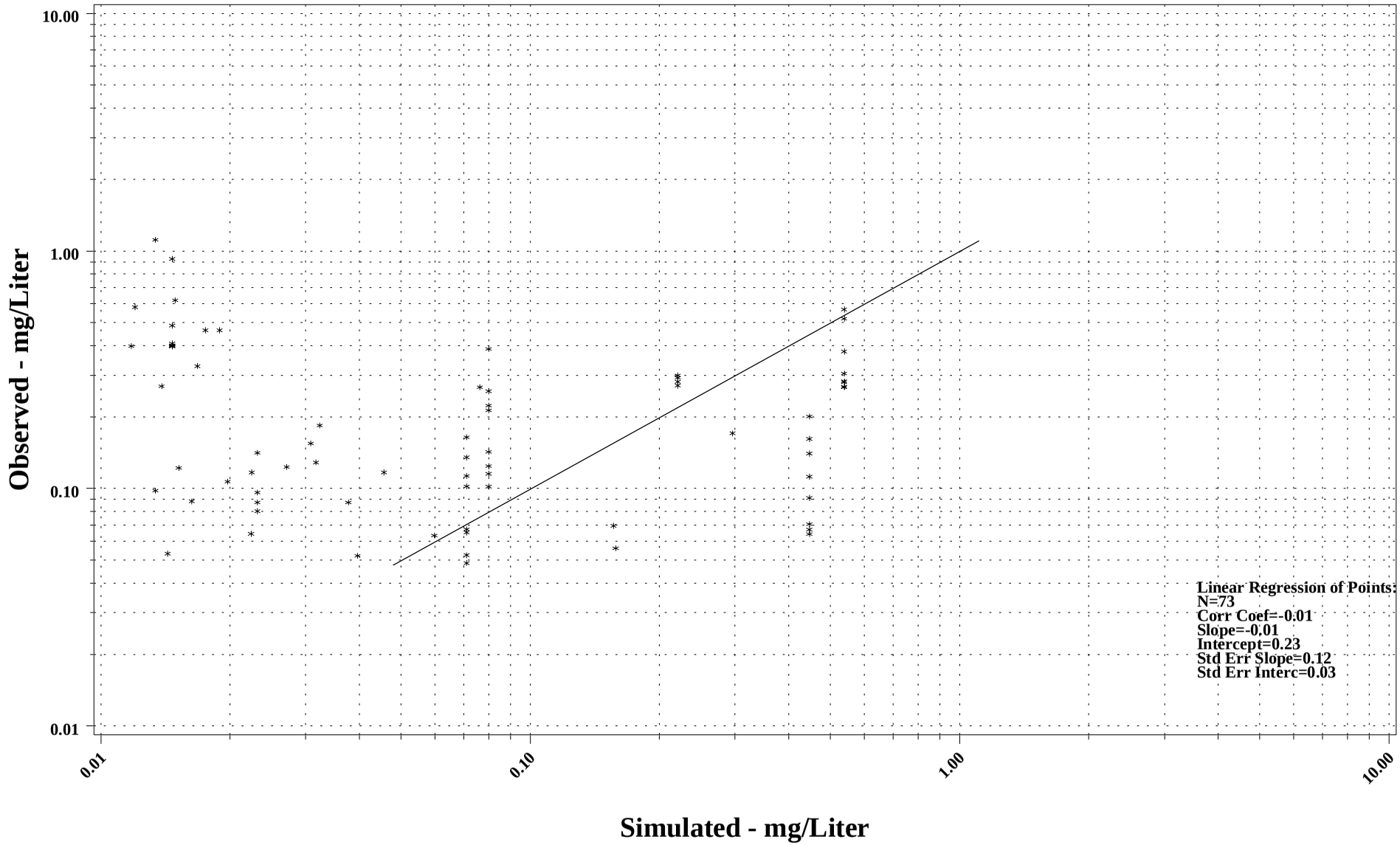


(10SEP02 13:14)
(plot.sas, omtime)

Inland/ Segment 310 - Blackwater Creek: Calibration Run

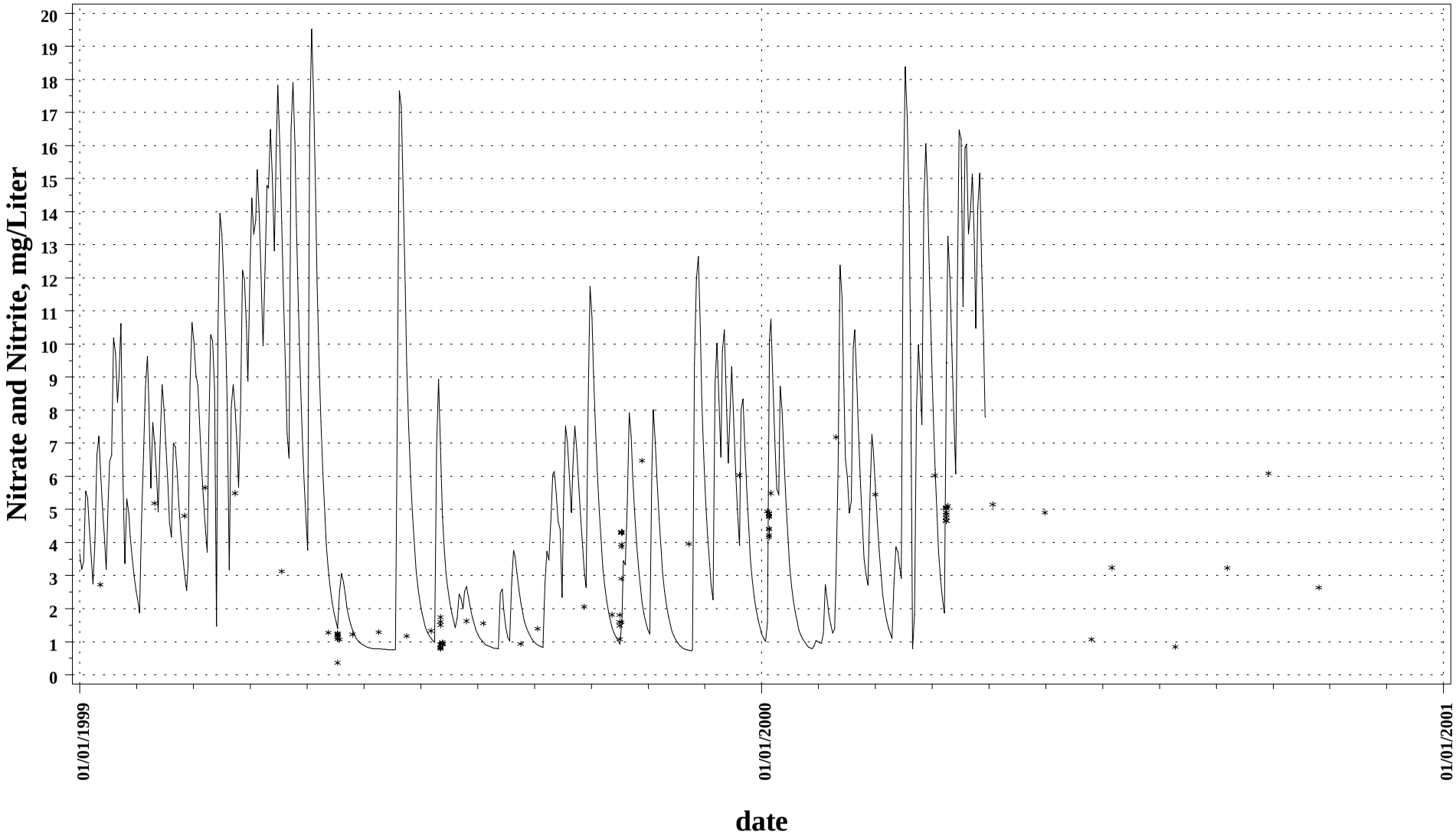
Scatter Plot and Regression of Simulated versus Observed with Ideal Line

Ammonia: 01JAN99 - 01JAN01



(10SEP02 13:14)
(plot.sas, llomregr.sas)

Inland/ Segment 310 - Blackwater Creek: Calibration Run
Nitrate and Nitrite
Observed and Simulated versus Time
(* =Observed, - =Simulated)

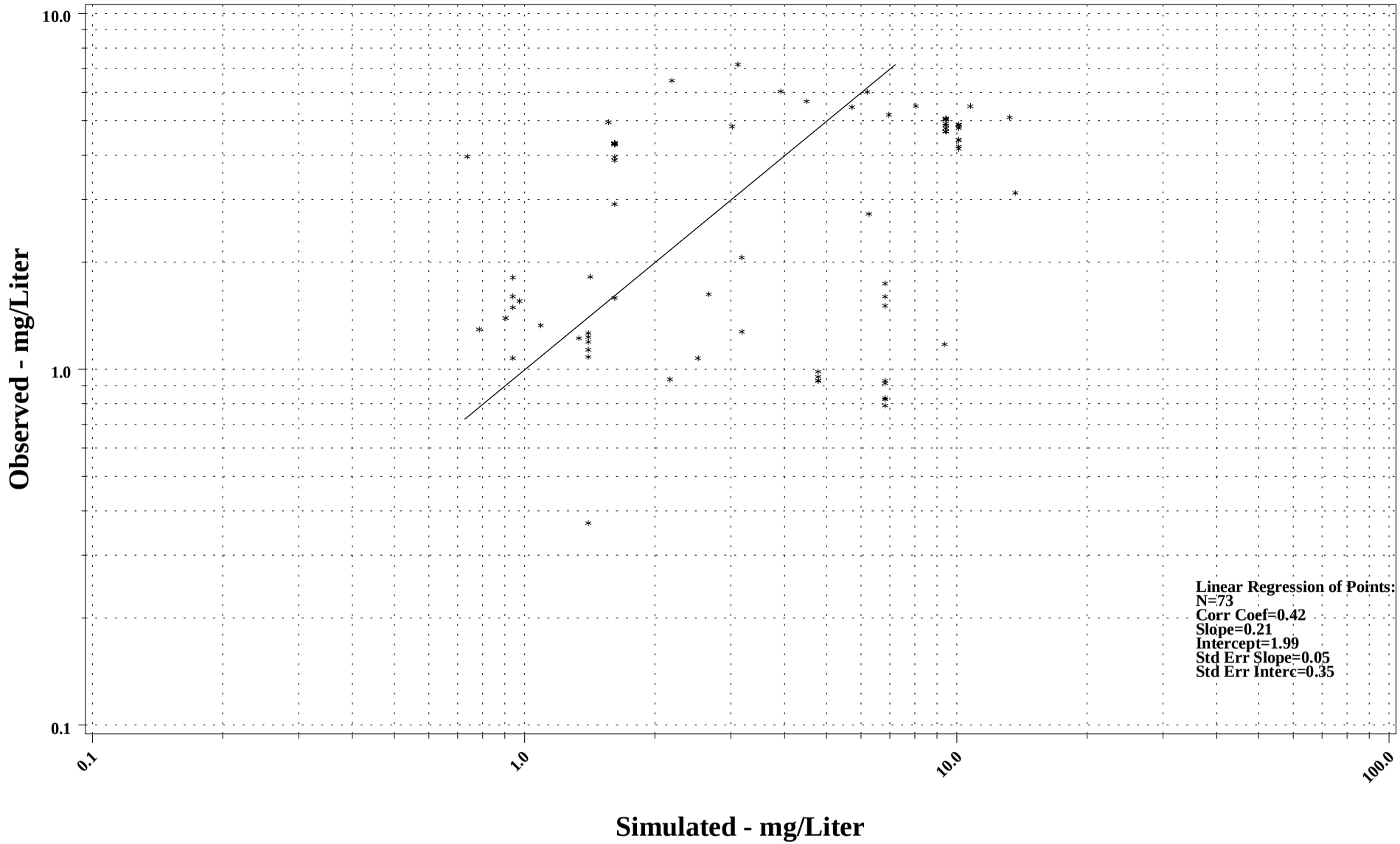


(10SEP02 13:14)
(plot.sas, omtime)

Inland/ Segment 310 - Blackwater Creek: Calibration Run

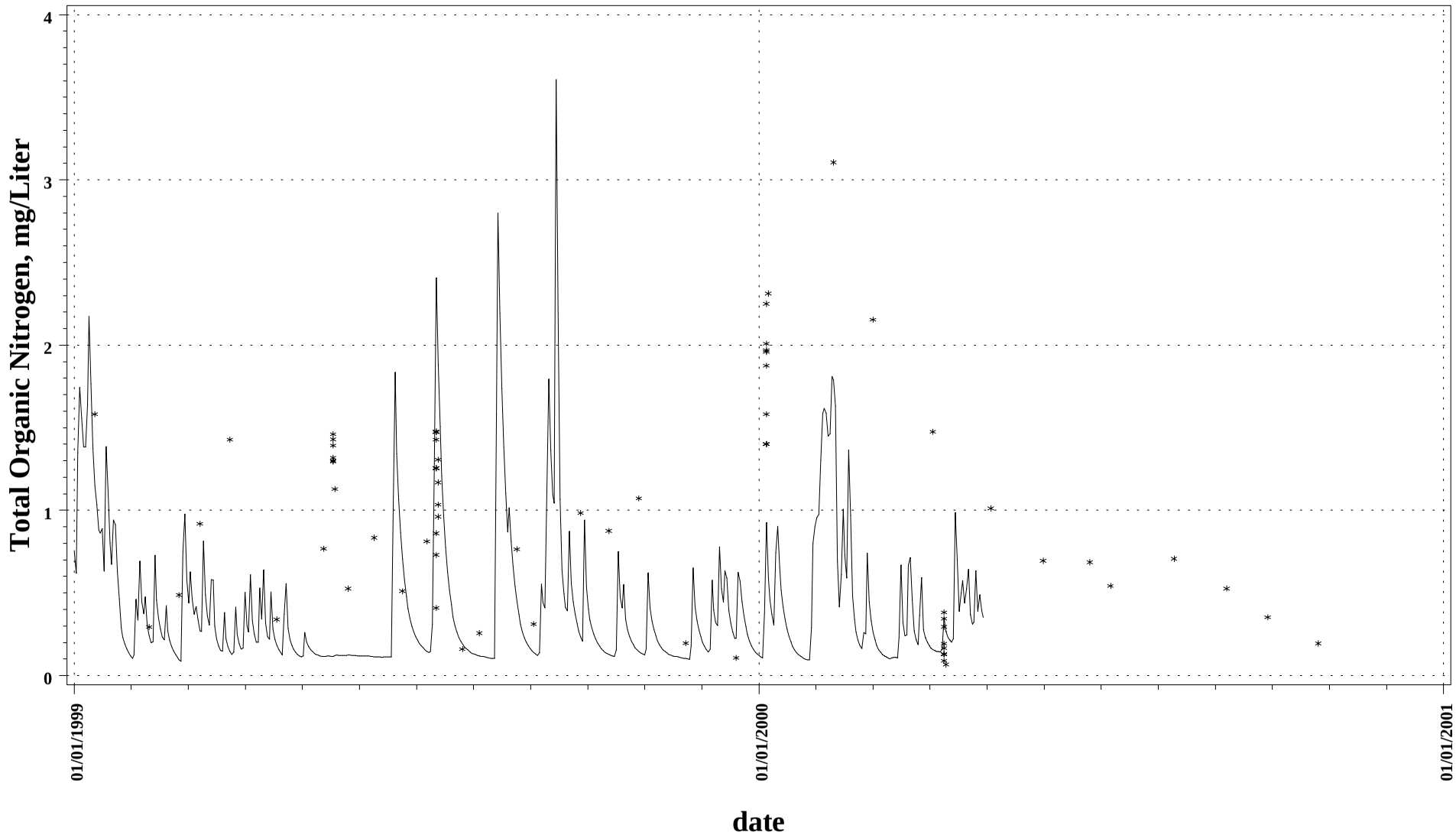
Scatter Plot and Regression of Simulated versus Observed with Ideal Line

Nitrate and Nitrite: 01JAN99 - 01JAN01



(10SEP02 13:14)
(plot.sas, llomregr.sas)

Inland/ Segment 310 - Blackwater Creek: Calibration Run
Total Organic Nitrogen
Observed and Simulated versus Time
(* =Observed, - =Simulated)

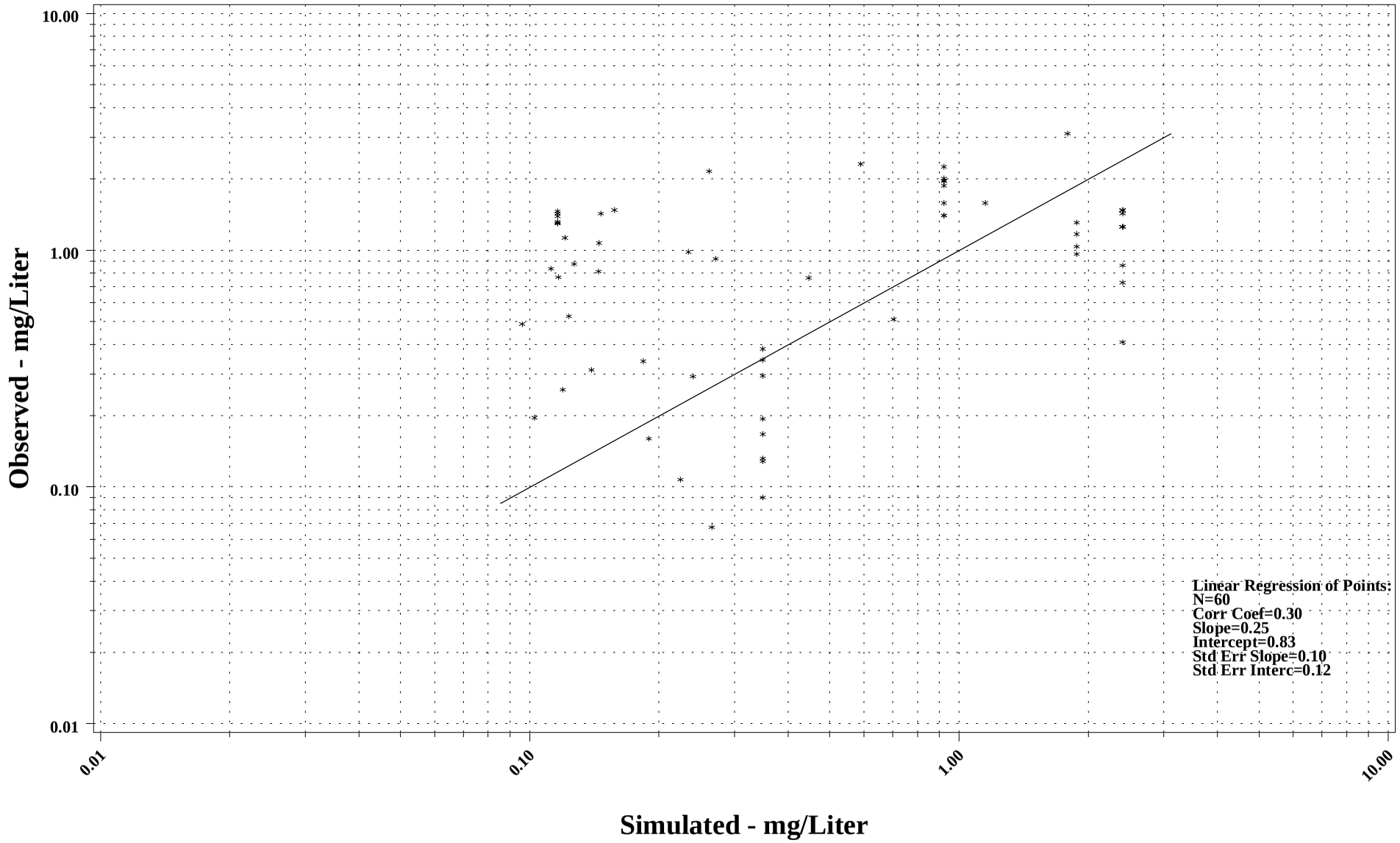


(10SEP02 13:14)
(plot.sas, omtime)

Inland/ Segment 310 - Blackwater Creek: Calibration Run

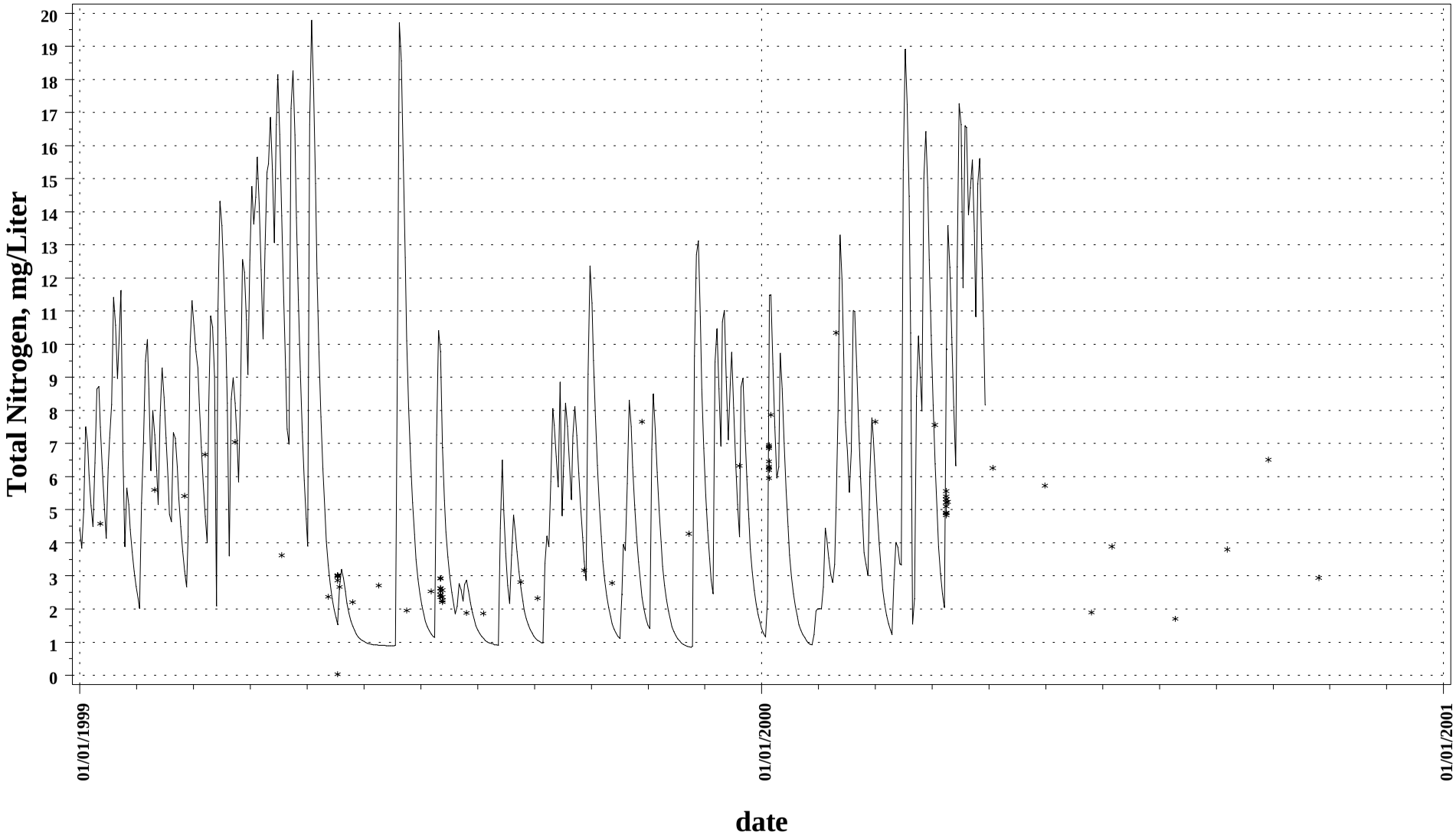
Scatter Plot and Regression of Simulated versus Observed with Ideal Line

Total Organic Nitrogen: 01JAN99 - 01JAN01



(10SEP02 13:14)
(plot.sas, llomregr.sas)

Inland/ Segment 310 - Blackwater Creek: Calibration Run
Total Nitrogen
Observed and Simulated versus Time
(* =Observed, - =Simulated)

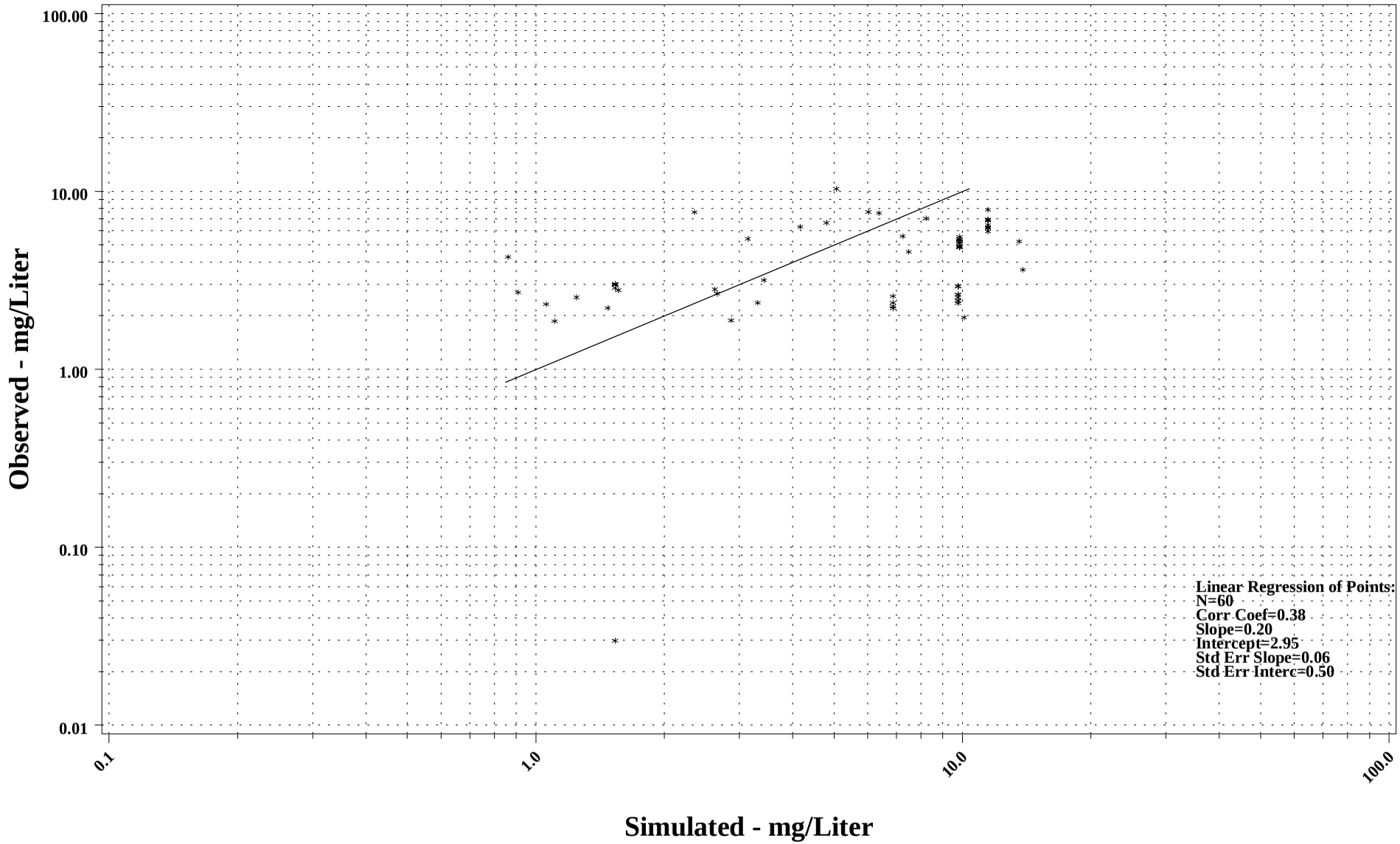


(10SEP02 13:14)
(plot.sas, omtime)

Inland/ Segment 310 - Blackwater Creek: Calibration Run

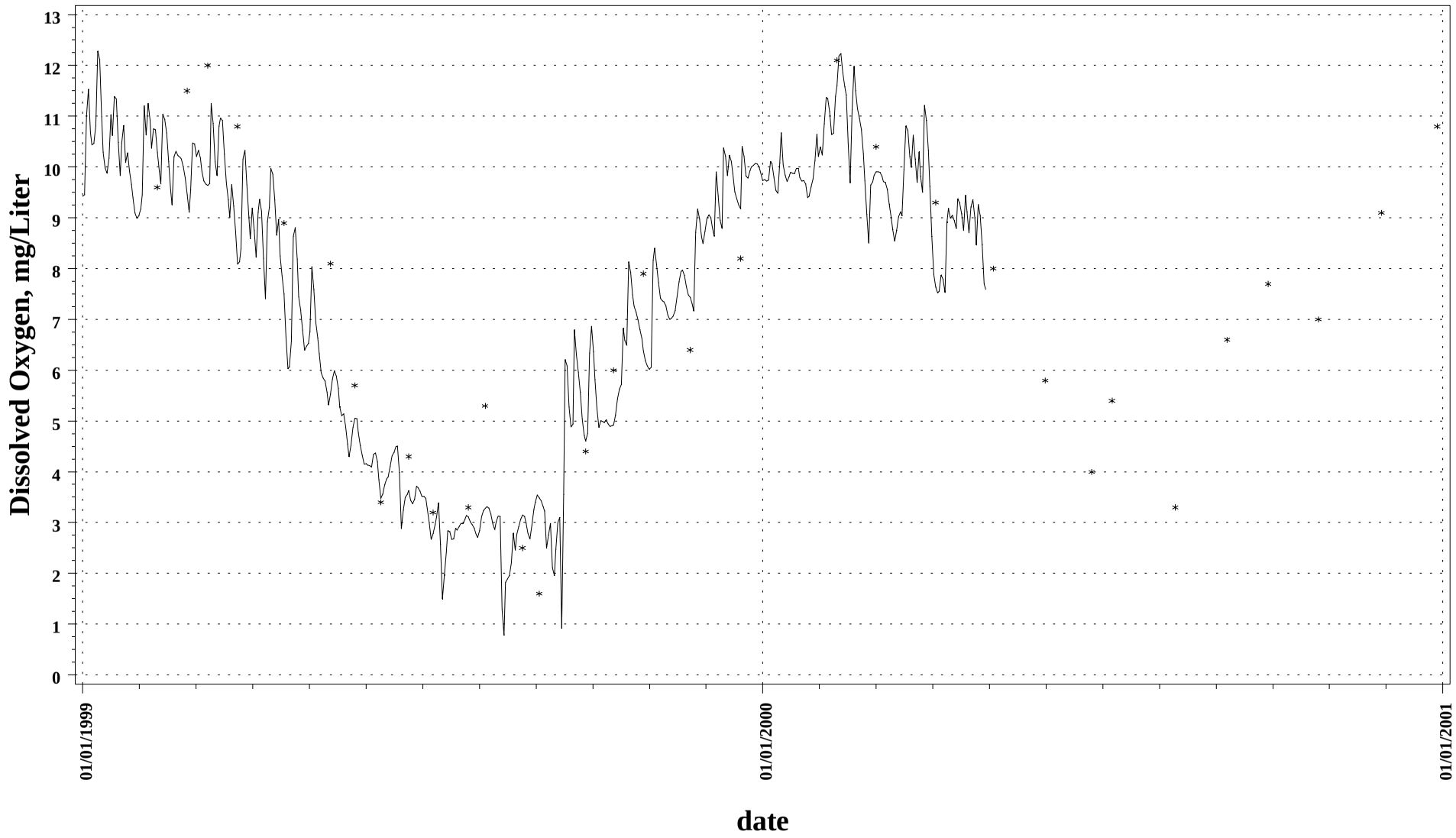
Scatter Plot and Regression of Simulated versus Observed with Ideal Line

Total Nitrogen: 01JAN99 - 01JAN01



(10SEP02 13:14)
(plot.sas, llomregr.sas)

Inland/ Segment 310 - Blackwater Creek: Calibration Run
Dissolved Oxygen
Observed and Simulated versus Time
(* =Observed, - =Simulated)

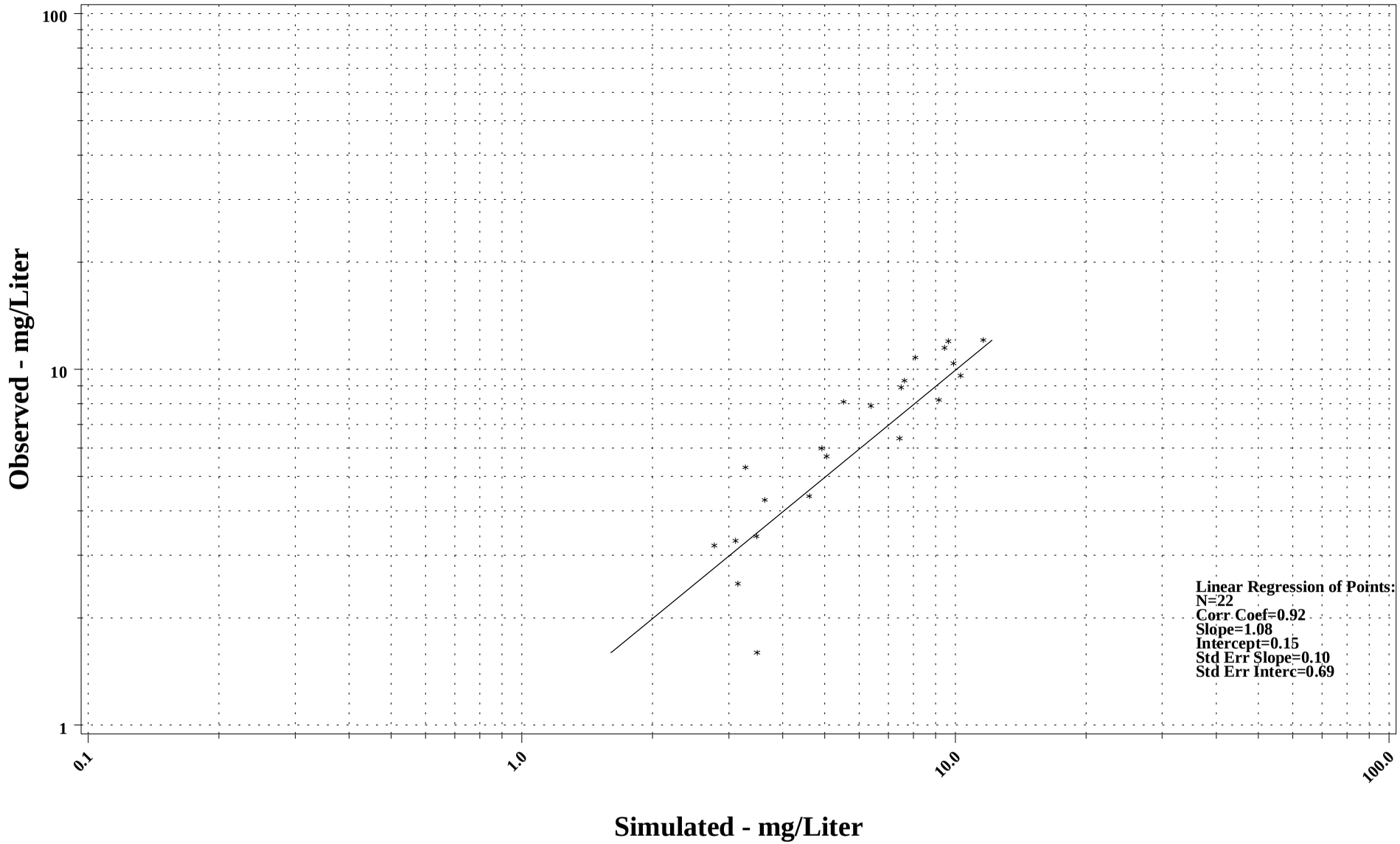


(10SEP02 13:14)
(plot.sas, omtime)

Inland/ Segment 310 - Blackwater Creek: Calibration Run

Scatter Plot and Regression of Simulated versus Observed with Ideal Line

Dissolved Oxygen: 01JAN99 - 01JAN01

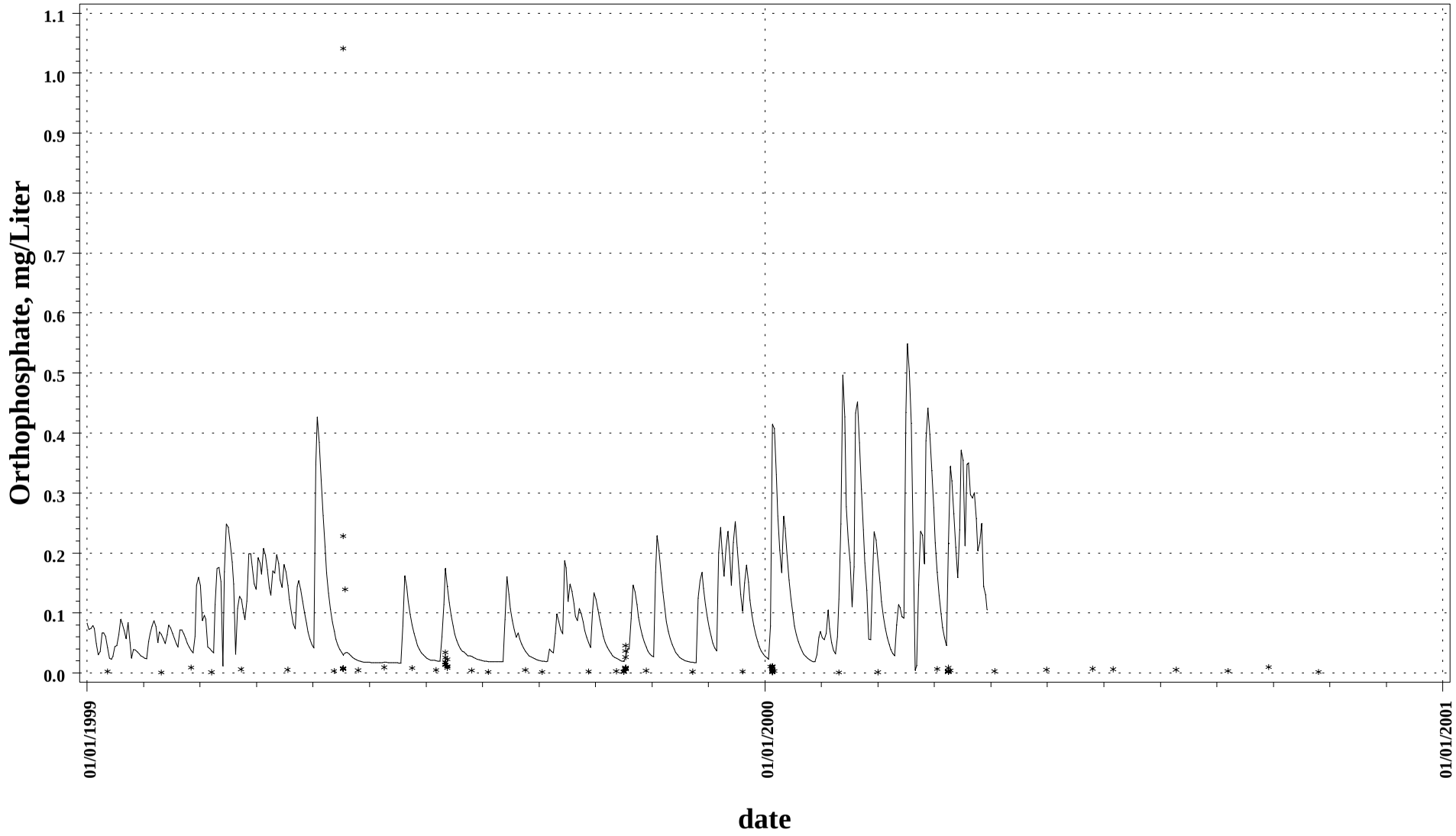


(10SEP02 13:14)
(plot.sas, llomregr.sas)

Inland/ Segment 310 - Blackwater Creek: Calibration Run Orthophosphate

Observed and Simulated versus Time

(* =Observed, - =Simulated)

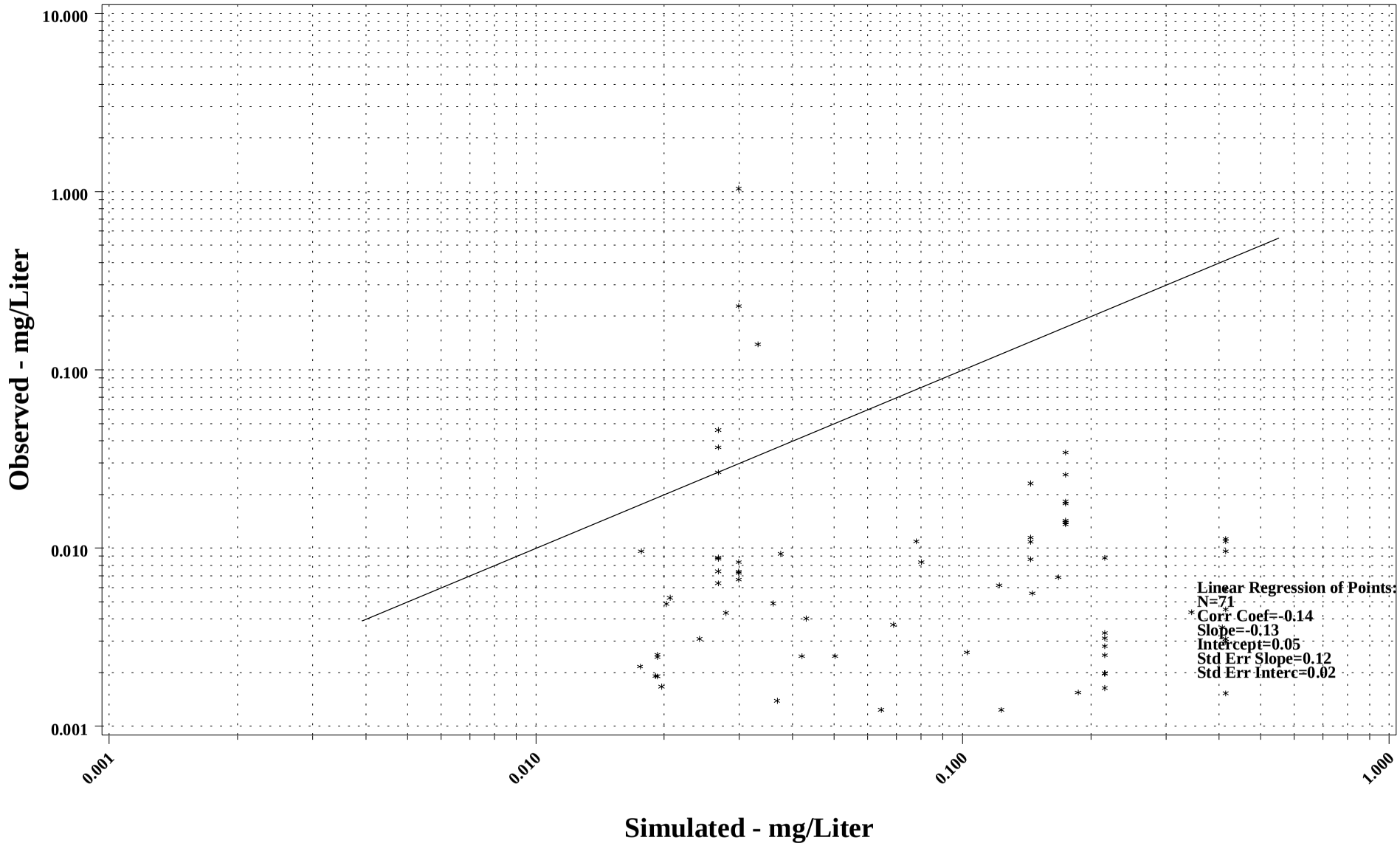


(10SEP02 13:14)
(plot.sas, omtime)

Inland/ Segment 310 - Blackwater Creek: Calibration Run

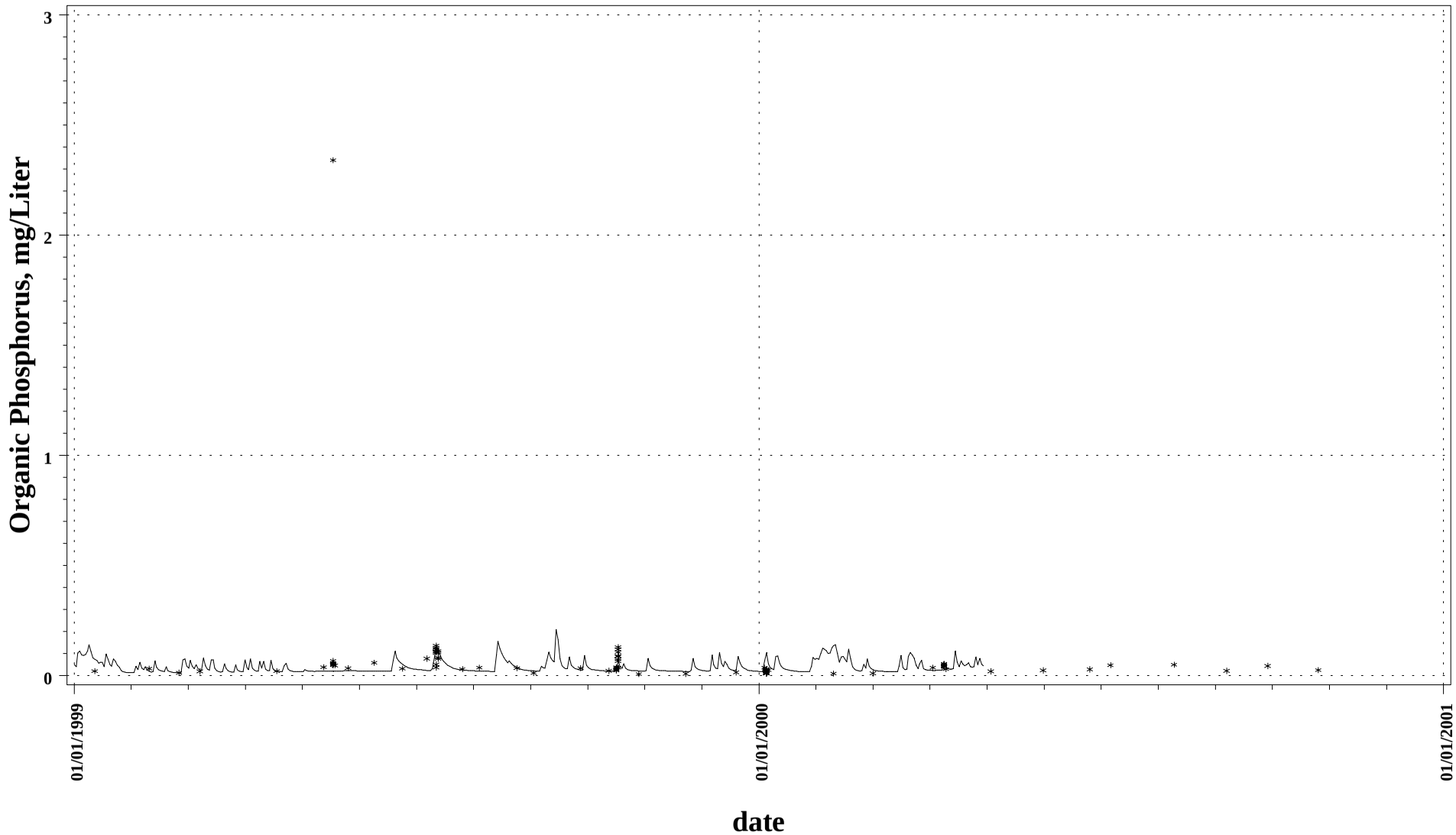
Scatter Plot and Regression of Simulated versus Observed with Ideal Line

Orthophosphate: 01JAN99 - 01JAN01



(10SEP02 13:14)
(plot.sas, llomregr.sas)

Inland/ Segment 310 - Blackwater Creek: Calibration Run
Organic Phosphorus
Observed and Simulated versus Time
(* =Observed, - =Simulated)

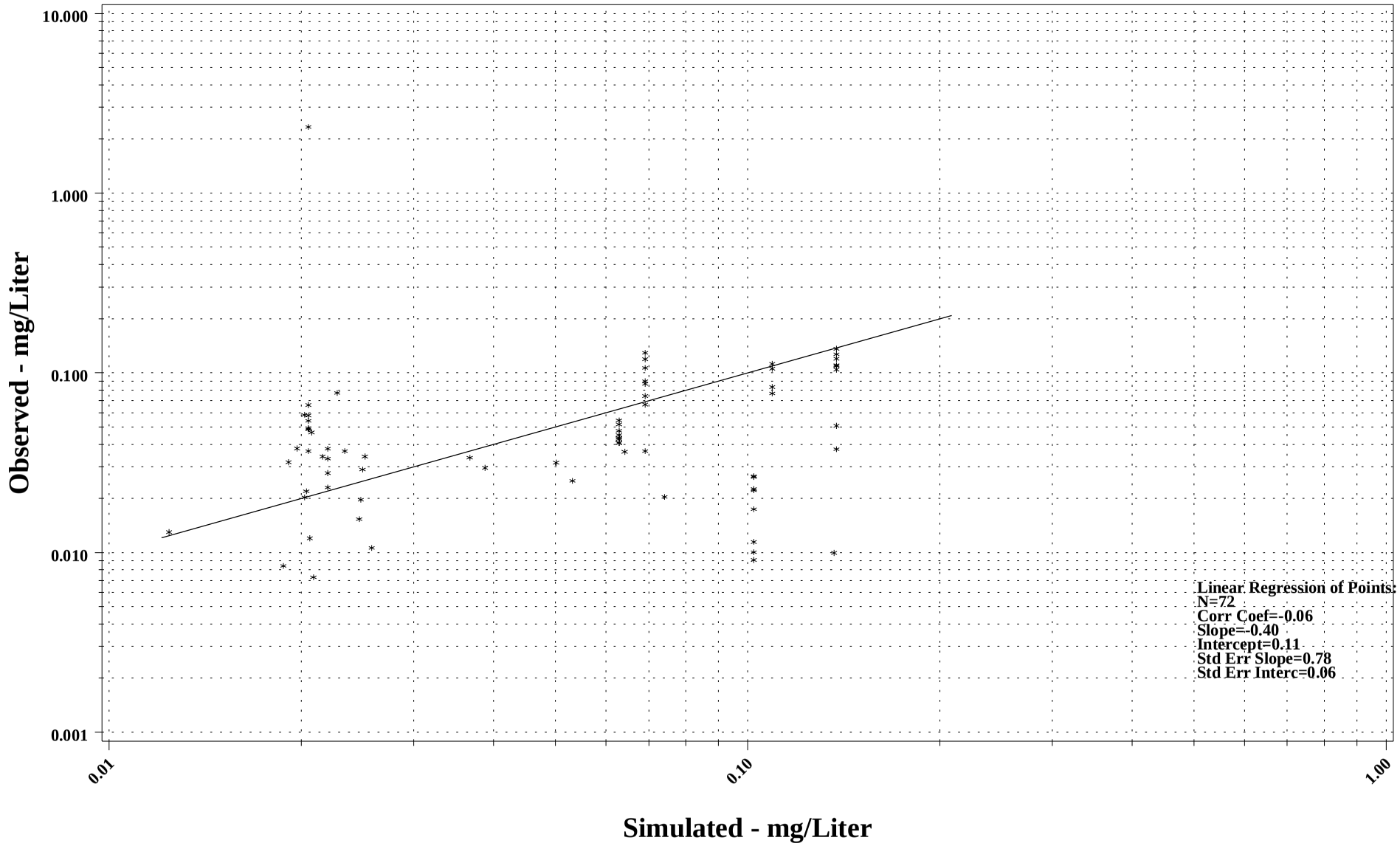


(10SEP02 13:14)
(plot.sas, omtime)

Inland/ Segment 310 - Blackwater Creek: Calibration Run

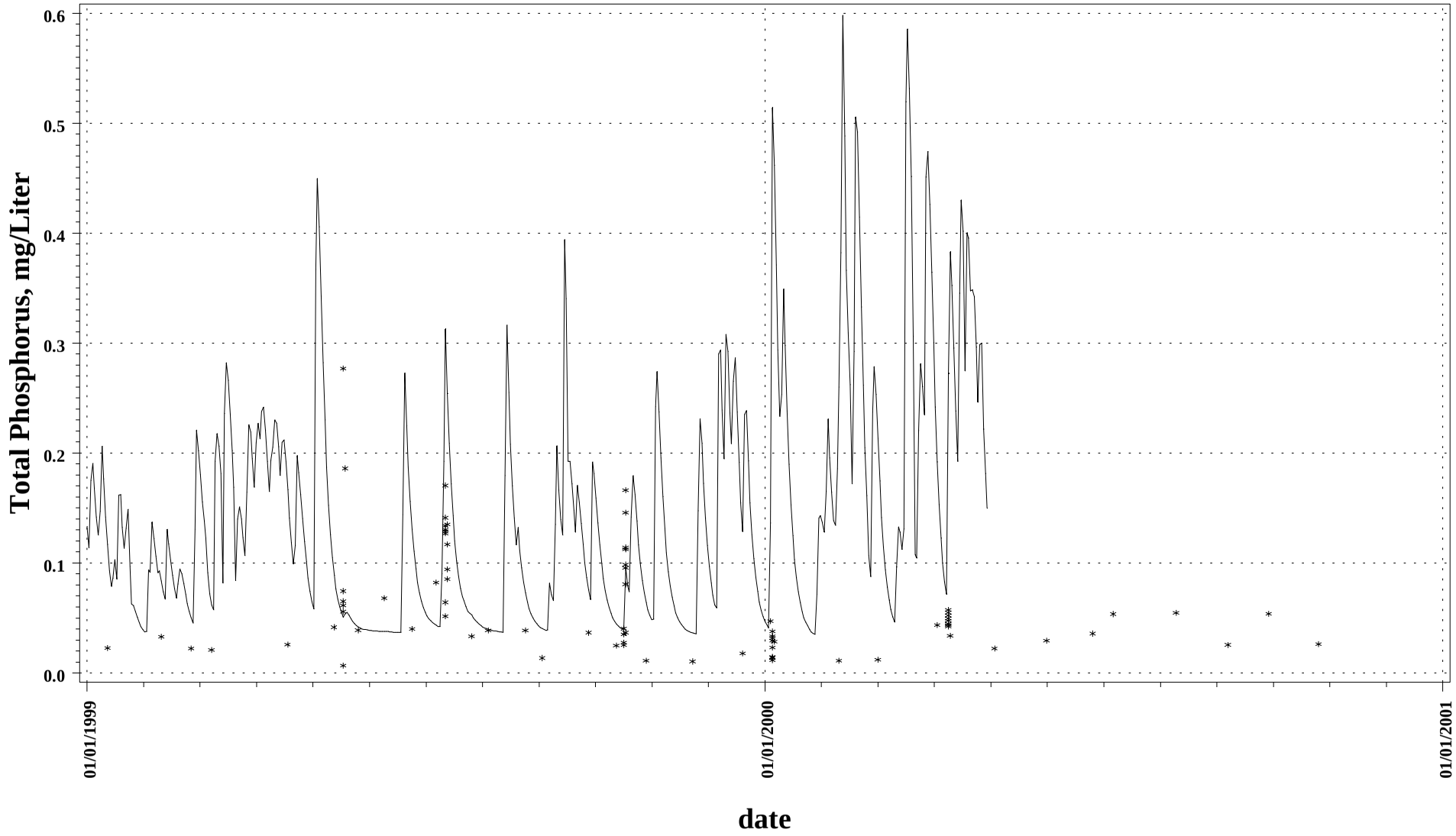
Scatter Plot and Regression of Simulated versus Observed with Ideal Line

Organic Phosphorus: 01JAN99 - 01JAN01



(10SEP02 13:14)
(plot.sas, llomregr.sas)

Inland/ Segment 310 - Blackwater Creek: Calibration Run
Total Phosphorus
Observed and Simulated versus Time
(* =Observed, - =Simulated)

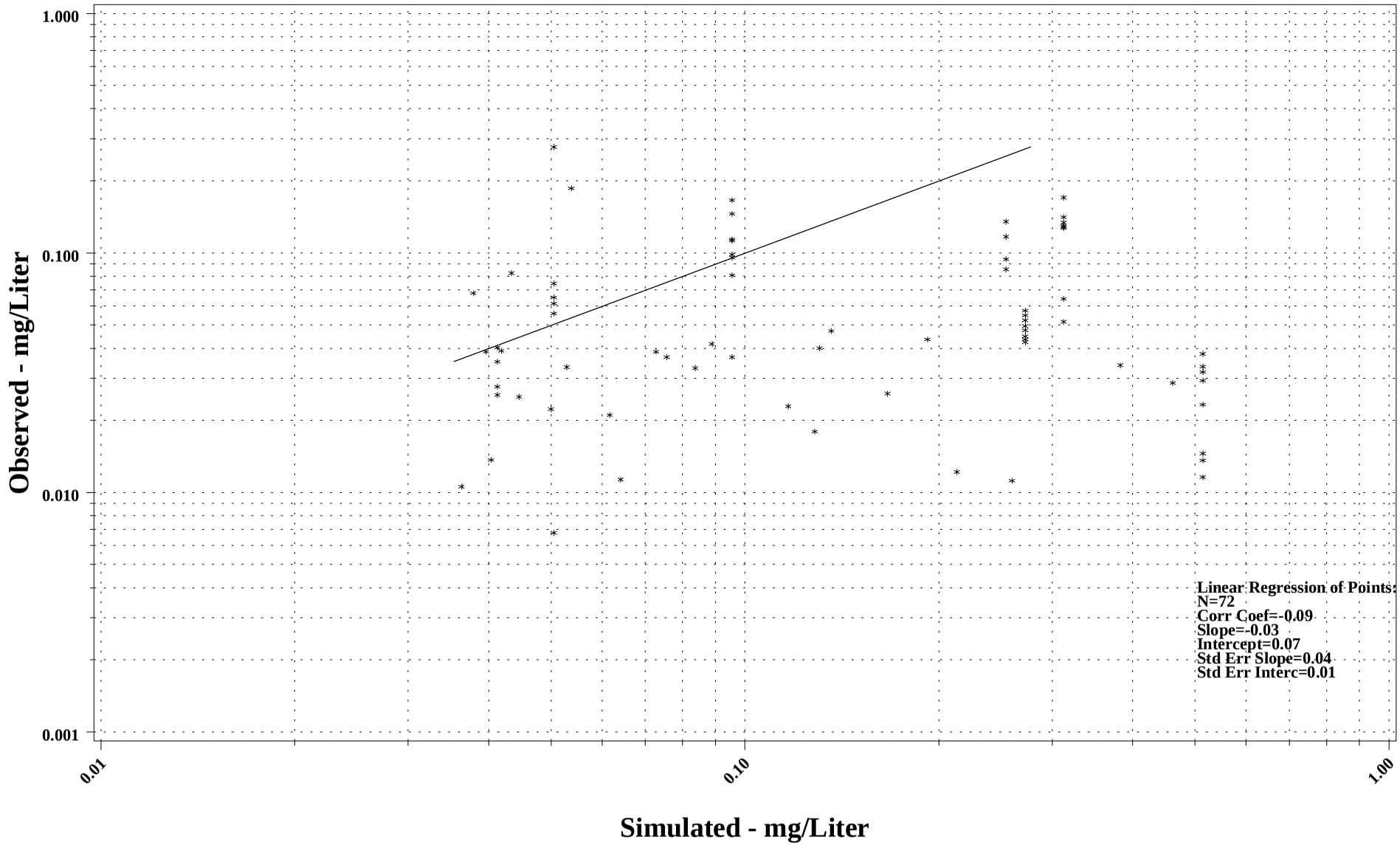


(10SEP02 13:14)
(plot.sas, omtime)

Inland/ Segment 310 - Blackwater Creek: Calibration Run

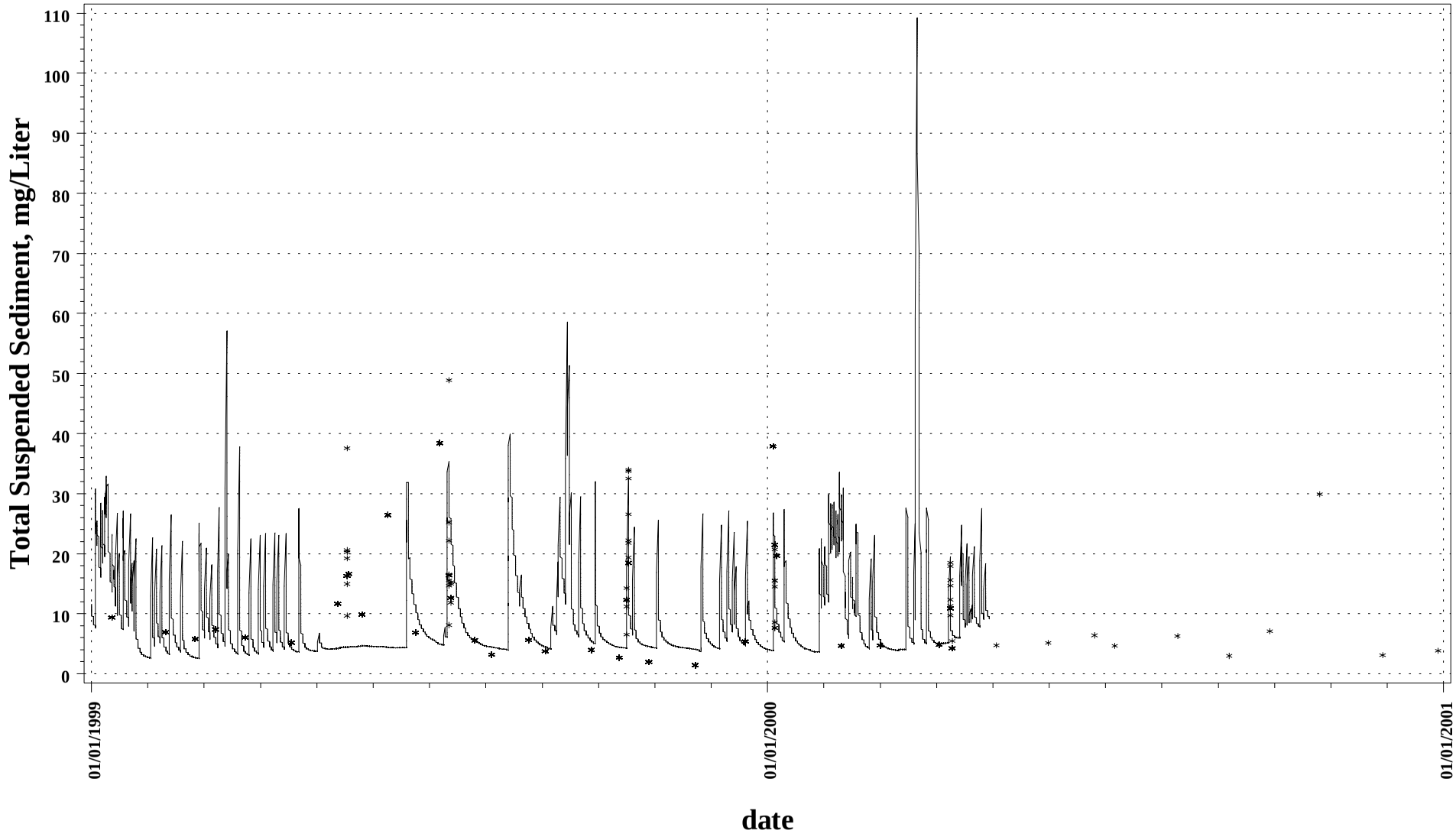
Scatter Plot and Regression of Simulated versus Observed with Ideal Line

Total Phosphorus: 01JAN99 - 01JAN01



(10SEP02 13:14)
(plot.sas, llomregr.sas)

Inland/ Segment 310 - Blackwater Creek: Calibration Run
Total Suspended Sediment
Observed and Simulated versus Time
(* =Observed, - =Simulated)

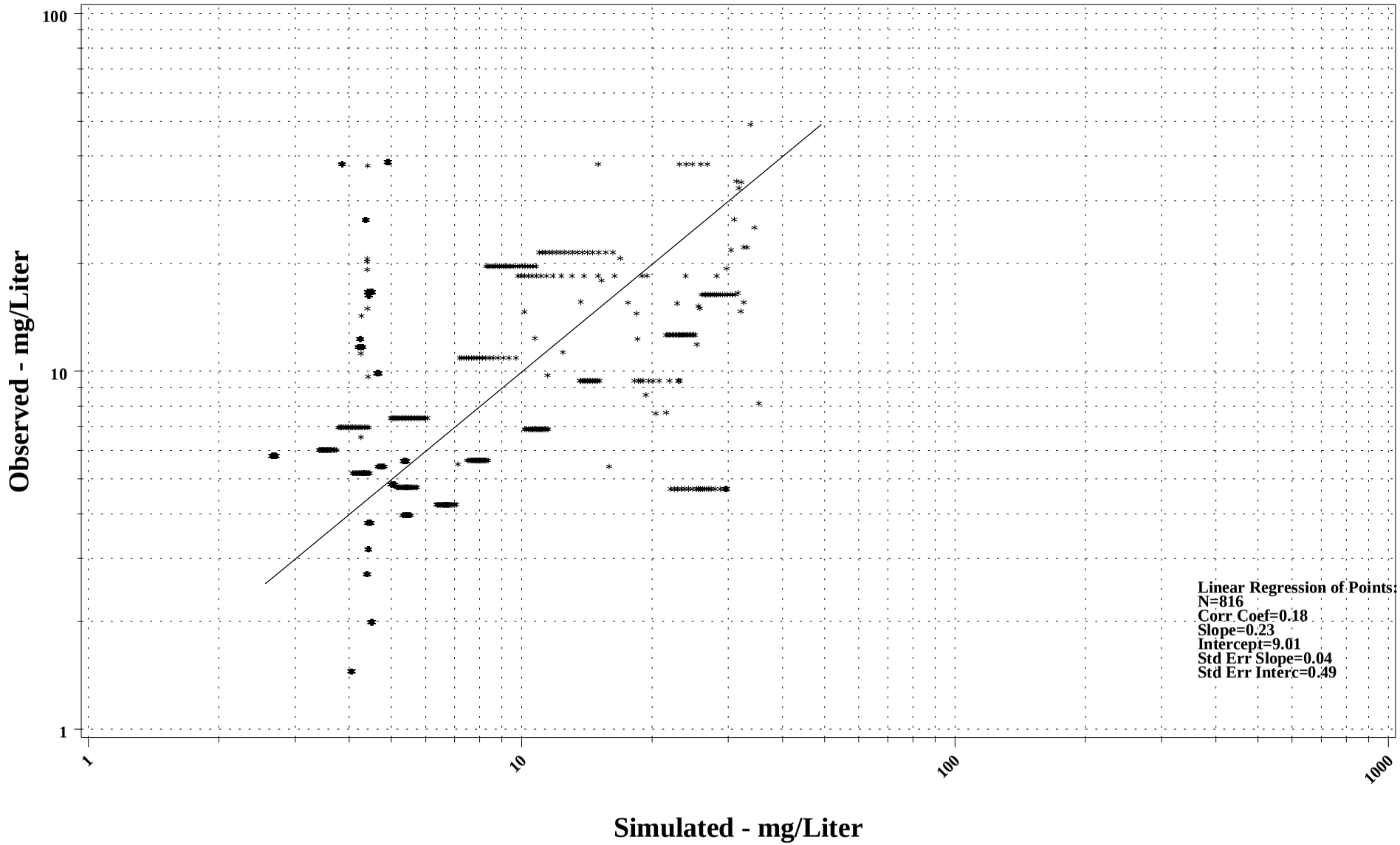


(10SEP02 13:14)
(plot.sas, omtime)

Inland/ Segment 310 - Blackwater Creek: Calibration Run

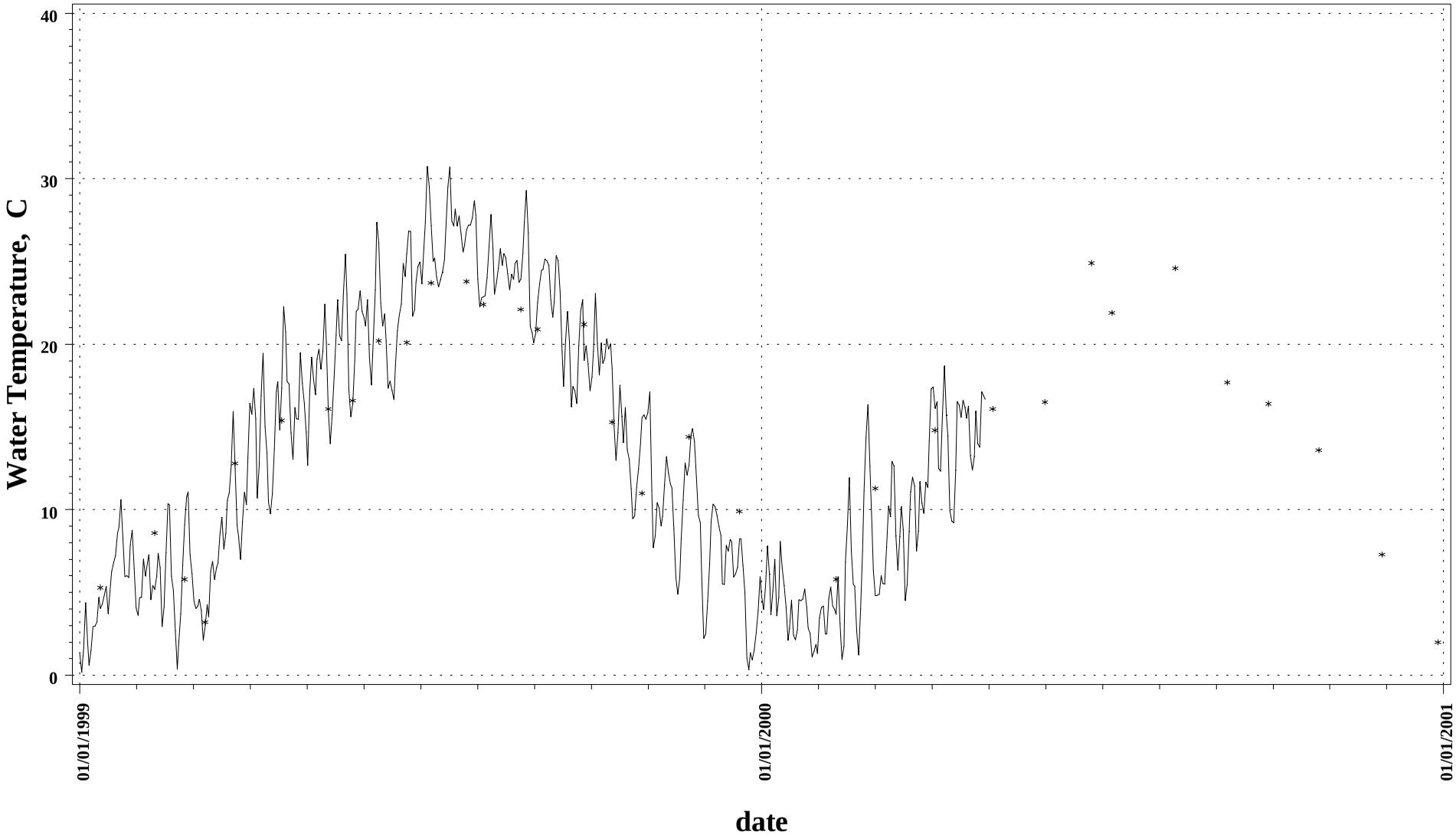
Scatter Plot and Regression of Simulated versus Observed with Ideal Line

Total Suspended Sediment: 01JAN99 - 01JAN01



(10SEP02 13:14)
(plot.sas, llomregr.sas)

Inland/ Segment 310 - Blackwater Creek: Calibration Run
Water Temperature
Observed and Simulated versus Time
(* =Observed, - =Simulated)

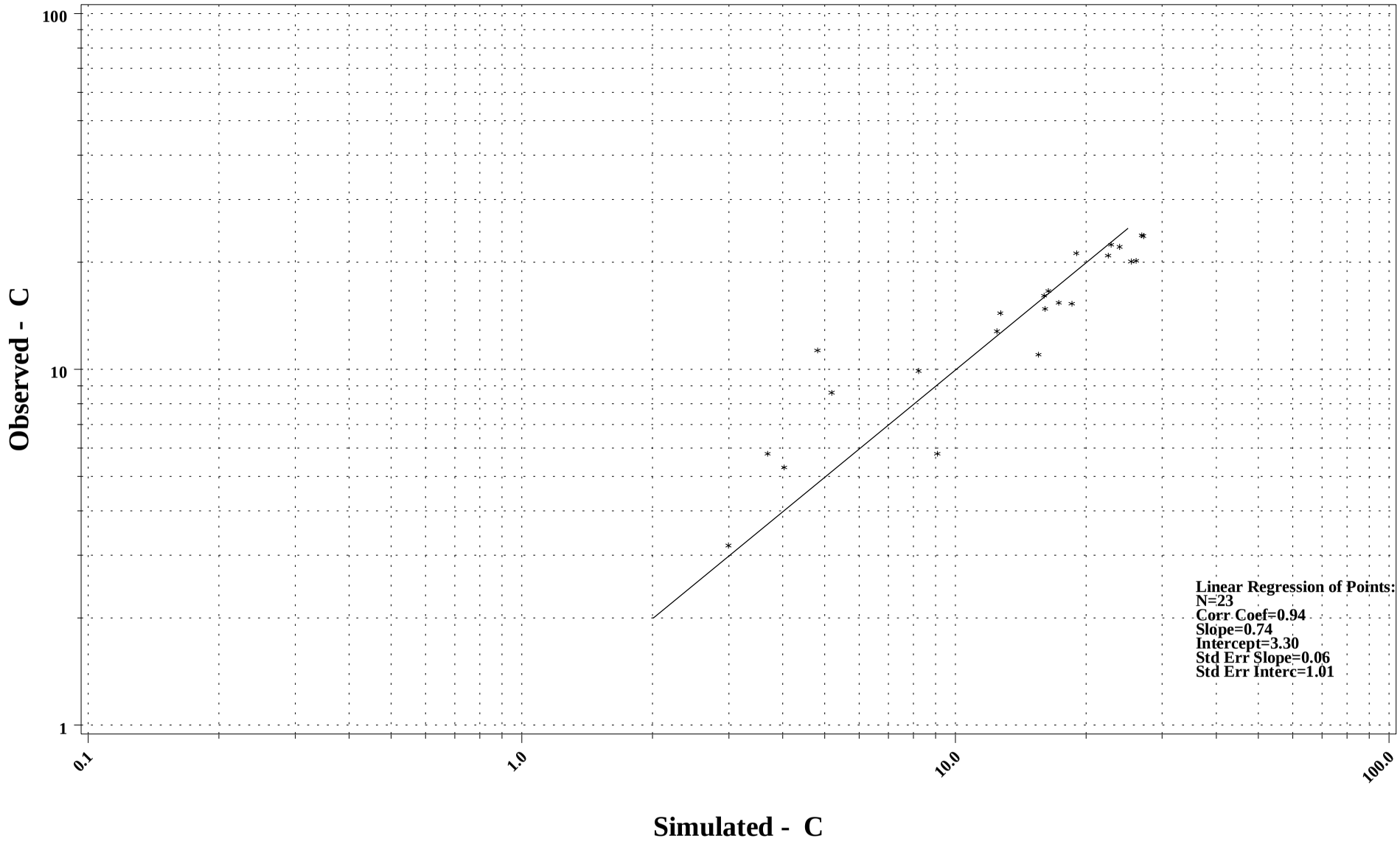


(10SEP02 13:14)
(plot.sas, omtime)

Inland/ Segment 310 - Blackwater Creek: Calibration Run

Scatter Plot and Regression of Simulated versus Observed with Ideal Line

Water Temperature: 01JAN99 - 01JAN01

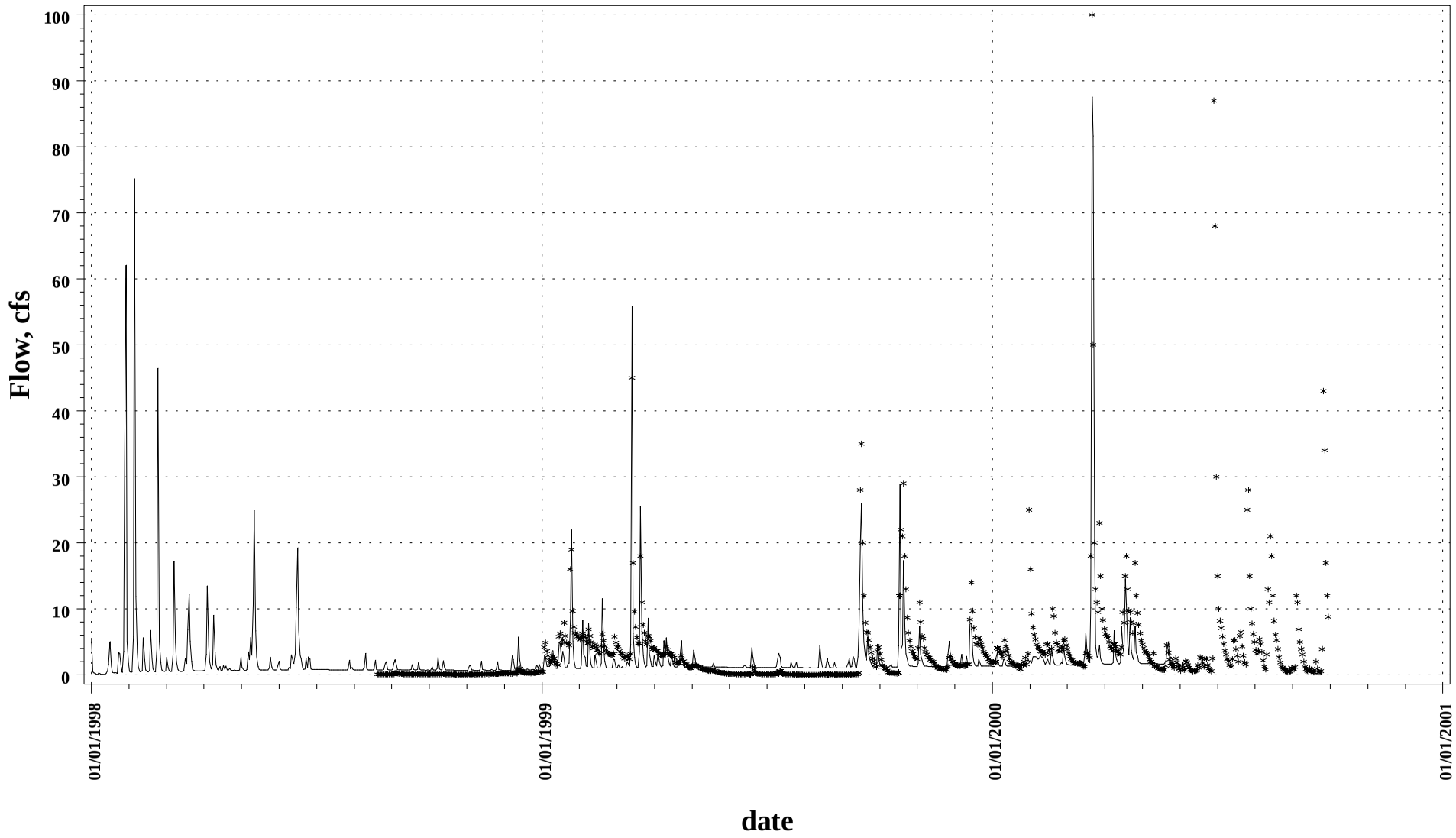


(10SEP02 13:14)
(plot.sas, llomregr.sas)

Inland/ Segment 330 - Beaver Dam Ditch: Calibration Run Flow

Observed and Simulated versus Time

(* =Observed, - =Simulated)

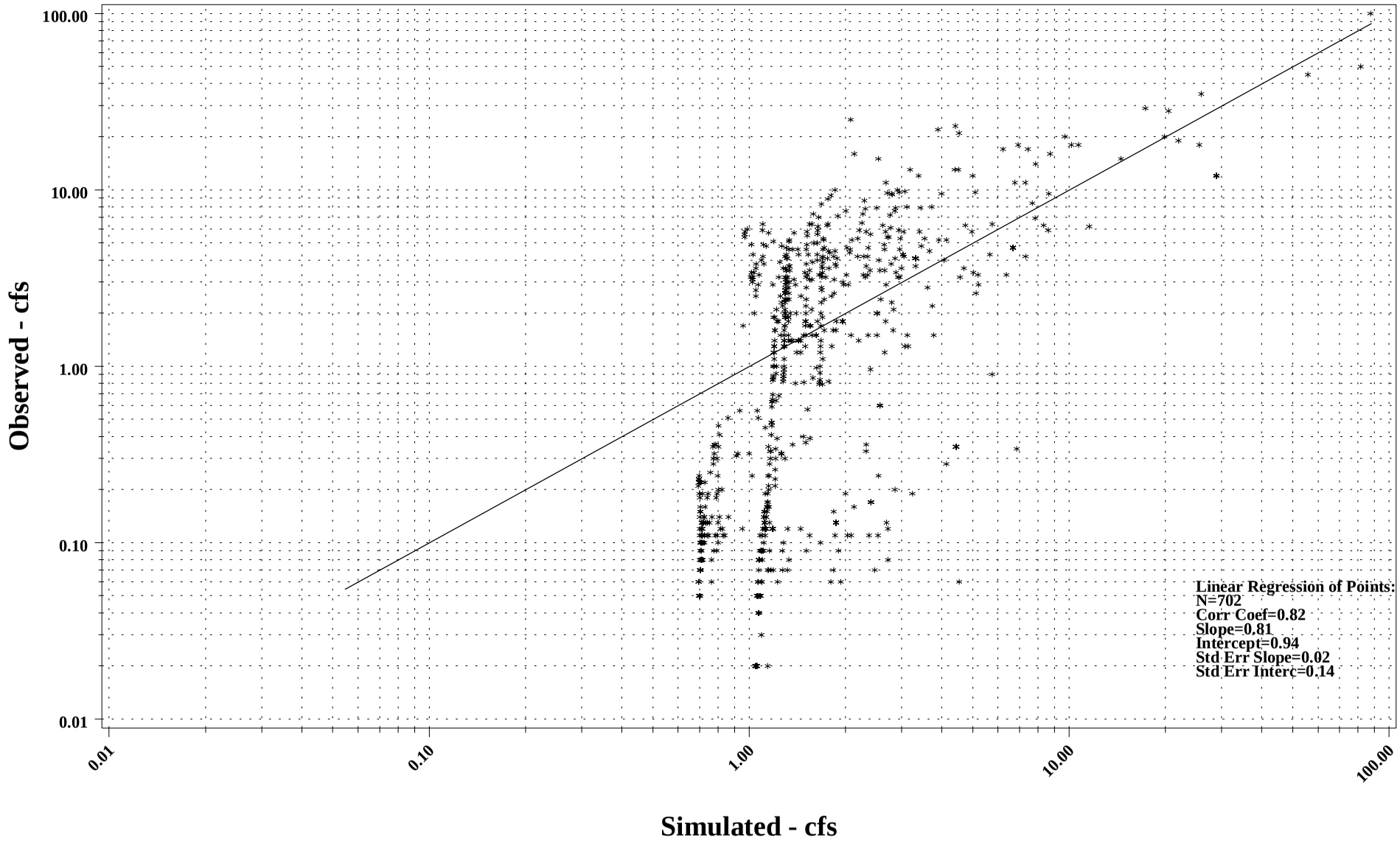


(10SEP02 13:14)
(plot.sas, omtime)

Inland/ Segment 330 - Beaver Dam Ditch: Calibration Run

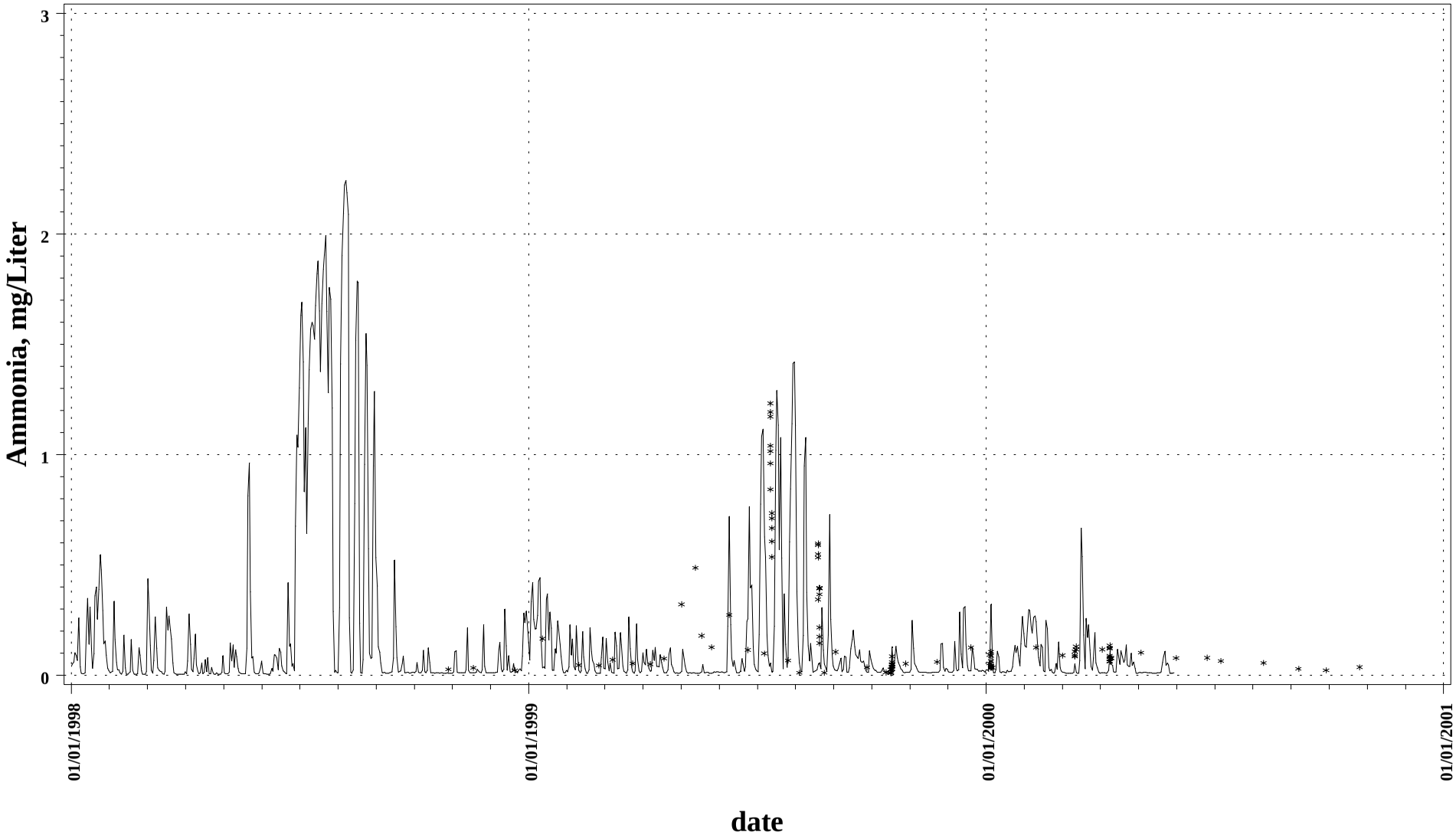
Scatter Plot and Regression of Simulated versus Observed with Ideal Line

Flow: 01JAN98 - 01JAN01



(10SEP02 13:14)
(plot.sas, llomregr.sas)

Inland/ Segment 330 - Beaver Dam Ditch: Calibration Run
Ammonia
Observed and Simulated versus Time
(* =Observed, - =Simulated)

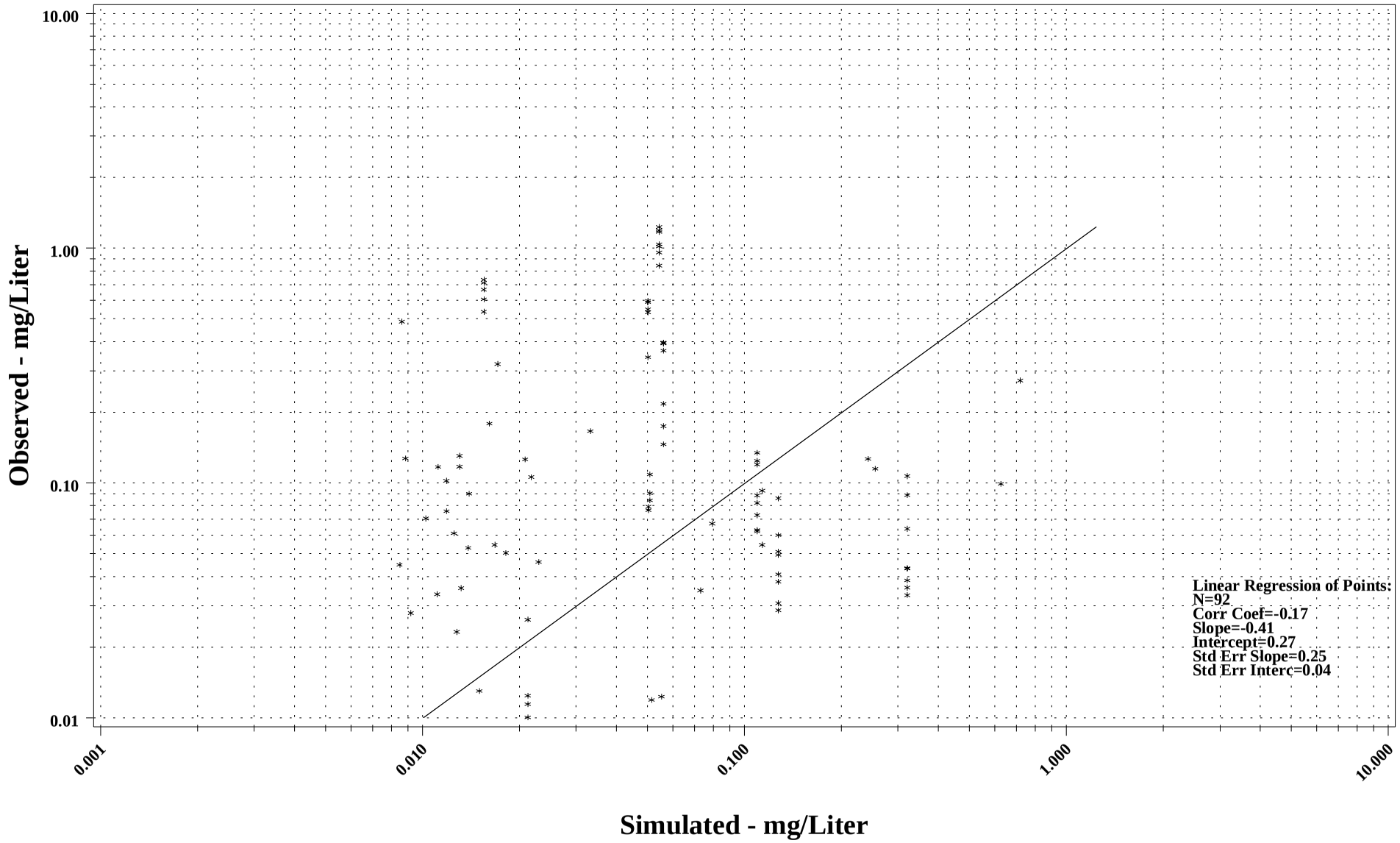


(10SEP02 13:14)
(plot.sas, omtime)

Inland/ Segment 330 - Beaver Dam Ditch: Calibration Run

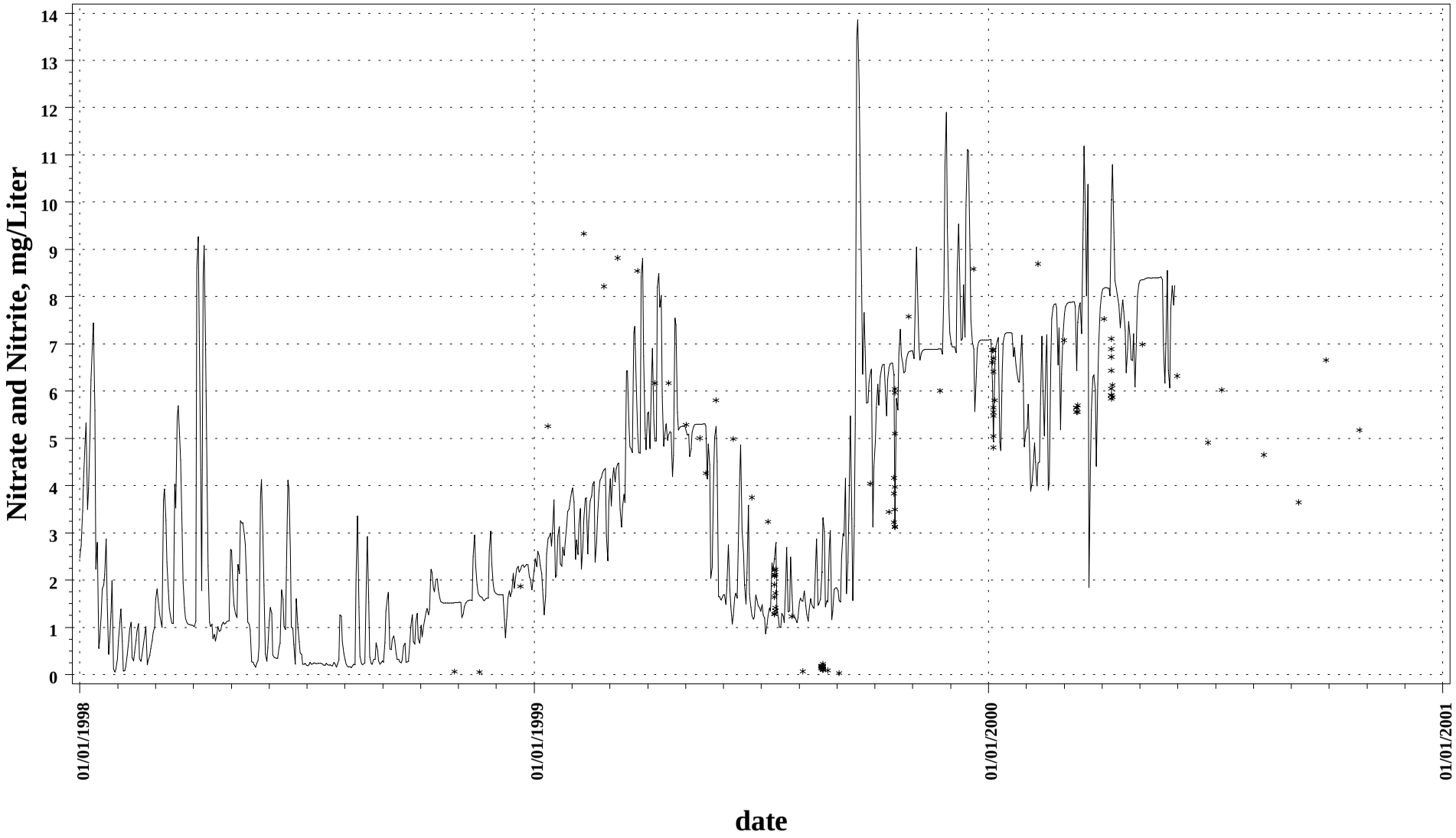
Scatter Plot and Regression of Simulated versus Observed with Ideal Line

Ammonia: 01JAN98 - 01JAN01



(10SEP02 13:14)
(plot.sas, llomregr.sas)

Inland/ Segment 330 - Beaver Dam Ditch: Calibration Run
Nitrate and Nitrite
Observed and Simulated versus Time
(* =Observed, - =Simulated)

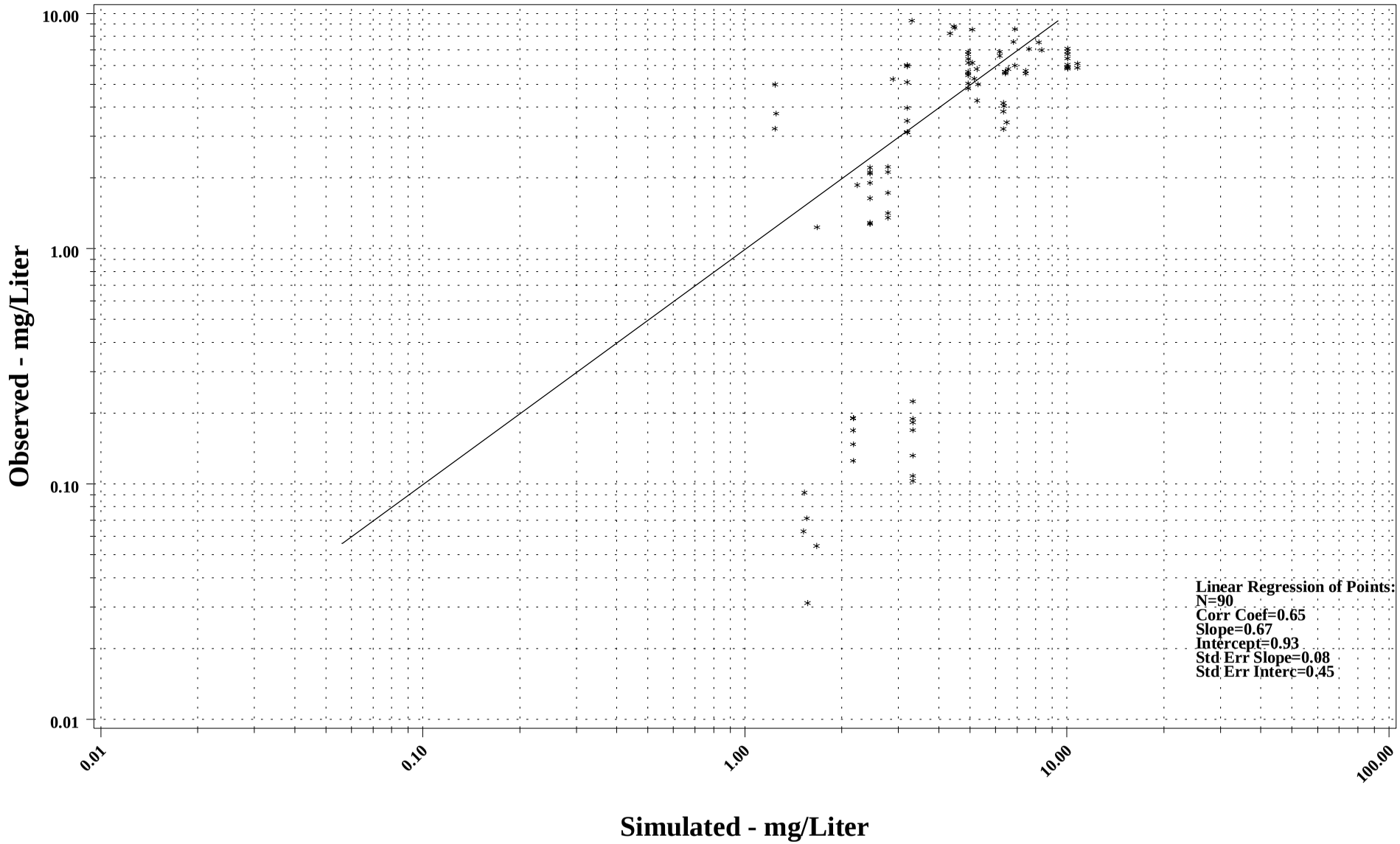


(10SEP02 13:14)
(plot.sas, omtime)

Inland/ Segment 330 - Beaver Dam Ditch: Calibration Run

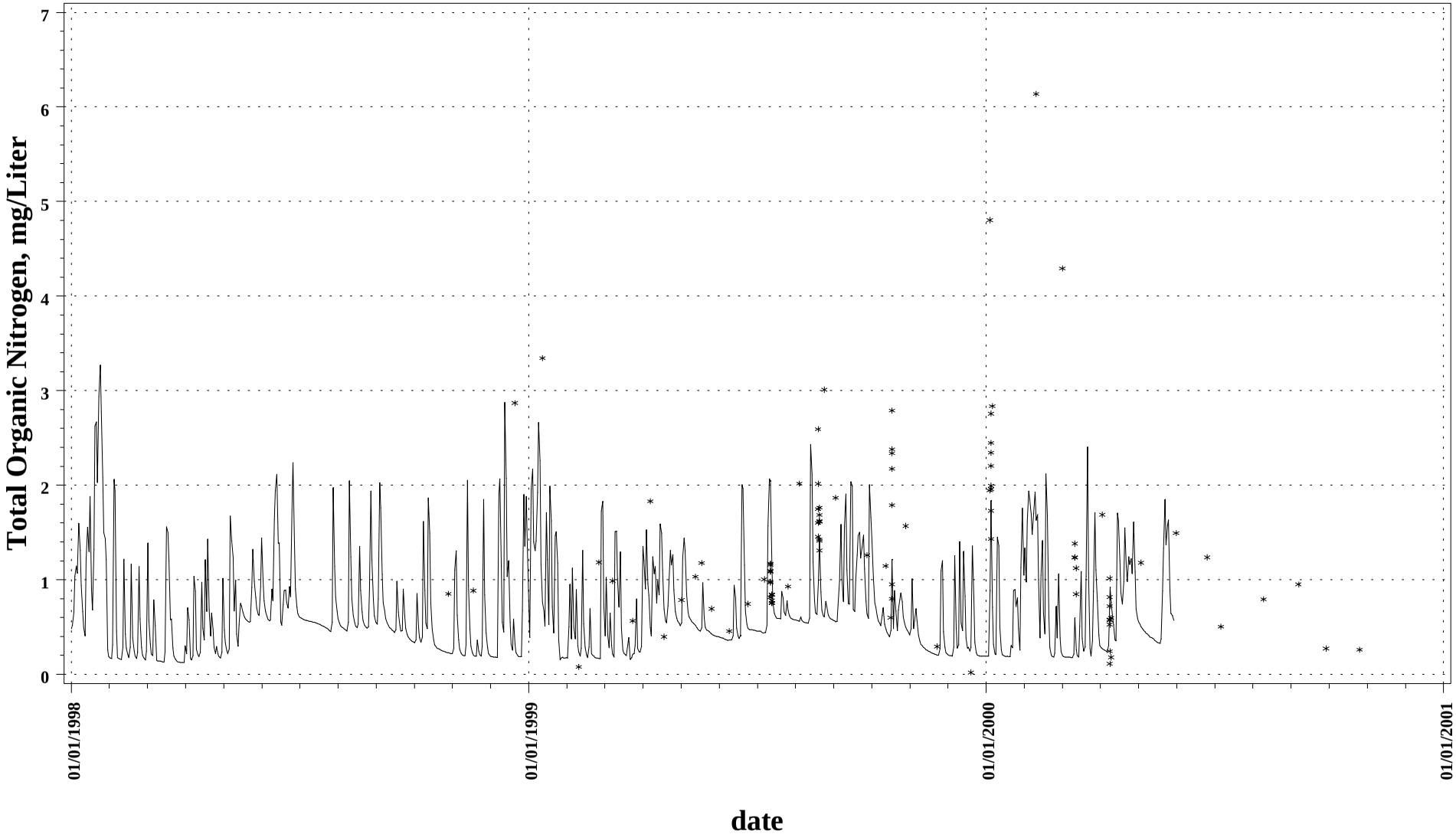
Scatter Plot and Regression of Simulated versus Observed with Ideal Line

Nitrate and Nitrite: 01JAN98 - 01JAN01



(10SEP02 13:14)
(plot.sas, llomregr.sas)

Inland/ Segment 330 - Beaver Dam Ditch: Calibration Run
Total Organic Nitrogen
Observed and Simulated versus Time
(* =Observed, - =Simulated)

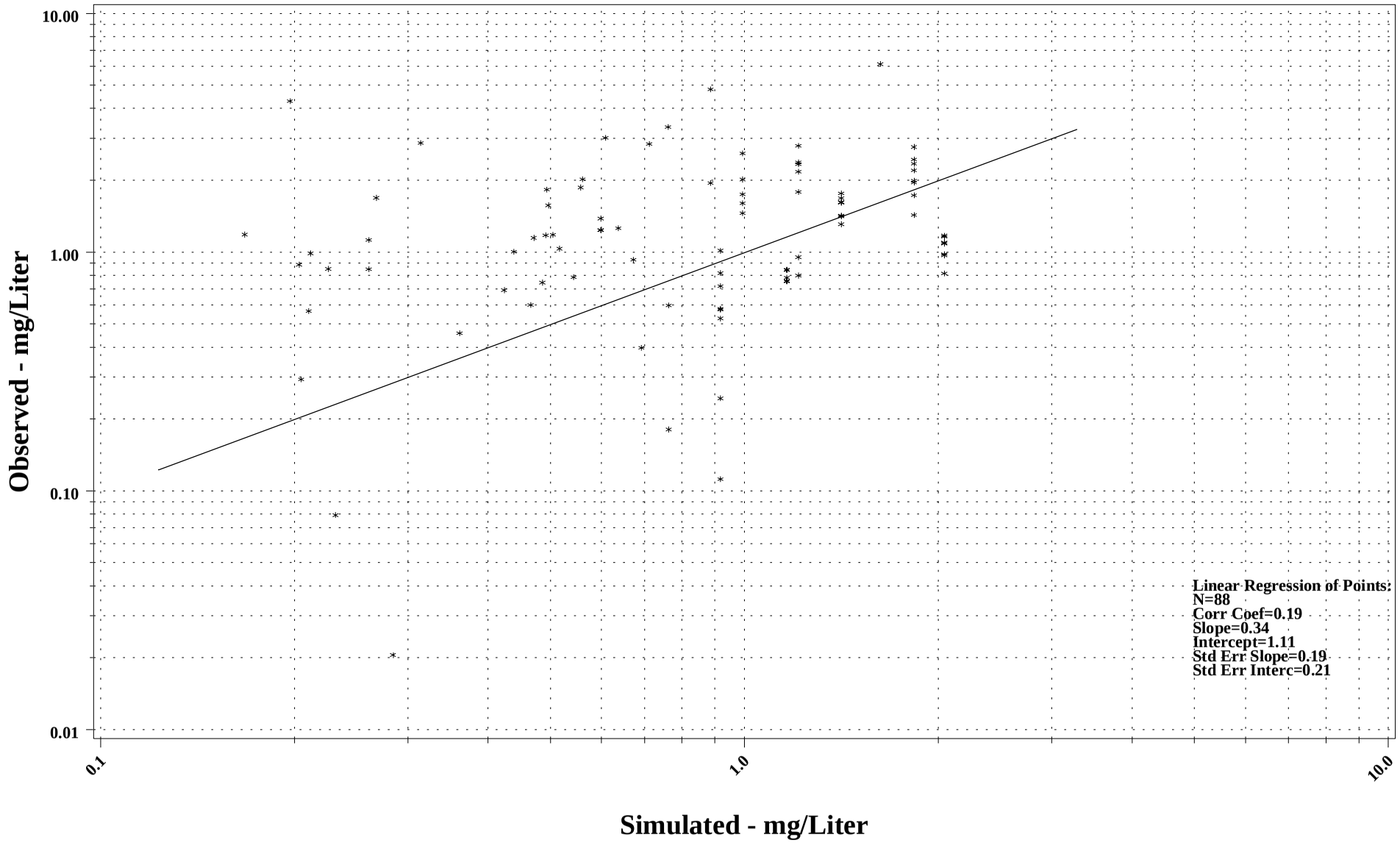


(10SEP02 13:14)
(plot.sas, omtime)

Inland/ Segment 330 - Beaver Dam Ditch: Calibration Run

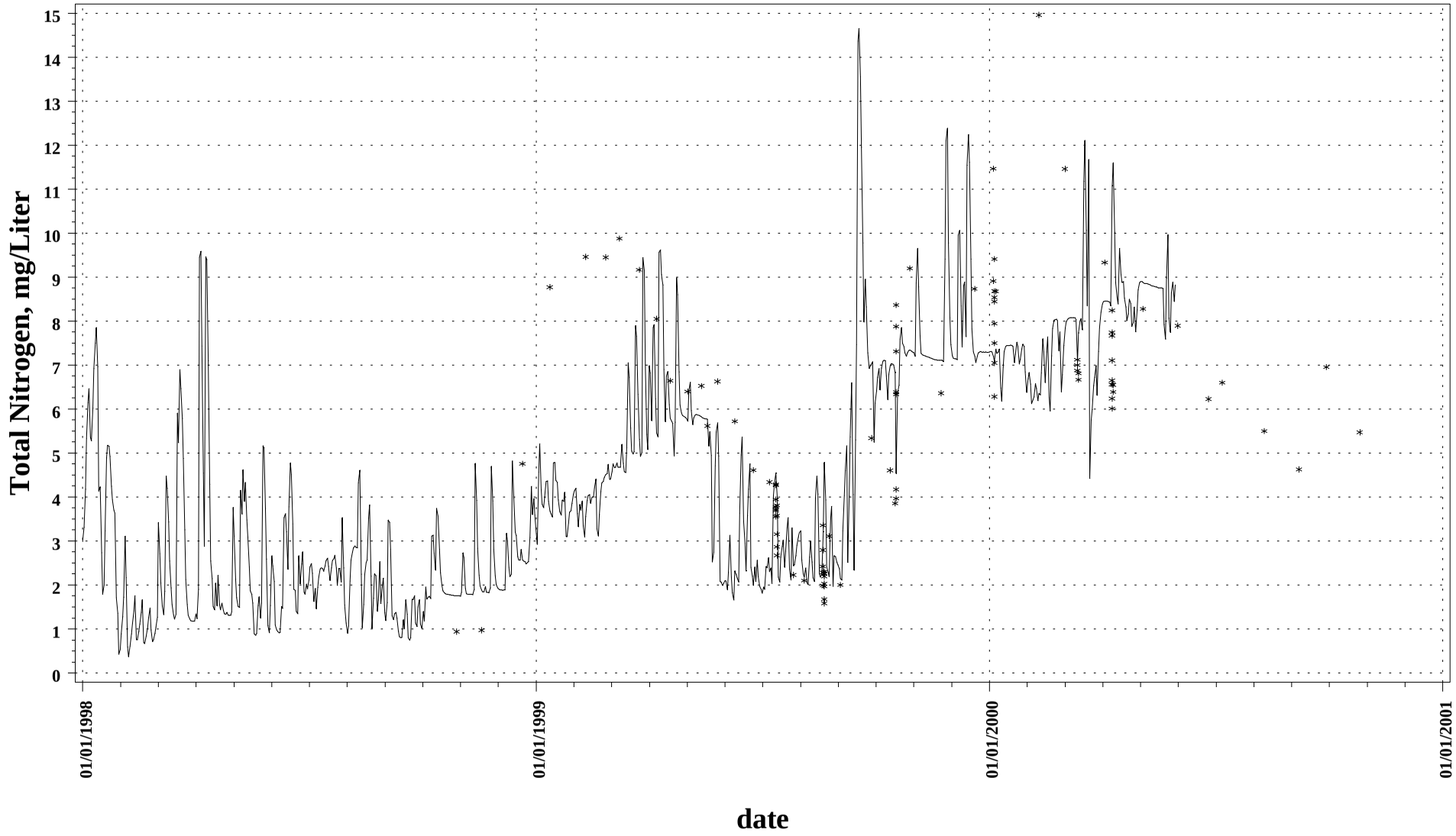
Scatter Plot and Regression of Simulated versus Observed with Ideal Line

Total Organic Nitrogen: 01JAN98 - 01JAN01



(10SEP02 13:14)
(plot.sas, llomregr.sas)

Inland/ Segment 330 - Beaver Dam Ditch: Calibration Run
Total Nitrogen
Observed and Simulated versus Time
(* =Observed, - =Simulated)

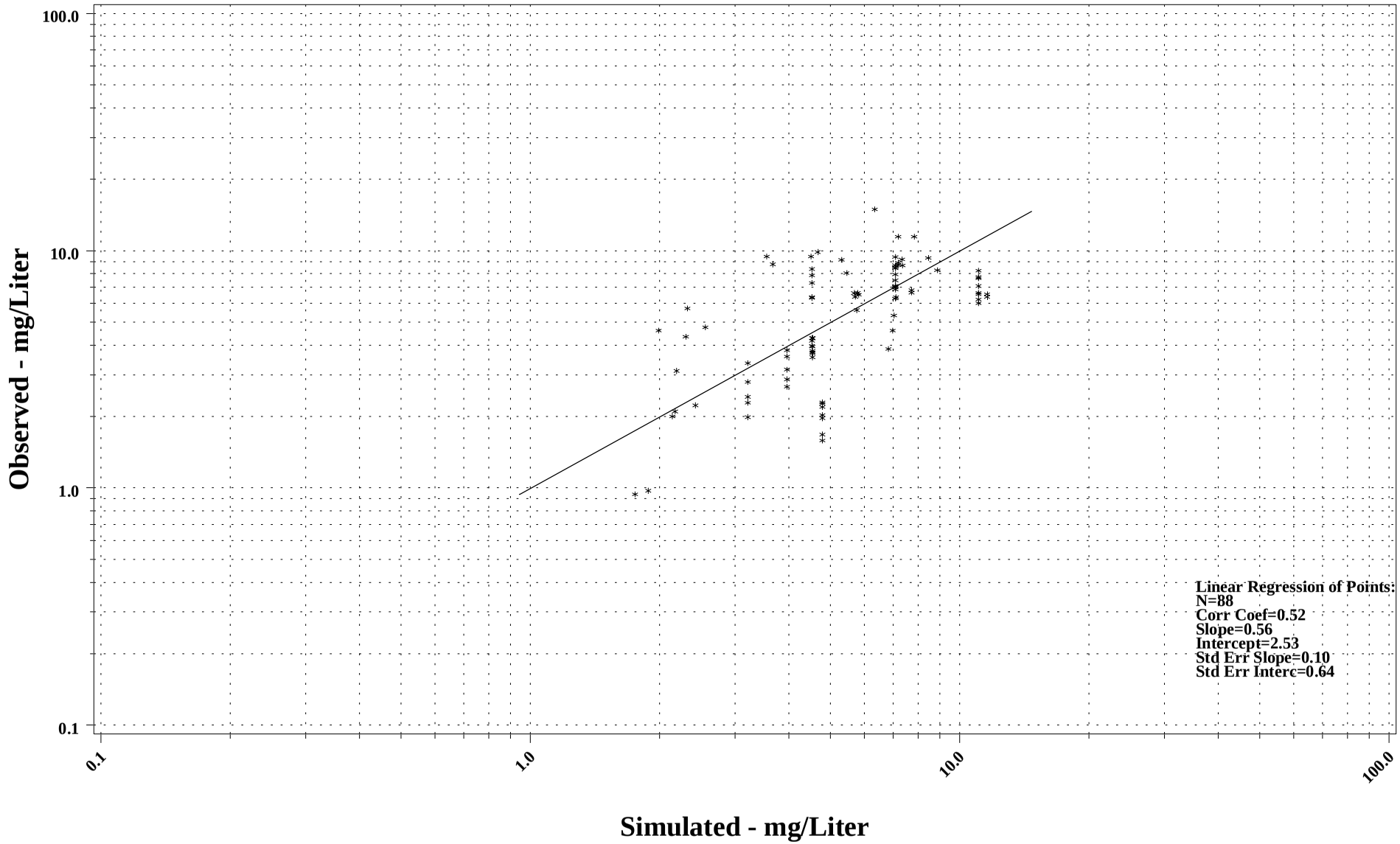


(10SEP02 13:14)
(plot.sas, omtime)

Inland/ Segment 330 - Beaver Dam Ditch: Calibration Run

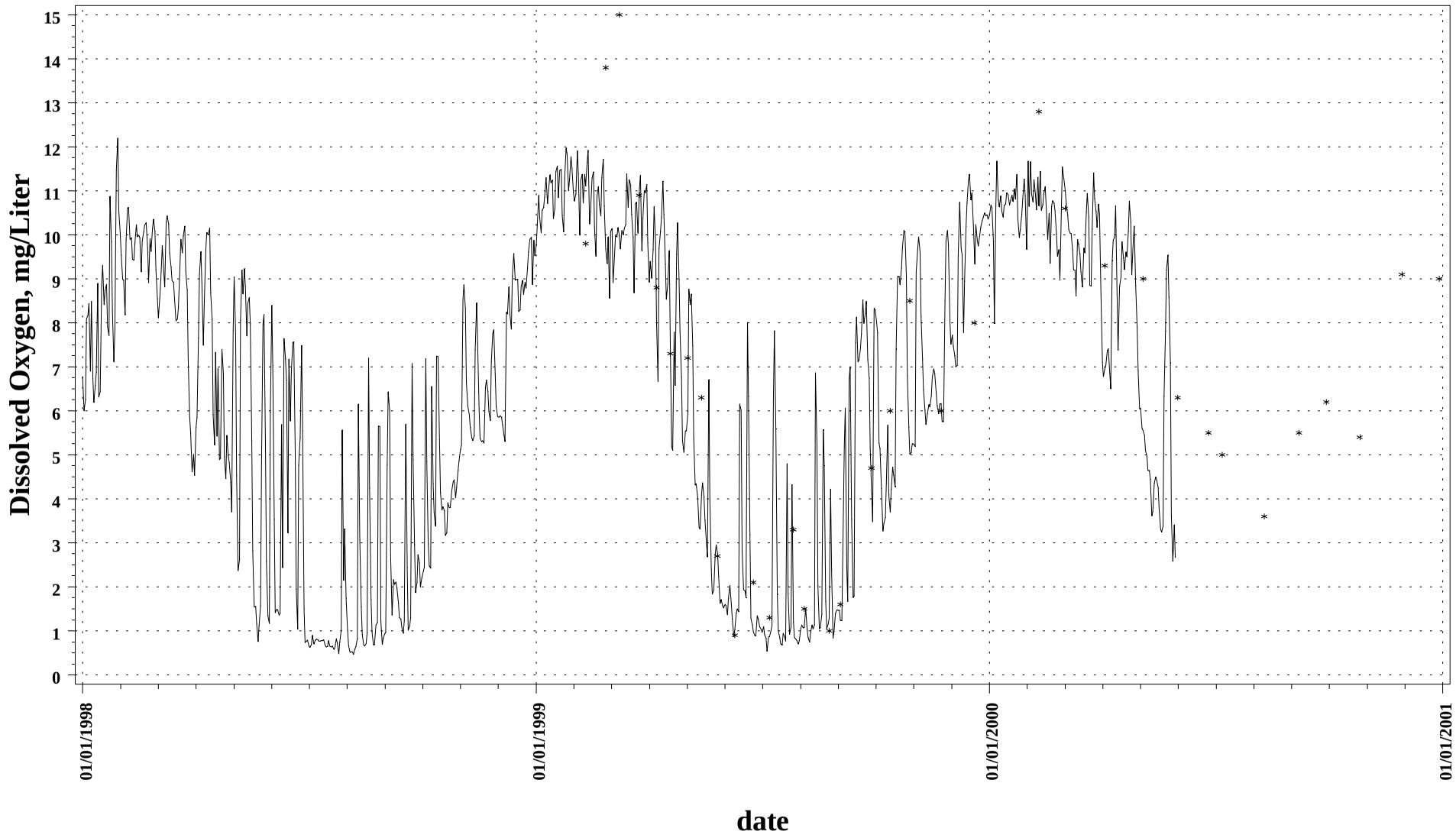
Scatter Plot and Regression of Simulated versus Observed with Ideal Line

Total Nitrogen: 01JAN98 - 01JAN01



(10SEP02 13:14)
(plot.sas, llomregr.sas)

Inland/ Segment 330 - Beaver Dam Ditch: Calibration Run
Dissolved Oxygen
Observed and Simulated versus Time
(* =Observed, - =Simulated)

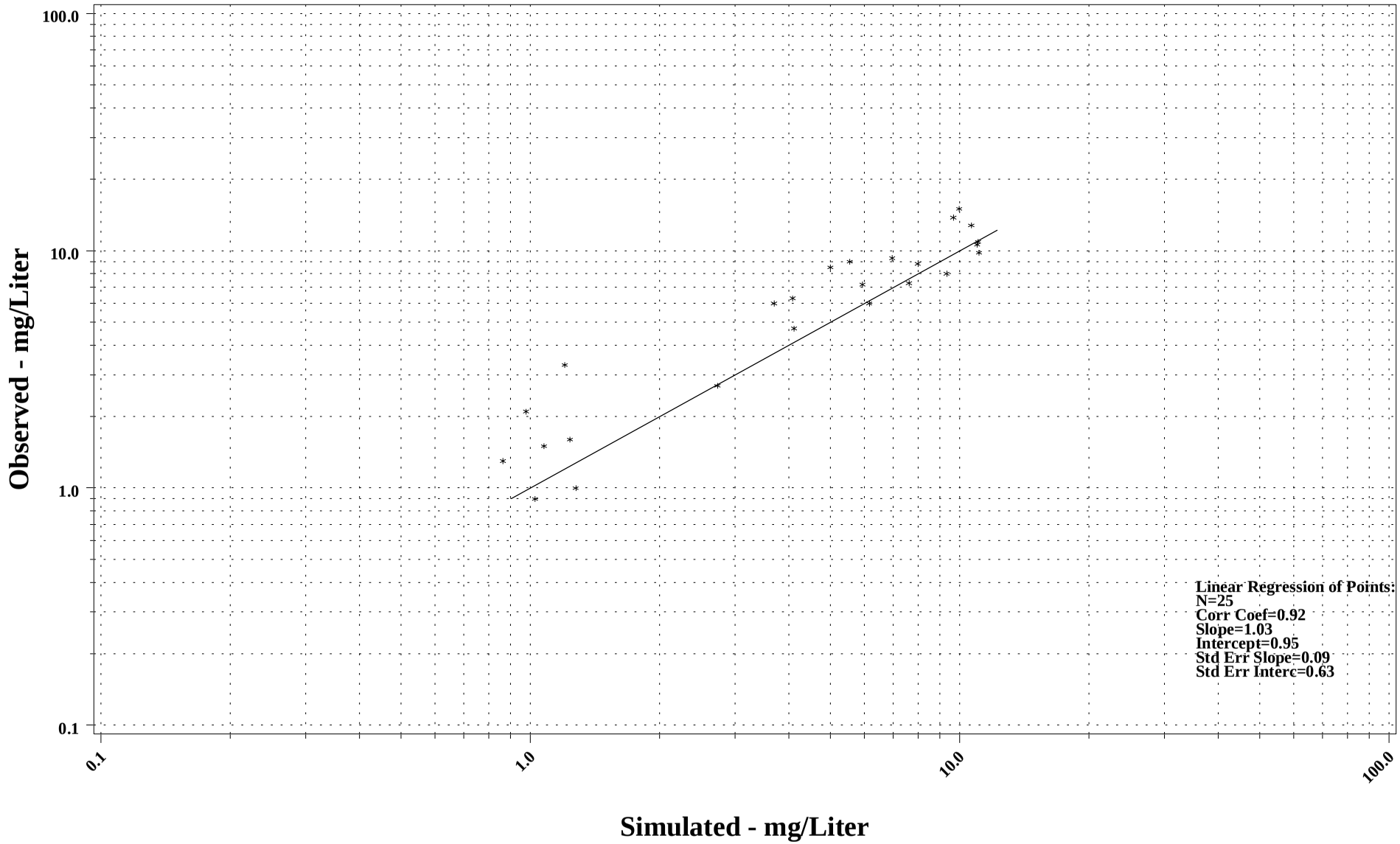


(10SEP02 13:14)
(plot.sas, omtime)

Inland/ Segment 330 - Beaver Dam Ditch: Calibration Run

Scatter Plot and Regression of Simulated versus Observed with Ideal Line

Dissolved Oxygen: 01JAN98 - 01JAN01

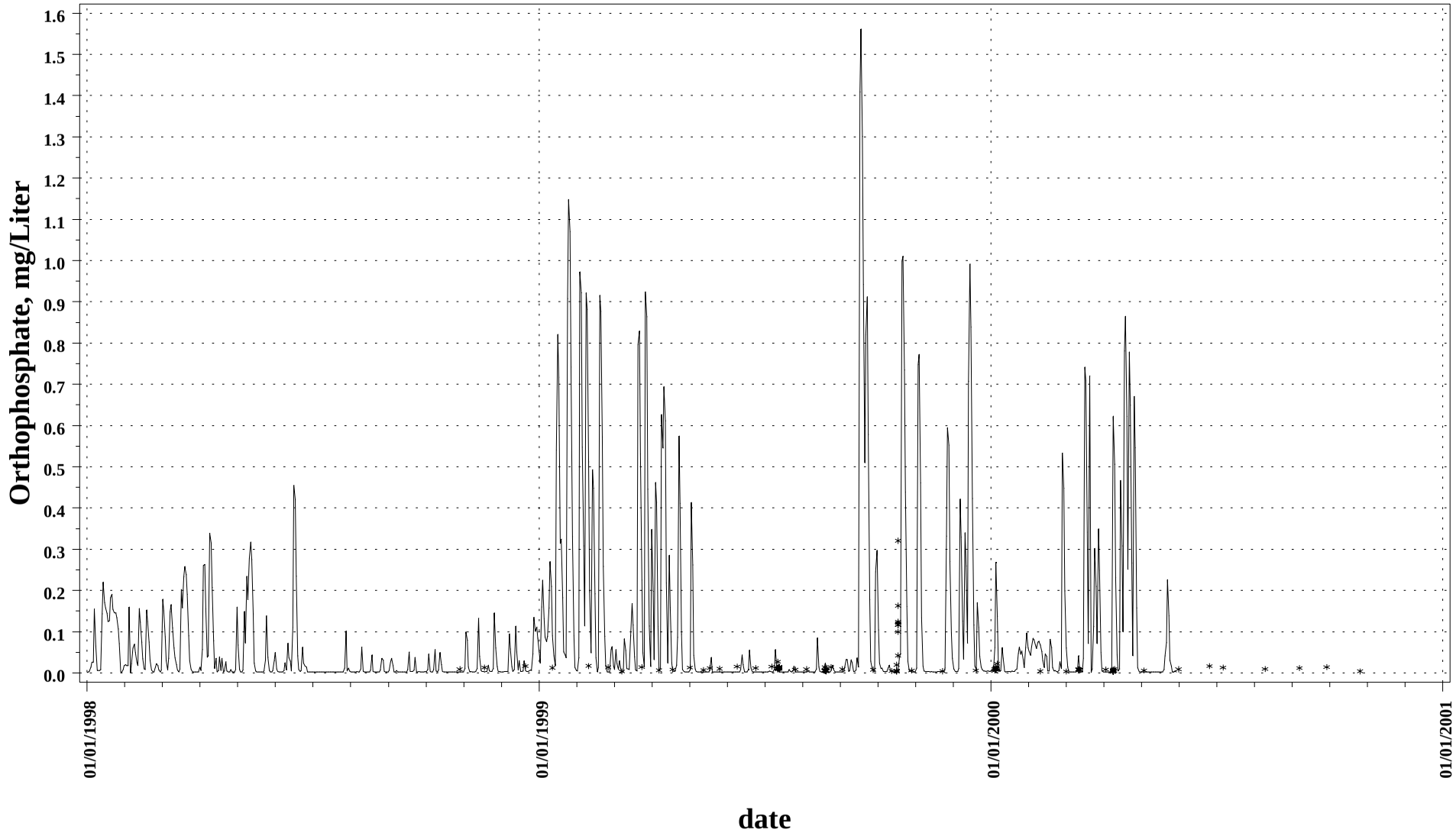


(10SEP02 13:14)
(plot.sas, llomregr.sas)

Inland/ Segment 330 - Beaver Dam Ditch: Calibration Run Orthophosphate

Observed and Simulated versus Time

(* =Observed, - =Simulated)

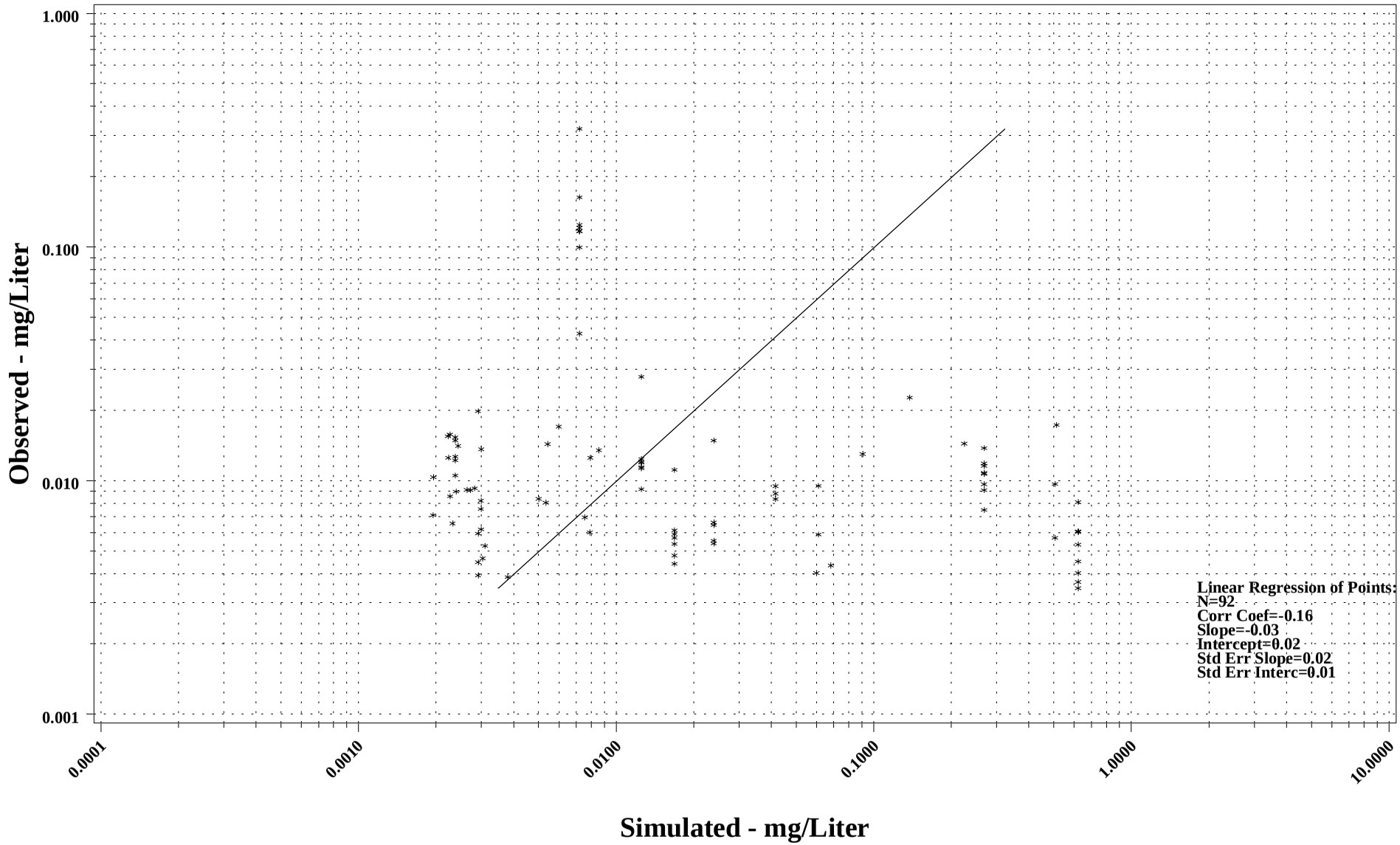


(10SEP02 13:14)
(plot.sas, omtime)

Inland/ Segment 330 - Beaver Dam Ditch: Calibration Run

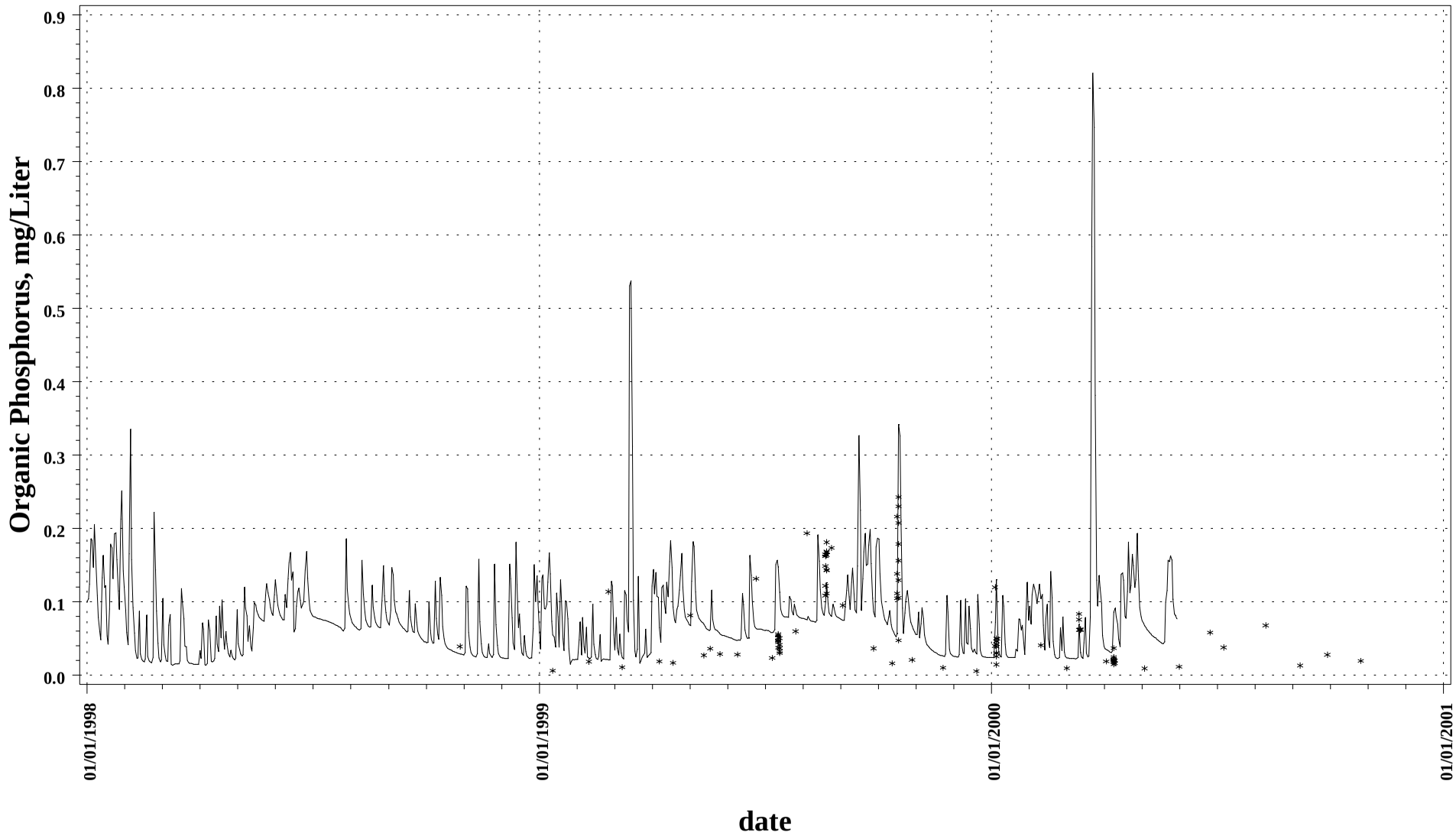
Scatter Plot and Regression of Simulated versus Observed with Ideal Line

Orthophosphate: 01JAN98 - 01JAN01



(10SEP02 13:14)
(plot.sas, llomregr.sas)

Inland/ Segment 330 - Beaver Dam Ditch: Calibration Run
Organic Phosphorus
Observed and Simulated versus Time
(* =Observed, - =Simulated)

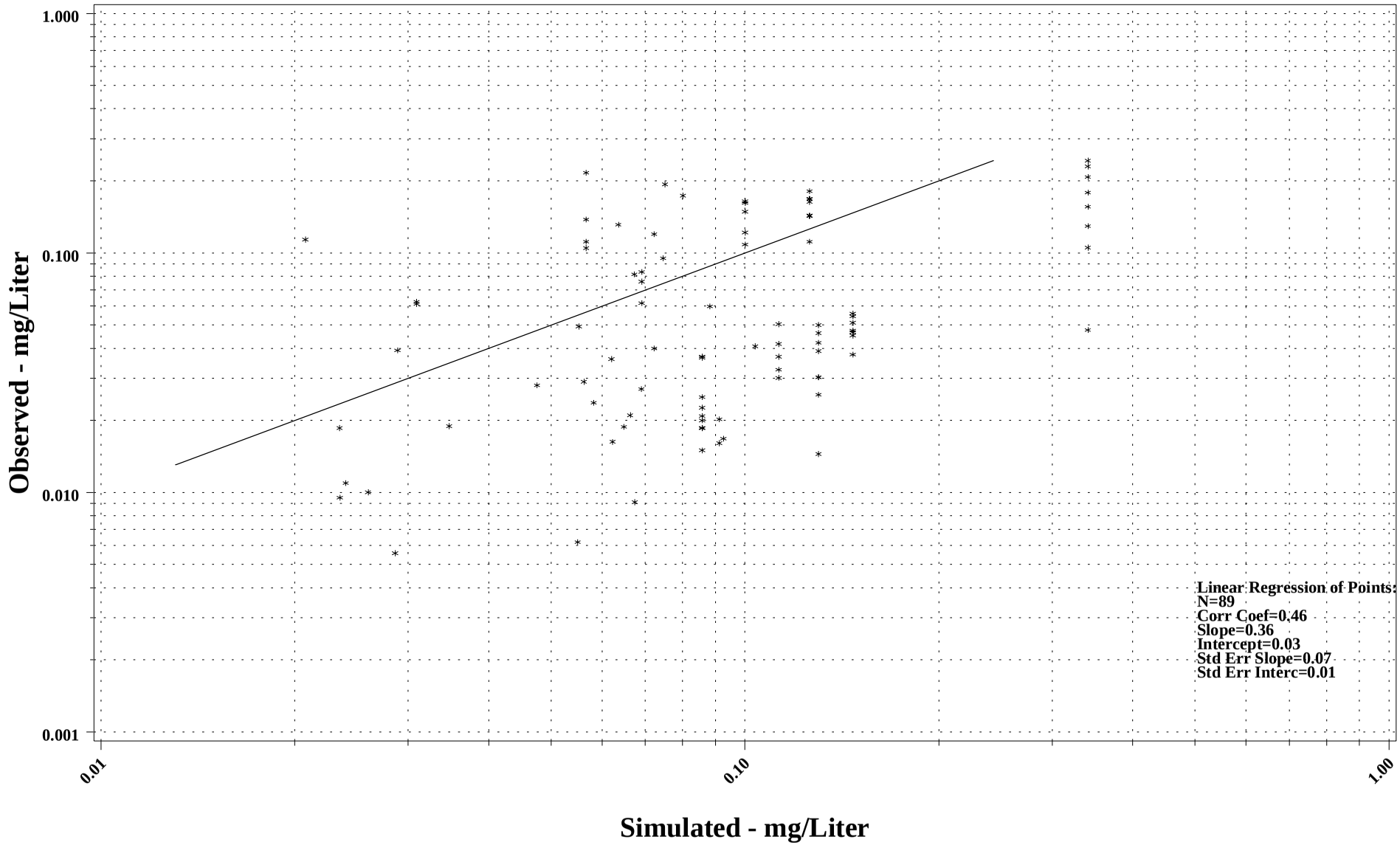


(10SEP02 13:14)
(plot.sas, omtime)

Inland/ Segment 330 - Beaver Dam Ditch: Calibration Run

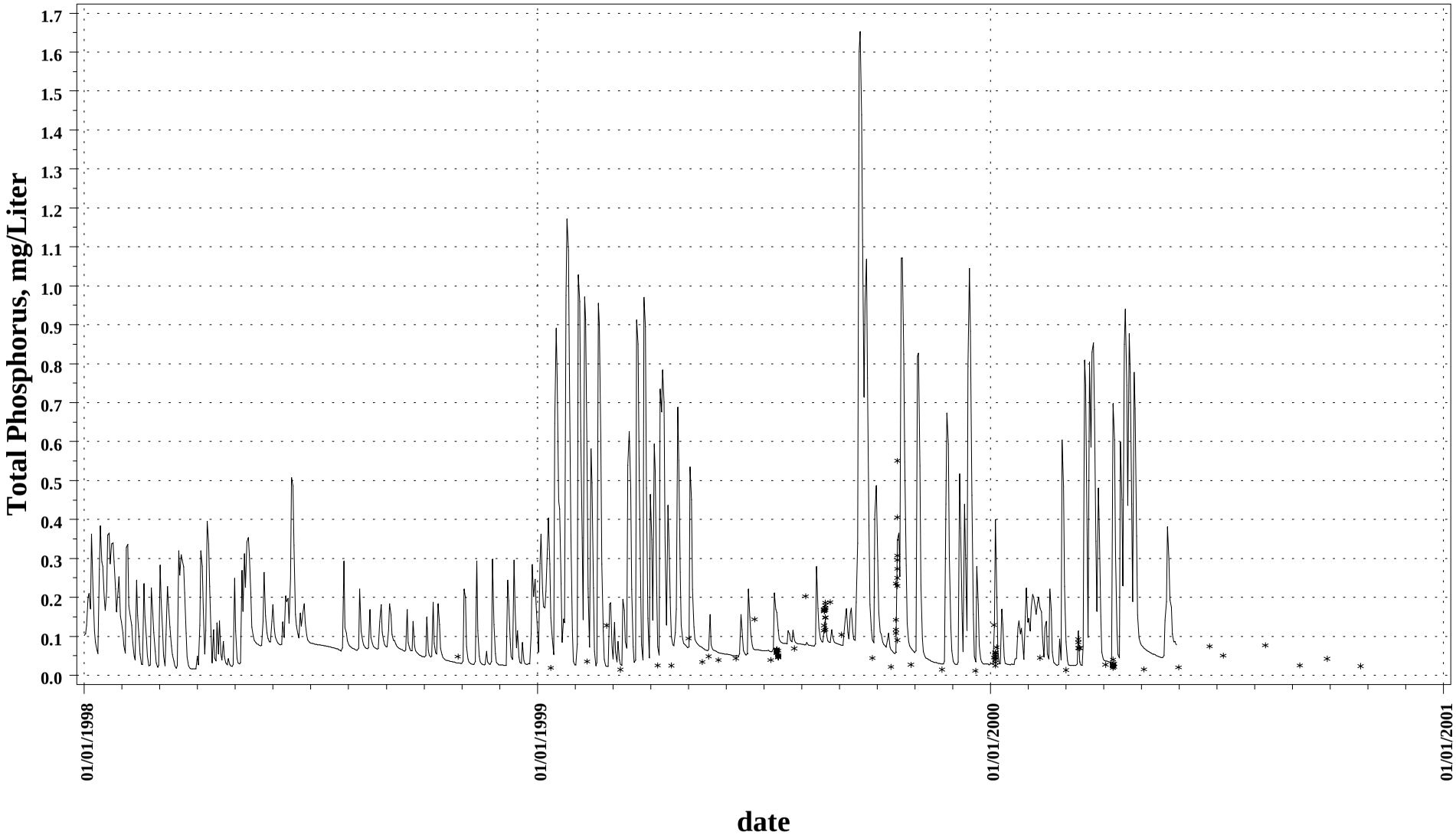
Scatter Plot and Regression of Simulated versus Observed with Ideal Line

Organic Phosphorus: 01JAN98 - 01JAN01



(10SEP02 13:14)
(plot.sas, llomregr.sas)

Inland/ Segment 330 - Beaver Dam Ditch: Calibration Run
Total Phosphorus
Observed and Simulated versus Time
(* =Observed, - =Simulated)

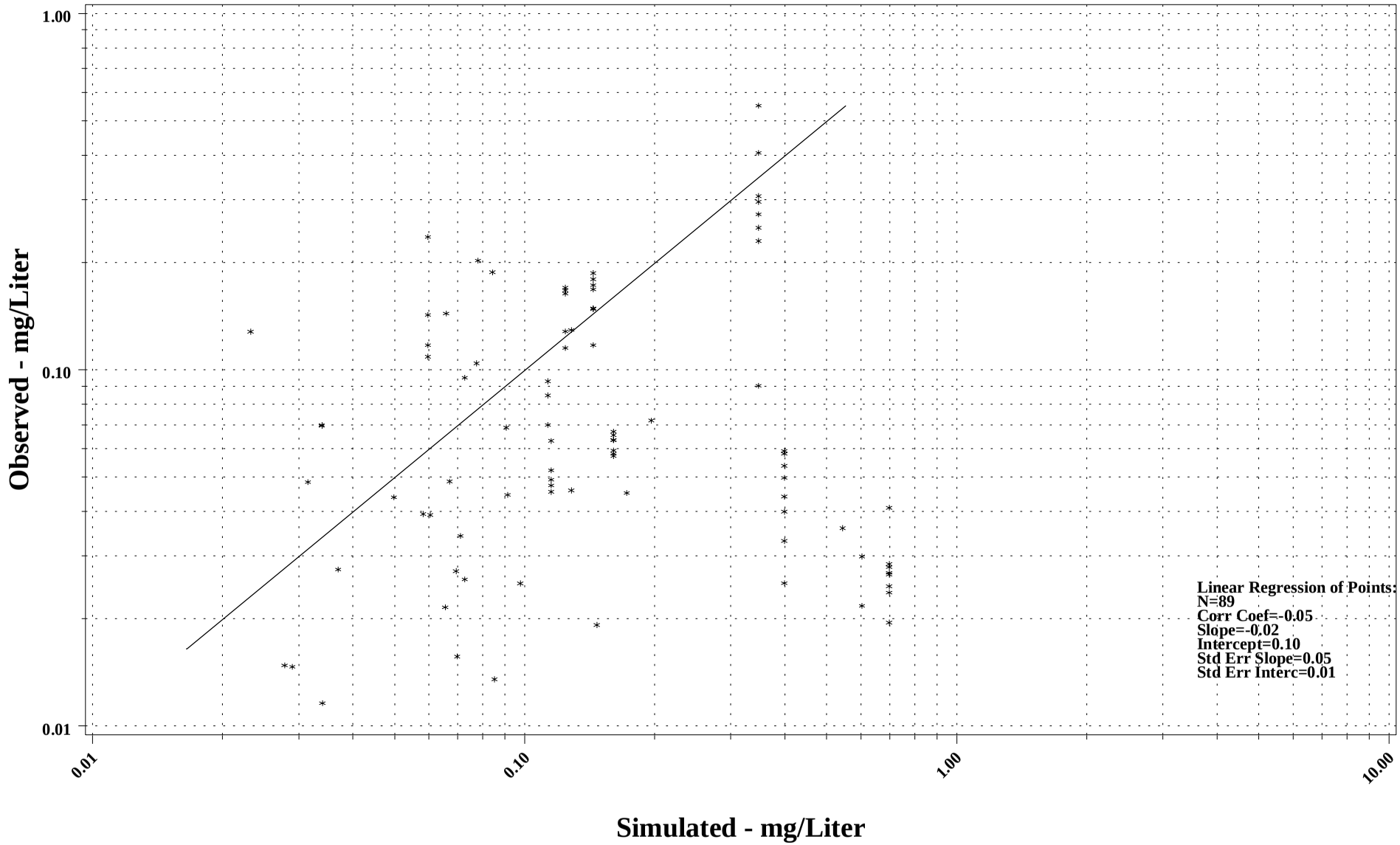


(10SEP02 13:14)
(plot.sas, omtime)

Inland/ Segment 330 - Beaver Dam Ditch: Calibration Run

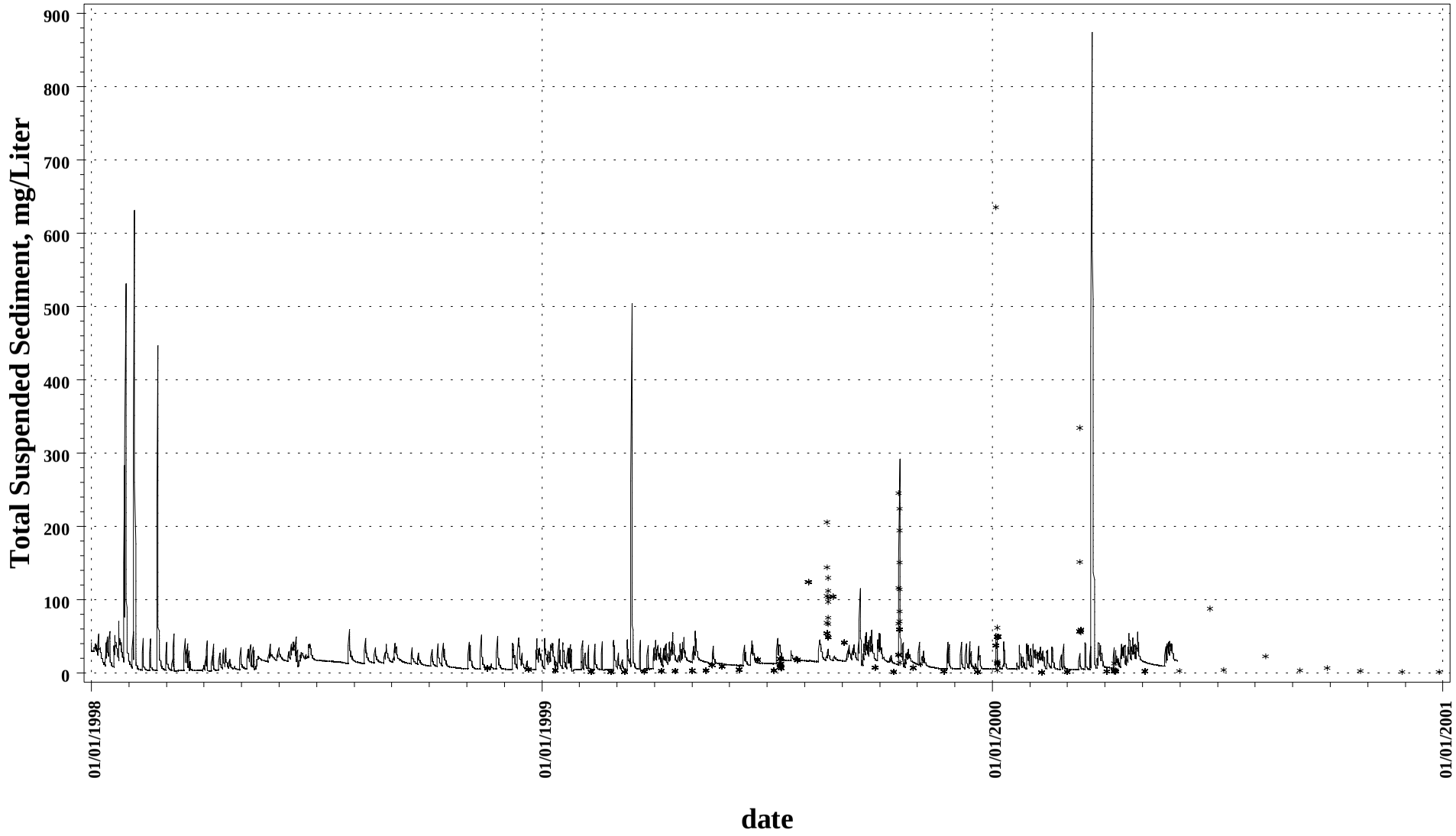
Scatter Plot and Regression of Simulated versus Observed with Ideal Line

Total Phosphorus: 01JAN98 - 01JAN01



(10SEP02 13:14)
(plot.sas, llomregr.sas)

Inland/ Segment 330 - Beaver Dam Ditch: Calibration Run
Total Suspended Sediment
Observed and Simulated versus Time
(* =Observed, - =Simulated)

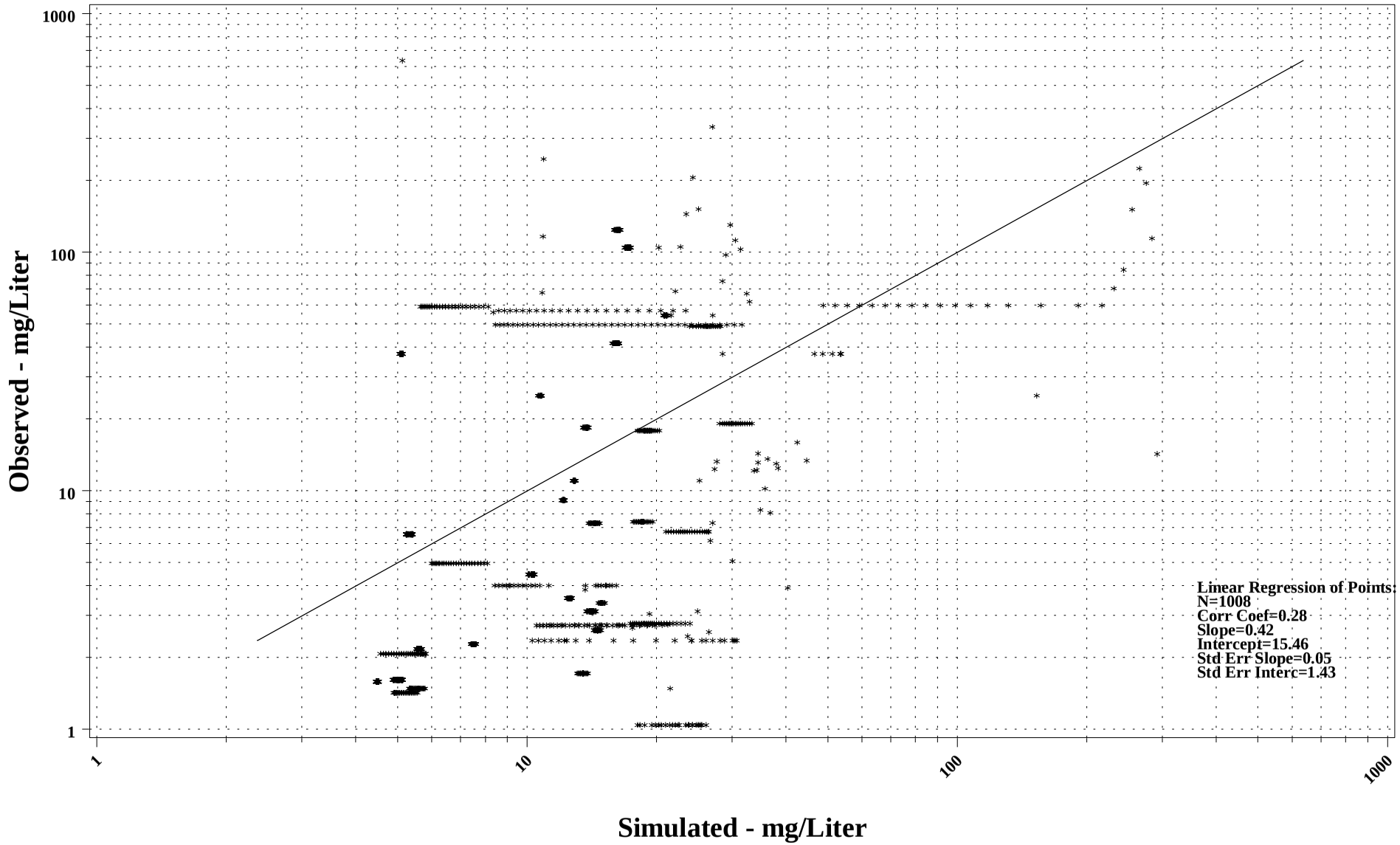


(10SEP02 13:14)
(plot.sas, omtime)

Inland/ Segment 330 - Beaver Dam Ditch: Calibration Run

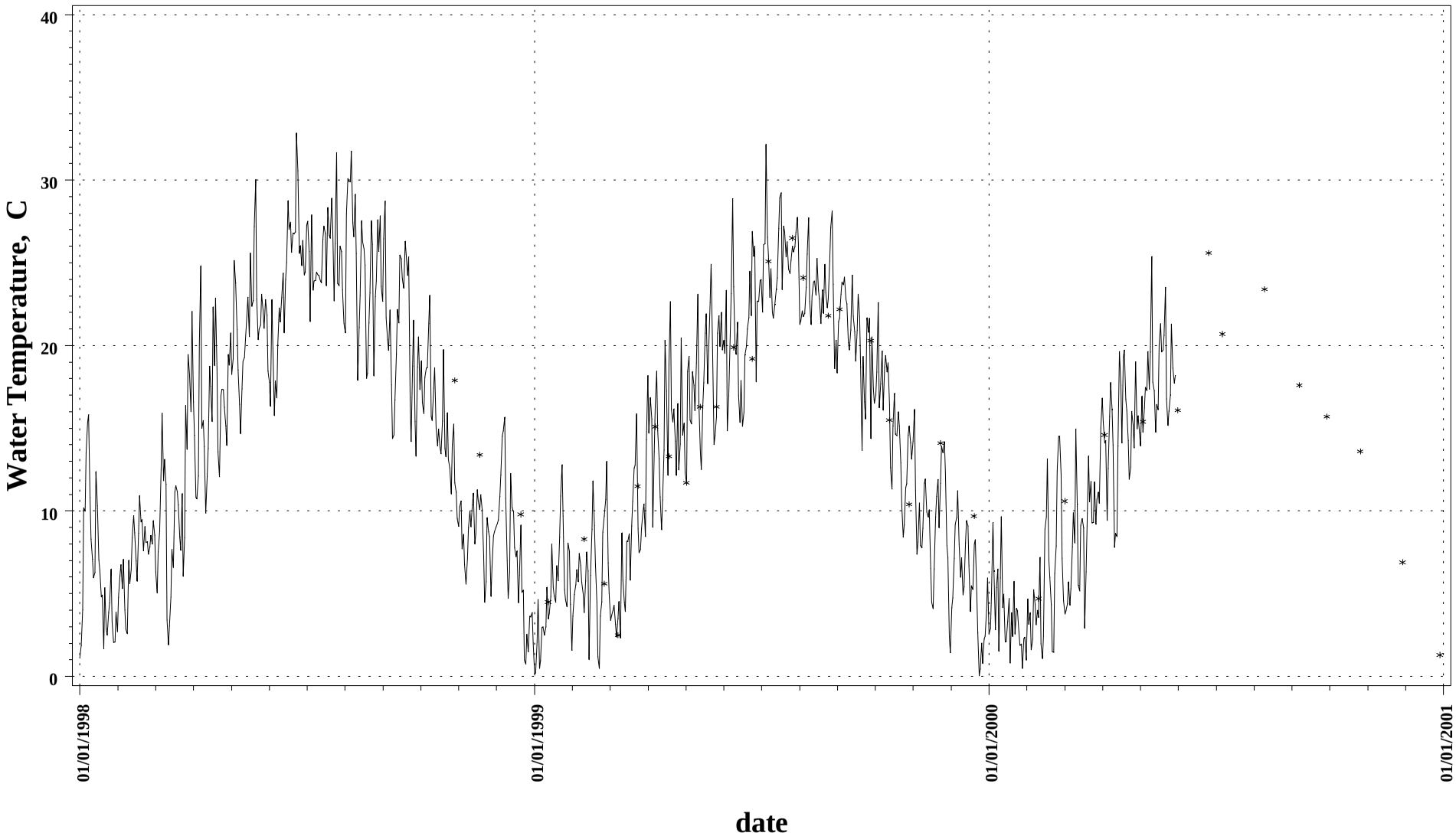
Scatter Plot and Regression of Simulated versus Observed with Ideal Line

Total Suspended Sediment: 01JAN98 - 01JAN01



(10SEP02 13:14)
(plot.sas, llomregr.sas)

Inland/ Segment 330 - Beaver Dam Ditch: Calibration Run
Water Temperature
Observed and Simulated versus Time
(* =Observed, - =Simulated)

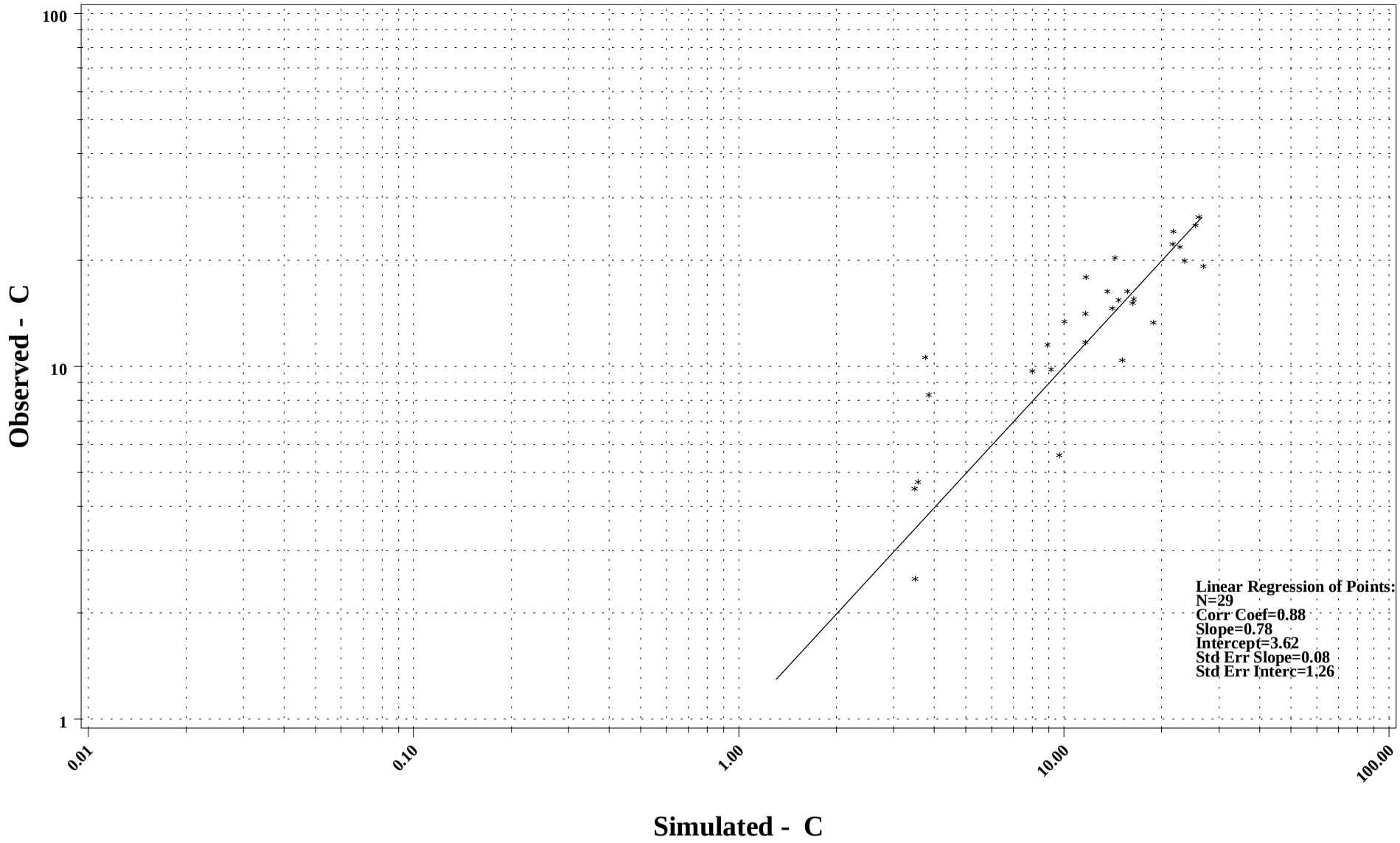


(10SEP02 13:14)
(plot.sas, omtime)

Inland/ Segment 330 - Beaver Dam Ditch: Calibration Run

Scatter Plot and Regression of Simulated versus Observed with Ideal Line

Water Temperature: 01JAN98 - 01JAN01



(10SEP02 13:14)
(plot.sas, llomregr.sas)