Tampa Bay Estuary Program
Model Evaluation and Update:

Chlorophyll a – Light Attenuation Relationship

Prepared for:

Tampa Bay Estuary Program
Mail Station I-1/NEP
100 8th Avenue SE
St. Petersburg, FL 33701

Prepared by:

Janicki Environmental, Inc.

1155 Eden Isle Drive NE
St. Petersburg, FL 33704

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FOREWORD

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ACKNOWLEDGMENTS

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1 INTRODUCTION

The Tampa Bay National Estuary Program (TBNEP) developed a Comprehensive Conservation & Management Plan (CCMP), entitled *Charting the Course,* which was the culmination of five years of effort aimed at bringing together the participants of the TBNEP to address the key environmental issues affecting Tampa Bay. The CCMP specifically addressed several major issues, including water quality and habitat loss. The loss of seagrasses in Tampa Bay drew particular interest, given their important role in the ecological functioning of the bay.

Seagrasses provide critical habitat for recreationally and commercially important fish and invertebrate species. Seagrasses in Florida provide juvenile nursery and adult feeding areas for red drum, spotted seatrout, spot, silver perch, sheepshead, snook, shrimp, and the bay scallop (Zieman and Zieman, 1989). Seagrass meadows are also important feeding areas for the Florida manatee. Seagrasses serve to improve water quality by reducing nutrients in the water column and are an important component of the energy and nutrient cycles in coastal environments.

Seagrass extent and condition can be impacted by many factors, including water quality, physical factors such as prop scarring and currents, seagrass disease, and location of seagrass beds in relation to offshore transverse sandbars. The TBNEP Technical Advisory Committee (TAC) recognizes that these and other factors may affect progress towards reaching adopted seagrass restoration goals, and is currently initiating actions which will assist with addressing factors in addition to water clarity and quality (including the initiation of measuring the depth of water at various seagrass beds around the bay, and the monitoring of potential seagrass disease). Actions needed to address additional factors, such as the bay-wide effects of prop scarring or the location of various seagrass beds, will be included in discussions of future monitoring needs.

In Tampa Bay, seagrasses typically grow at depths no deeper than six to eight feet. Light is one of the limiting factors on the depth at which seagrasses can be found. Light requirements for growth vary by seagrass species. Turtle grass, the most common seagrass species in Tampa Bay, has an estimated light requirement of 20.5% of the incident subsurface light (Dixon and Leverone, 1995). For the purposes of seagrass restoration target setting, this was assumed to be the minimum light requirement for seagrasses in Tampa Bay (Janicki and Wade, 1996).

To address the issue of seagrass habitat loss, recommended seagrass protection and restoration targets were developed (Janicki et al., 1995). Seagrass restoration targets were determined by comparing 1990 seagrass extent to that observed in 1950. Seagrass targets were defined as those portions of Tampa Bay that had seagrasses in 1950, did not have seagrasses in 1990, and had not been permanently altered to preclude restoration of seagrasses.

To strive toward the seagrass restoration goal, the TBNEP developed the Nitrogen Management Strategy. The Strategy seeks to prevent future impacts due to excessive nitrogen loadings to Tampa Bay. To address these concerns, a paradigm that relates nitrogen loading to chlorophyll and seagrass was utilized, as shown in Figure 1-1.

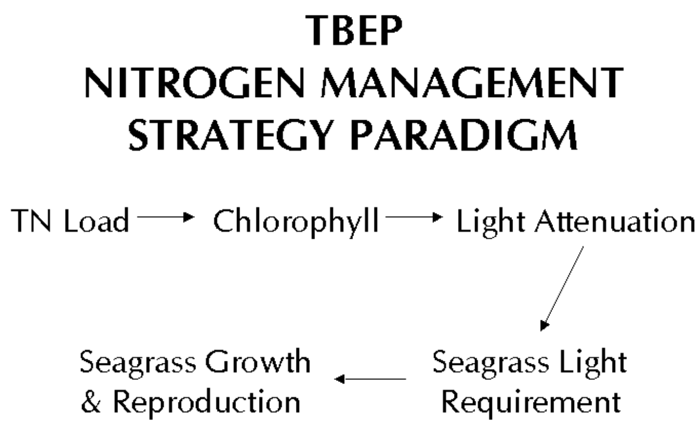

Figure 1-1. The TBNEP Nitrogen Management Strategy Paradigm.

An empirical modeling approach was taken to define the relationships between TN loads and chlorophyll a concentrations and between chlorophyll a concentrations and light attenuation (Janicki and Wade, 1996).

The objective of this report is to re-evaluate the empirical relationship between chlorophyll a concentrations and light attenuation using the water quality data collected since 1994 by the Environmental Protection Commission of Hillsborough County (EPCHC).

2 METHODS

A principal working hypothesis was earlier developed that observed light attenuation is directly related to chlorophyll a concentrations, turbidity, and color (Janicki and Wade, 1996). Regression results suggest that the variation in chlorophyll a concentrations could explain the majority of the variation in light attenuation as measured by the diffuse light attenuation coefficient, K_d. Beer's Law allows approximation of K_d as follows:

$$I_z = I_0 \times e^{-(K_d)z}$$

where: I_z = the incident light at depth *z*,

I_0 = the incident light just below the surface, and

K_d = the diffuse light attenuation coefficient (1/meters).

Giesen et al. (1990) reported that the diffuse attenuation coefficient K_d can be approximated by a factor (that typically ranges between 1.5 and 1.8) divided by the Secchi disc depth (expressed in meters). Concurrently measured K_d and Secchi disc depths reported by the City of Tampa Bay Study Group (Johansson, pers. comm.) were used to verify this relationship for Tampa Bay and to refine bay segment-specific factors.

The depth to which a particular amount of light penetrates, expressed as the percentage of incident irradiance, can be estimated using the following rearrangement of Beer's Law:

$$Z = (-1 \times \ln(\frac{\%\,Light}{100})) \times K_d\ factor$$

where: Z = the depth to which the defined % light penetrates

% Light = the desired % light (defined as 20.5% for this study)

K_d factor = the bay segment-specific factor that relates K_d and Secchi disc depth

The relationship between chlorophyll a concentrations and light attenuation, expressed as the depth to which 20.5% of the surface irradiance penetrates, was expressed by the following equation:

$$ln(C_{t,s}) = \alpha_{t,s} + \hat{a}_{t,s} \times ln(Z_{t,s})$$

where:

	$Z_{t,s}$	= the depth to which 20.5% of surface irradiance penetrates in month *t* and bay segment *s*
	$C_{t,s}$	= average chlorophyll a concentration in month *t* and bay segment *s*
	$\alpha_{t,s}$ and β_s	= regression parameters.

Least squares regression methods were used to estimate the regression parameters (Janicki and Wade, 1996). The results of the regressions indicated that the variation in the observed depths to which 20.5% of surface irradiance penetrates could be explained by the variation in observed chlorophyll a concentrations. Monthly specific regression intercept terms were used to avoid any potentially confounding effects of seasonality in the independent and dependent variables. Turbidity data were also investigated as a possible explanation for a portion of the remaining unexplained variation in the light penetration data. No improvement in the model fit was found.

Water quality data collected by the EPCHC for the period 1995 through 1998 were obtained and incorporated into the TBEP water quality database (Janicki Environmental, 2000). These data were used to evaluate the chlorophyll a – light attenuation model developed previously using data from the period 1986 through 1994.

Initially, visual inspection of the relationship between chlorophyll a concentrations and $Z_{20.5\%}$ was completed by plotting these data and identifying the period from which the data were obtained. Secondly, the chlorophyll a – Z regression was used to estimate Z given the observed chlorophyll a concentrations during 1995 through 1998. Comparisons of the predicted and observed Z values, for both monthly and annual mean conditions, were also made. Thirdly, the residuals (i.e., the difference of the observed and predicted Z values) were related to observed turbidity and color values to assess whether differences in turbidity or color could account for the unexplained variation in the Z values.

3 RESULTS

The results of the three methods used to evaluate the chlorophyll a – Z regression for Tampa Bay are presented below.

Visual Comparison of the Chlorophyll a – Light Attenuation Relationship

The following figures present the chlorophyll a – light attenuation relationship for all bay segments and for each of the bay segments:

- Figure 3-1 - All bay segments
- Figure 3-2 - Old Tampa Bay
- Figure 3-3 - Hillsborough Bay
- Figure 3-4 - Middle Tampa Bay - 31
- Figure 3-5 - Middle Tampa Bay - 32
- Figure 3-6 - Middle Tampa Bay - 33.

Specifically, the depth to which 20.5% of incident radiation penetrates (Z) is plotted as a function of chlorophyll a concentration. In each plot, the 1995-1998 data are presented as triangles while the 1986-1994 data are presented as circles.

Clearly, there is considerable similarity in the chlorophyll a – Z relationships from the 1986-1994 and 1995-1998 periods. Close scrutiny of the data does suggest, however, that the 1995-1998 data tend toward shallower Z values for the same chlorophyll a concentrations. This seems to be particularly true when chlorophyll a concentrations are less than 10 μg/L. Therefore, there is some evidence that at lower chlorophyll a levels incident light penetrated to somewhat shallower depths in the 1995-1998 period as compared to the 1986-1994 period.

Comparison of Predicted and Observed Z Values Using the 1986-1994 Chlorophyll a – Light Attenuation Regressions

The following figures present a comparison of the observed mean monthly Z values for the 1995-1998 period to the Z values predicted by the ambient mean monthly chlorophyll a concentrations and the chlorophyll a – Z regressions developed from the 1986-1994 data (Janicki and Wade, 1996):

- Figure 3-7 – Old Tampa Bay
- Figure 3-8 – Hillsborough Bay
- Figure 3-9 – Middle Tampa Bay – 31
- Figure 3-10 – Middle Tampa Bay – 32
- Figure 3-11 – Middle Tampa Bay – 33.

These plots include a line that represents a 1:1 relationship between predicted and observed values. Data points above the line represent months when the predicted Z value was greater than that which was observed. Data points below the line represent months when the predicted Z value was less than that which was observed. Close agreement in the predicted and observed Z values would result in a plot where the points were in close proximity to the line. If any bias in the predicted Z values exists then a disproportionate number of points would be found either above (observed > predicted) or below (observed < predicted) the line.

These comparisons of mean monthly predicted and observed Z values also indicate that there is a small but consistent bias in the observed Z values. In all bay segments, the observed Z values were generally less than those predicted by the regressions. This suggests that for the same chlorophyll a concentration the mean monthly Z values observed during the 1995-1998 period was generally less than that observed during the 1986-1994 period.

Table 3-1 presents a comparison of the mean annual predicted and observed Z values by bay segment. The differences in the observed and predicted Z values were typically greatest in 1996 and 1997 in all bay segments. In both years, the predicted mean annual Z exceeded the observed mean annual Z. In 1995 there was relatively good agreement between the predicted and observed mean annual Z values. In 1998, the observed mean annual Z exceeded the predicted value. Overall, the difference in Z values was approximately 0.3 meters in Old Tampa Bay and Middle Tampa Bay segments 32 and 33 and between 0.1 and 0.2 meters in Hillsborough Bay and Middle Tampa Bay segment 31.

Table 3-1. Mean annual predicted and observed Z values.

Bay	1995		1996		1997		1998	
Segment	**Observed**	**Predicted**	**Observed**	**Predicted**	**Observed**	**Predicted**	**Observed**	**Predicted**
OTB	1.69	1.86	1.73	2.52	1.88	2.45	1.50	1.36
HB	1.11	1.12	1.26	1.58	1.16	1.40	0.99	0.95
MTB-1	1.24	1.24	1.35	1.93	1.07	1.31	0.98	0.87
MTB-2	1.79	1.95	1.88	2.48	1.84	2.52	1.42	1.26
MTB-3	1.81	2.05	2.3	3.32	1.91	2.25	1.47	1.38

Relationship Between Residuals from the Chlorophyll a – Light Attenuation Regressions and Other Variables

To examine the potential influence of other variables that can affect light attenuation, the residuals from the chlorophyll a – light attenuation model estimated for the 1995-1998 period were plotted as a function of these variables. Specifically, turbidity and color can affect light attenuation.

Residual Z values are plotted as a function of turbidity by bay segment in the following figures:

- Figure 3-12 – Old Tampa Bay
- Figure 3-13 – Hillsborough Bay
- Figure 3-14 – Middle Tampa Bay – 31
- Figure 3-15 – Middle Tampa Bay – 32
- Figure 3-16 – Middle Tampa Bay – 33.

Residual Z values are also plotted as a function of color by bay segment in the following figures:

- Figure 3-17 – Old Tampa Bay
- Figure 3-18 – Hillsborough Bay
- Figure 3-19 – Middle Tampa Bay – 31
- Figure 3-20 – Middle Tampa Bay – 32
- Figure 3-21 – Middle Tampa Bay – 33.

If either turbidity or color significantly influenced the chlorophyll a - light attenuation relationship, then a discernable pattern in the residuals would be expected. Thus, the residual Z values would be greater at higher values of either turbidity or color. Inspection of the residual plots suggests that neither turbidity nor color is significantly related to the residual Z value.

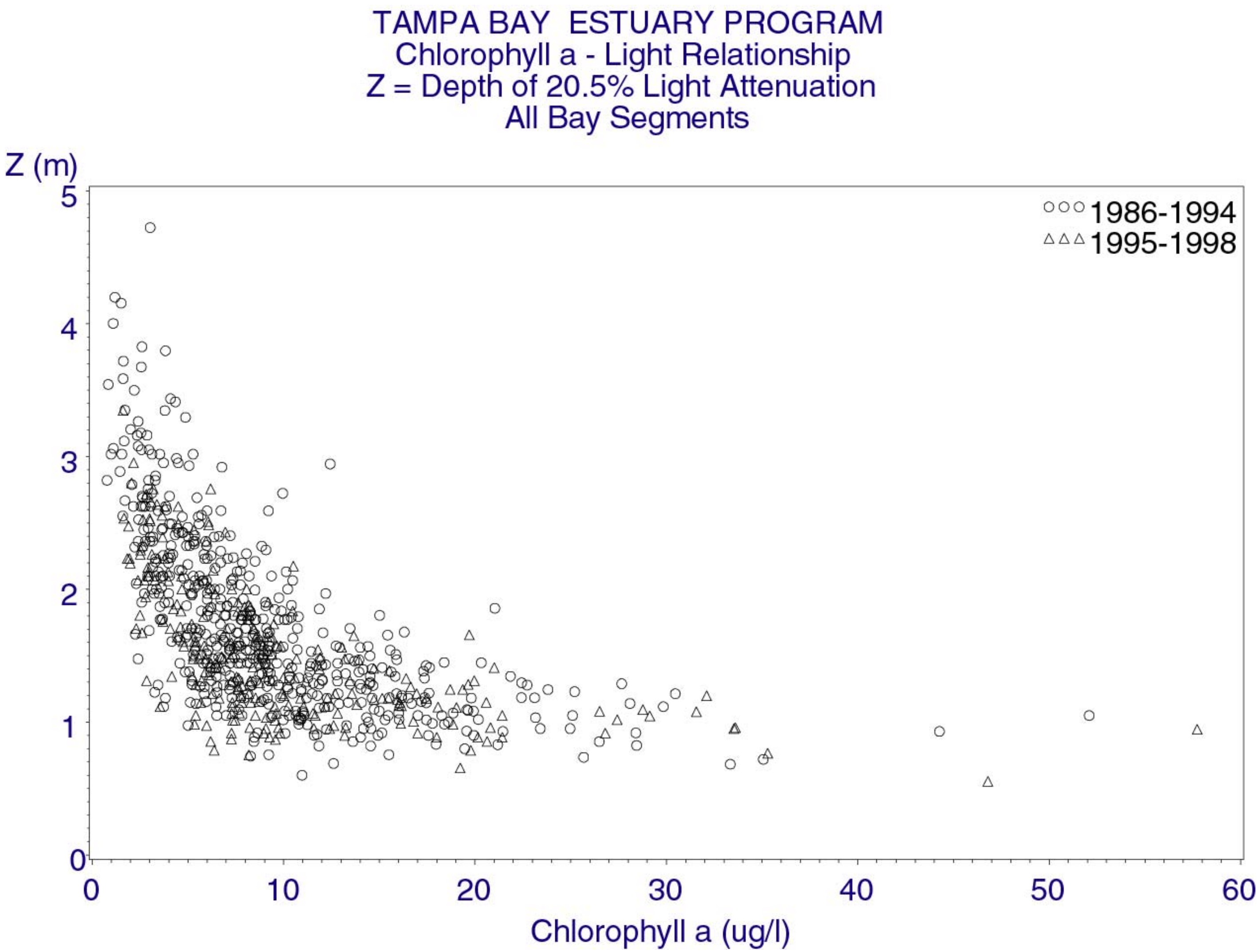

Figure 3-1. Relationship between chlorophyll a and depth of 20.5% light attenuation, all bay segments.

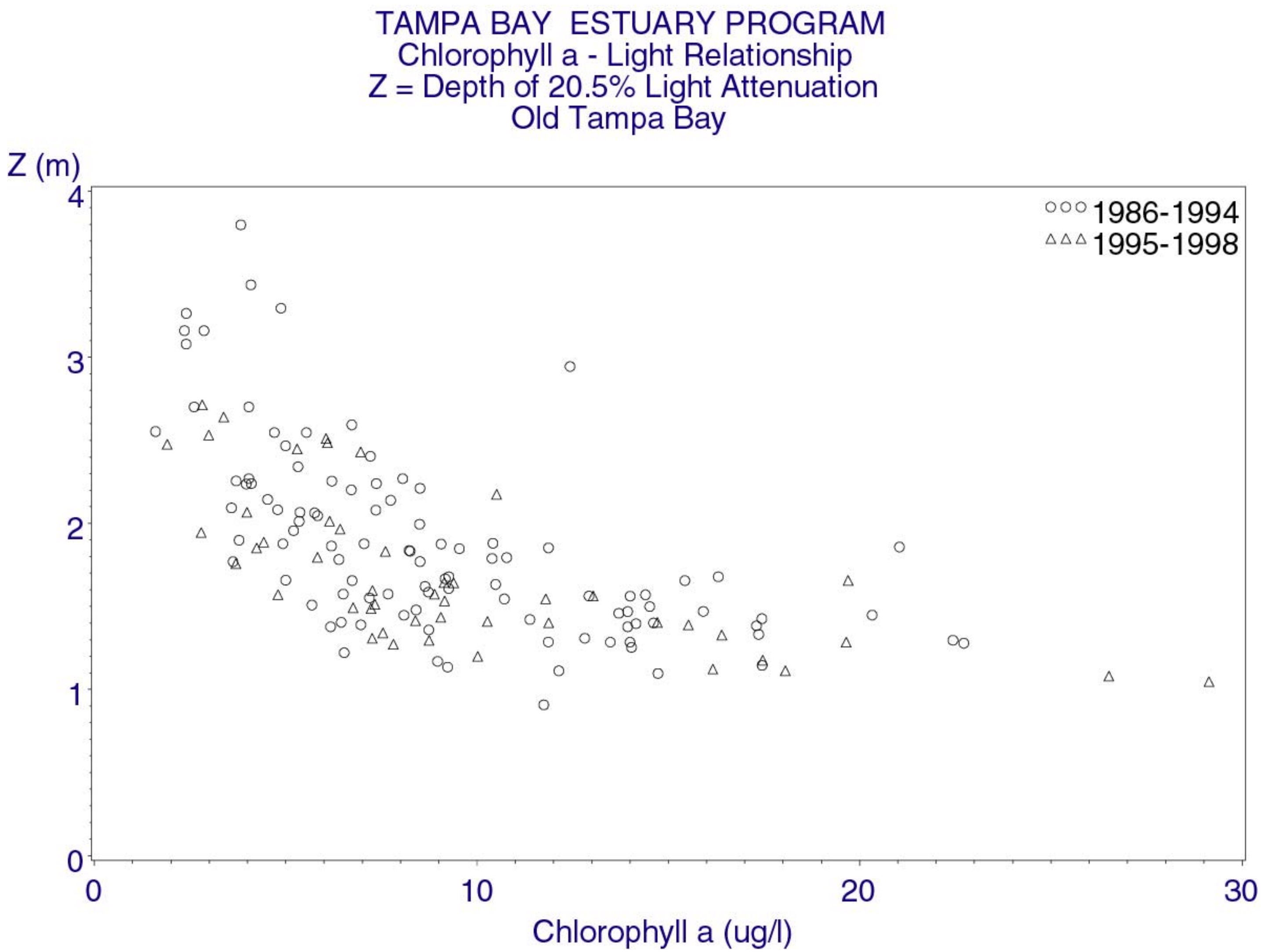

Figure 3-2. Relationship between chlorophyll a and depth of 20.5% light attenuation, Old Tampa Bay.

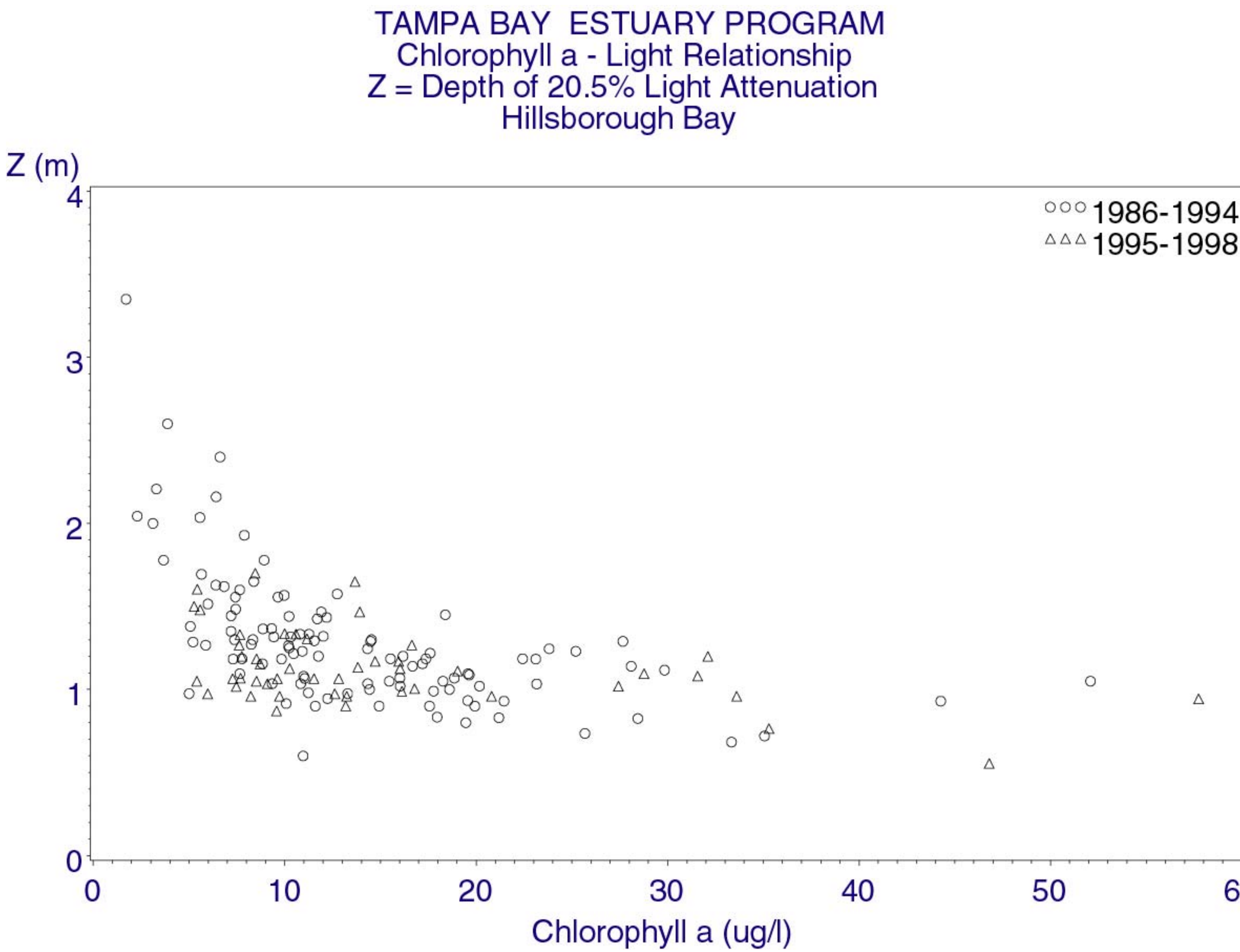

Figure 3-3. Relationship between chlorophyll a and depth of 20.5% light attenuation, Hillsborough Bay.

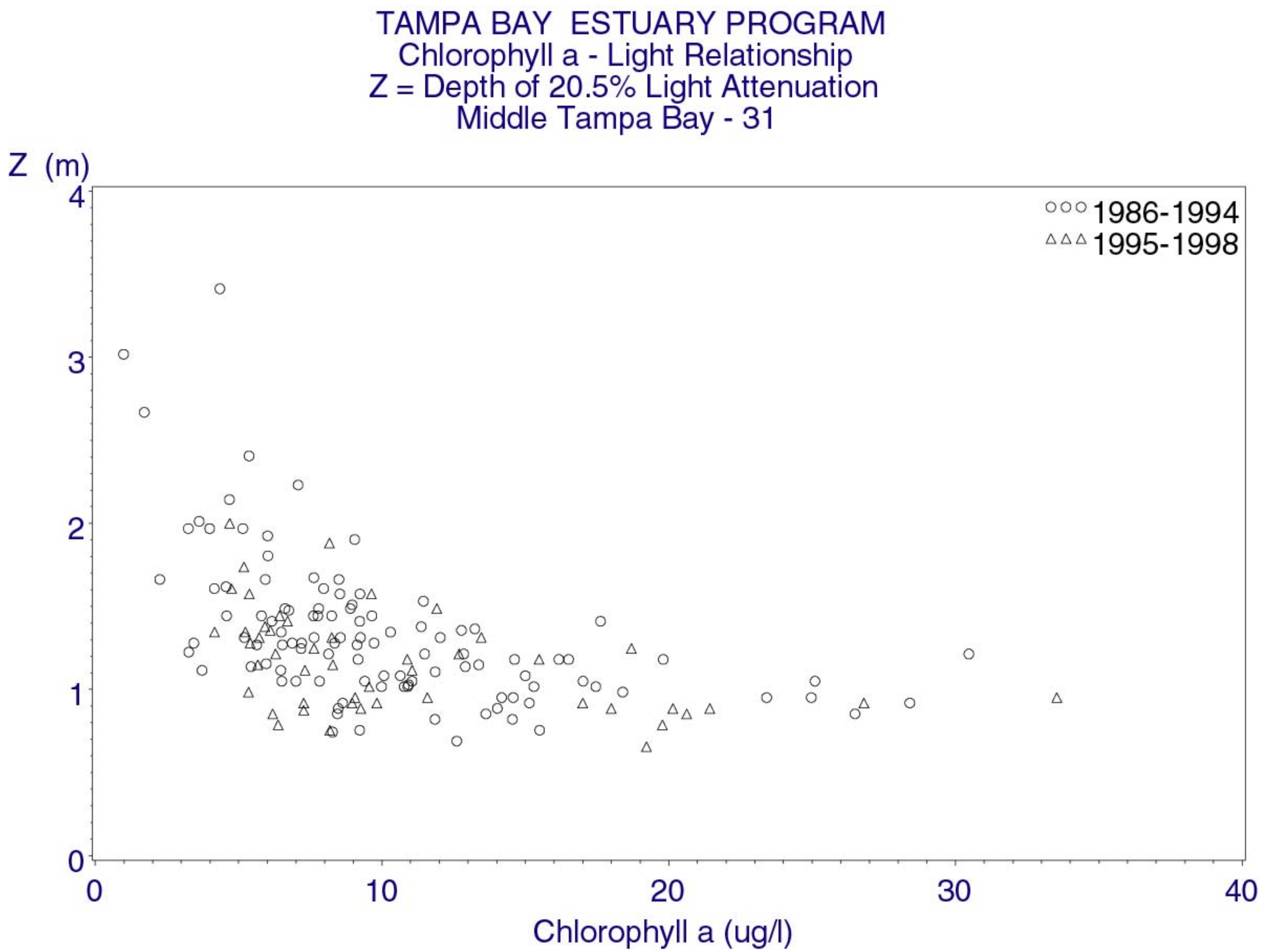

Figure 3-4. Relationship between chlorophyll a and depth of 20.5% light attenuation, Middle Tampa Bay 31.

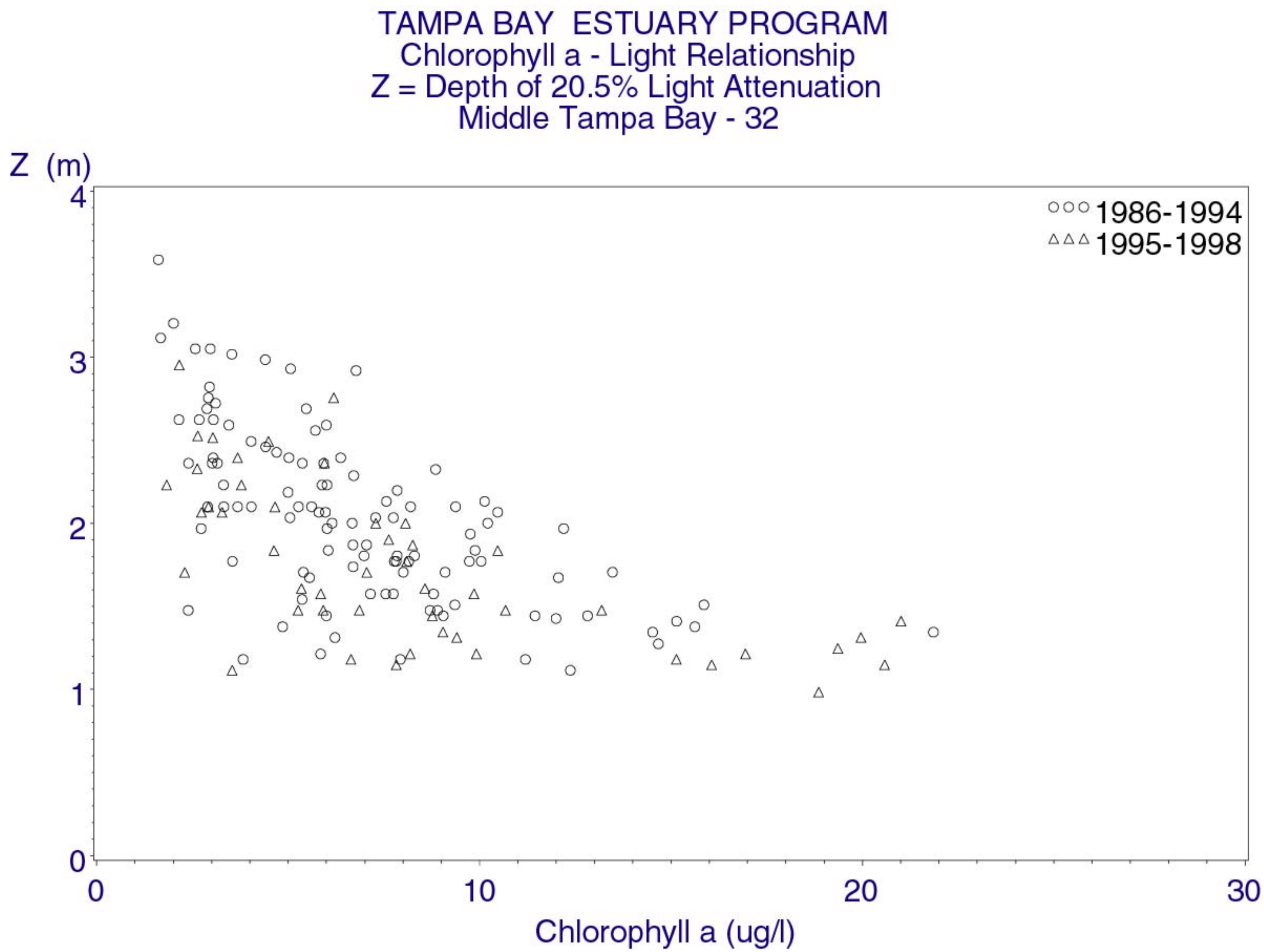

Figure 3-5. Relationship between chlorophyll a and depth of 20.5% light attenuation, Middle Tampa Bay 32.

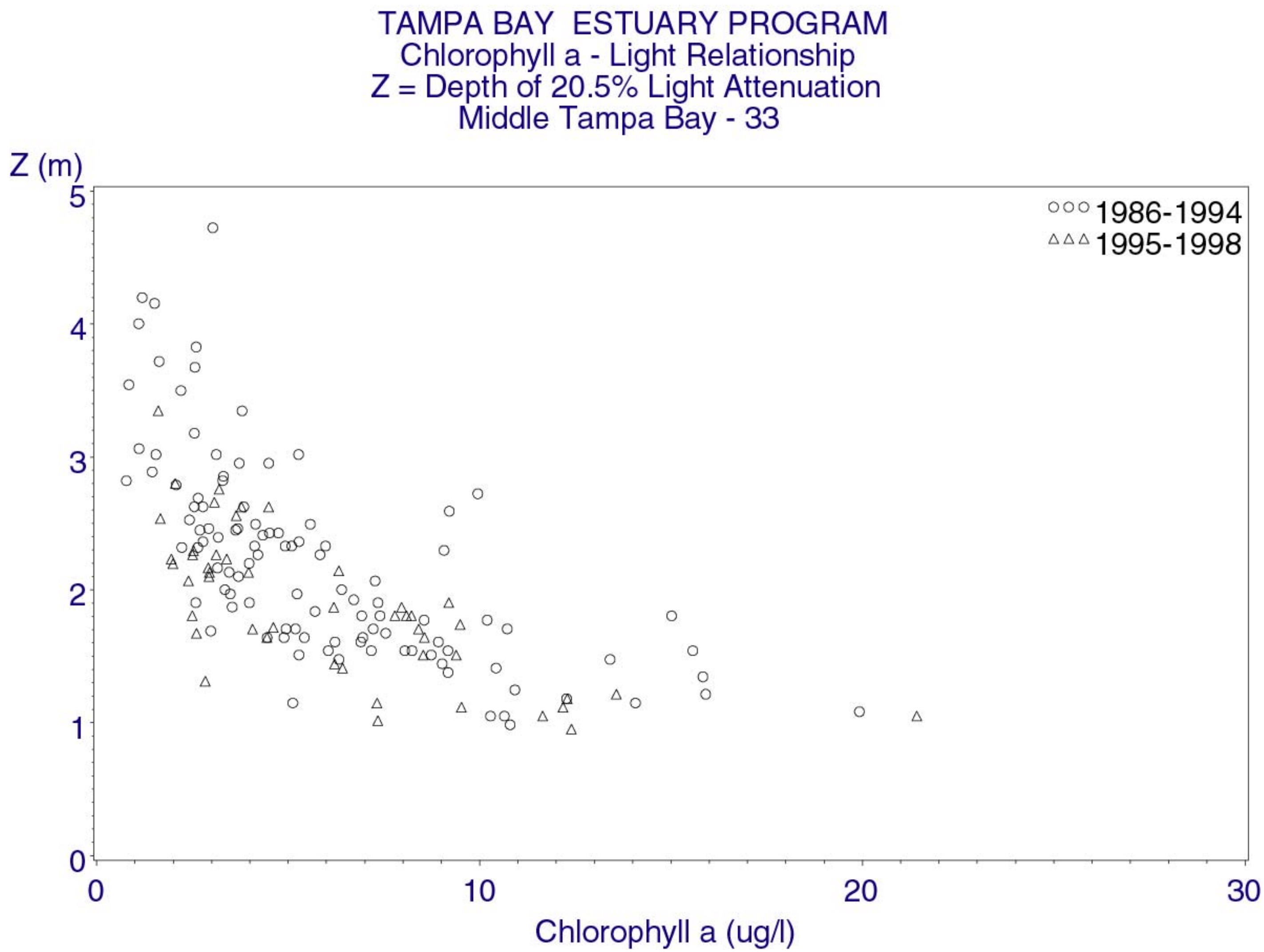

Figure 3-6. Relationship between chlorophyll a and depth of 20.5% light attenuation, Middle Tampa Bay 33.

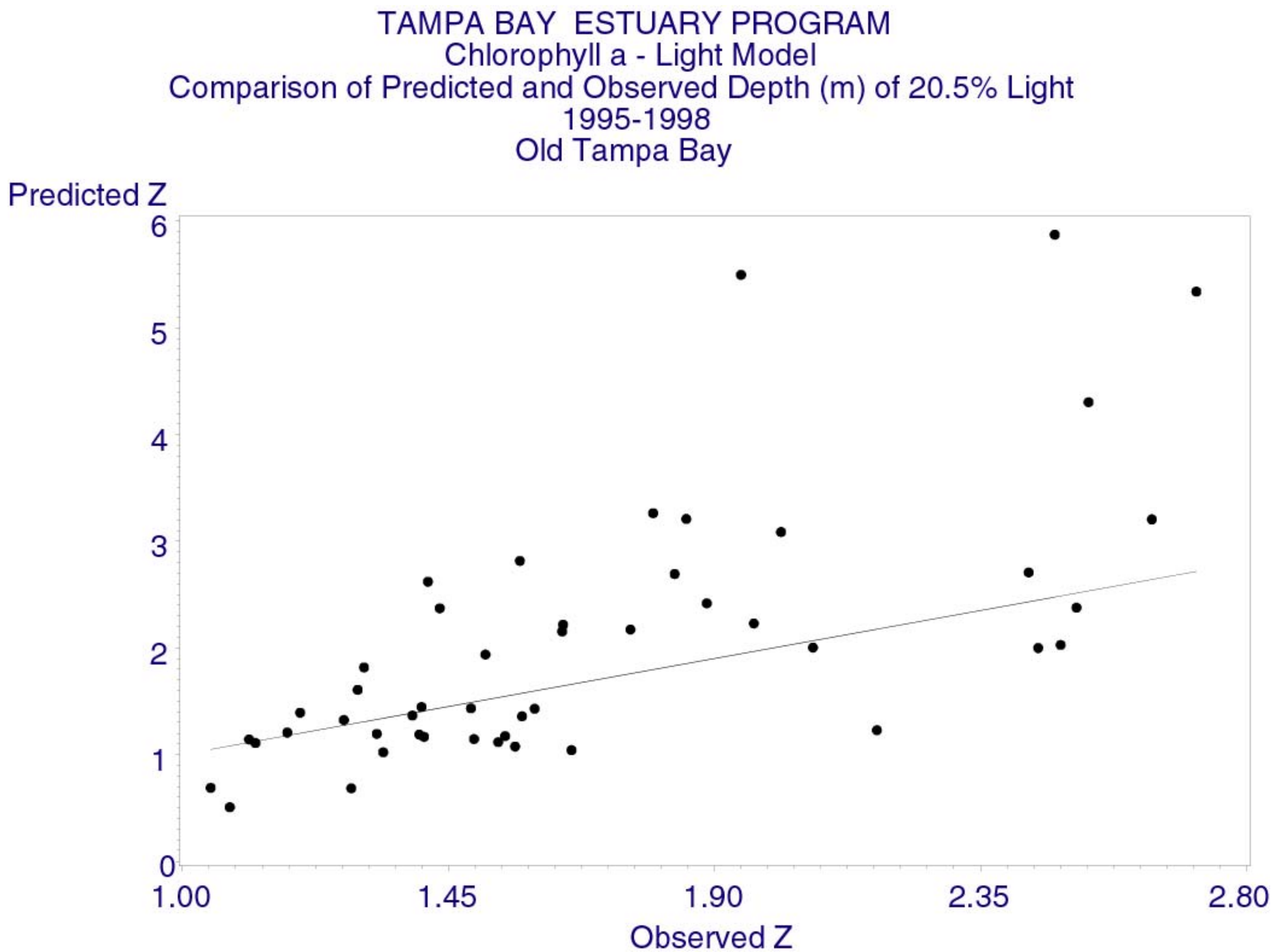

Figure 3-7. Relationship between observed and predicted depth of 20.5% light attenuation, Old Tampa Bay.

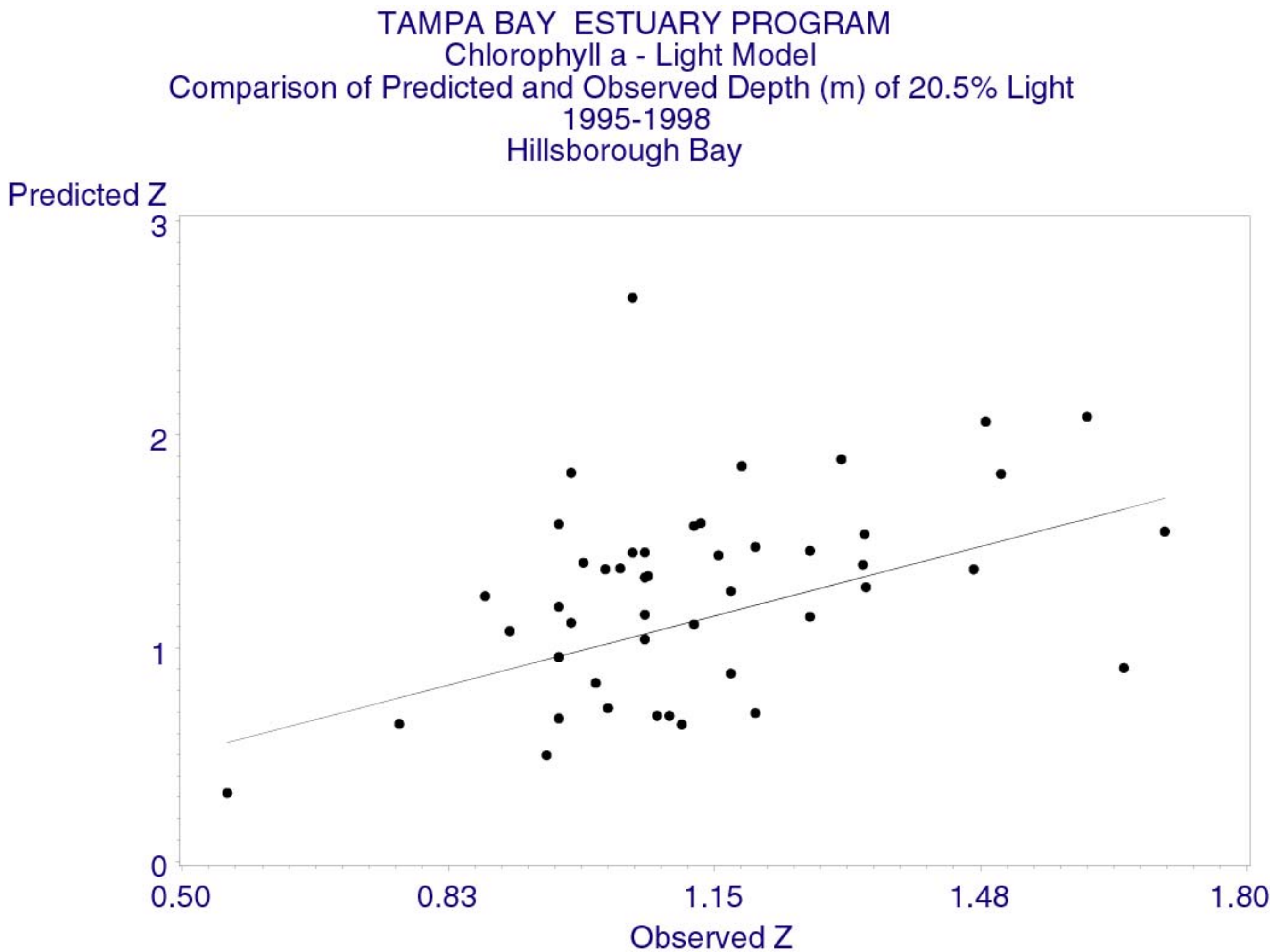

Figure 3-8. Relationship between observed and predicted depth of 20.5% light attenuation, Hillsborough Bay.

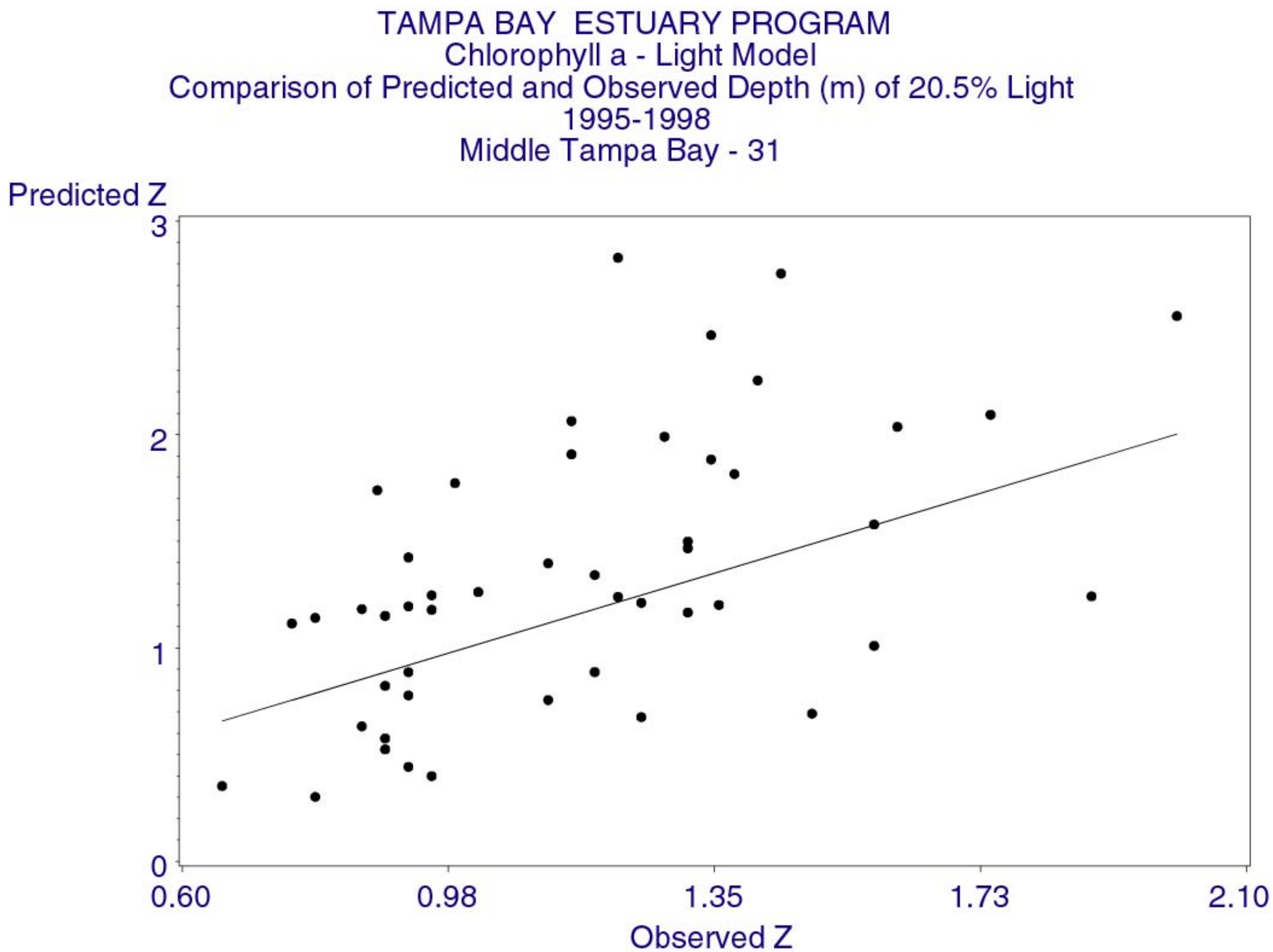

Figure 3-9. Relationship between observed and predicted depth of 20.5% light attenuation, Middle Tampa Bay 31.

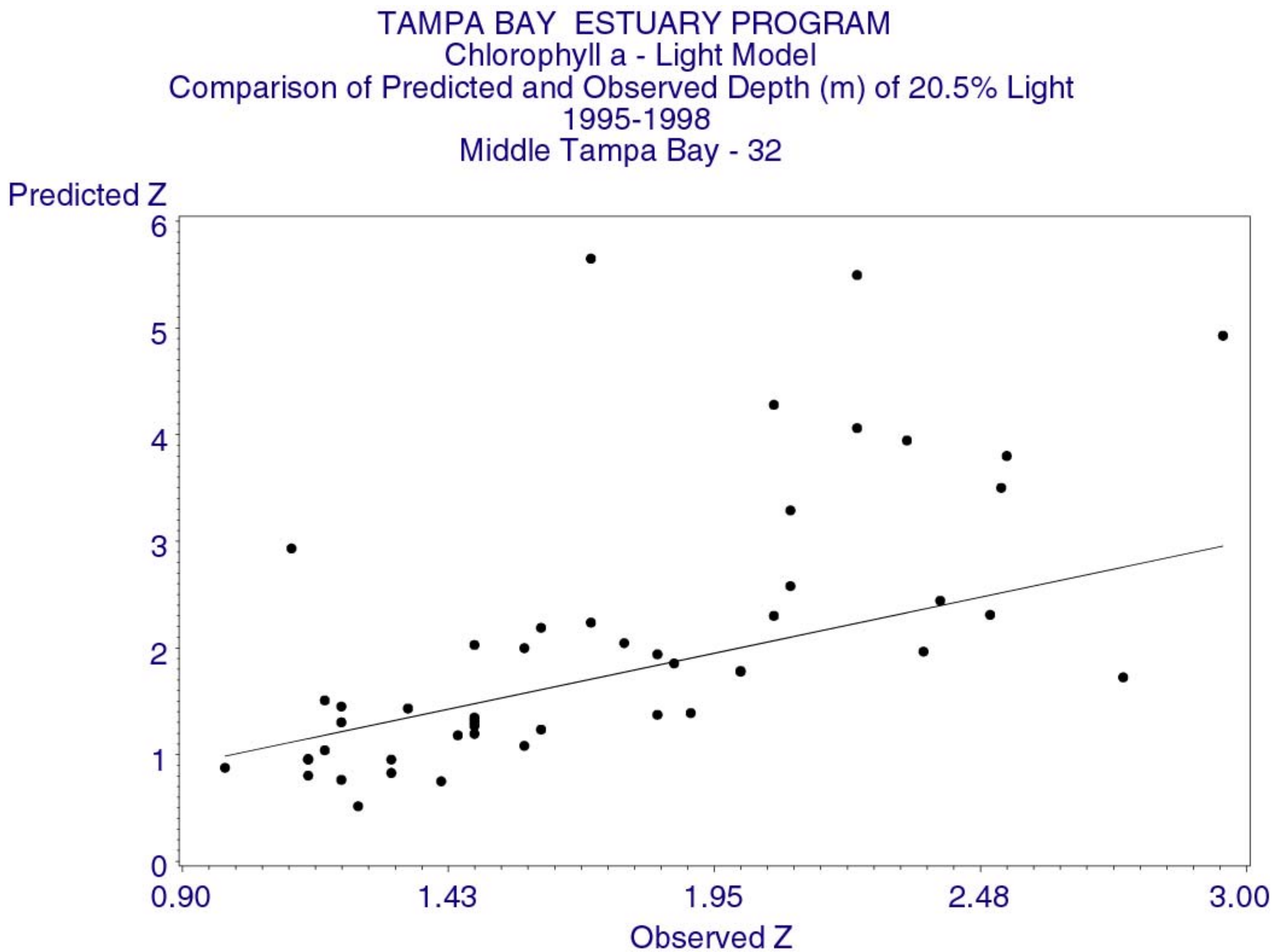

Figure 3-10. Relationship between observed and predicted depth of 20.5% light attenuation, Middle Tampa Bay 32.

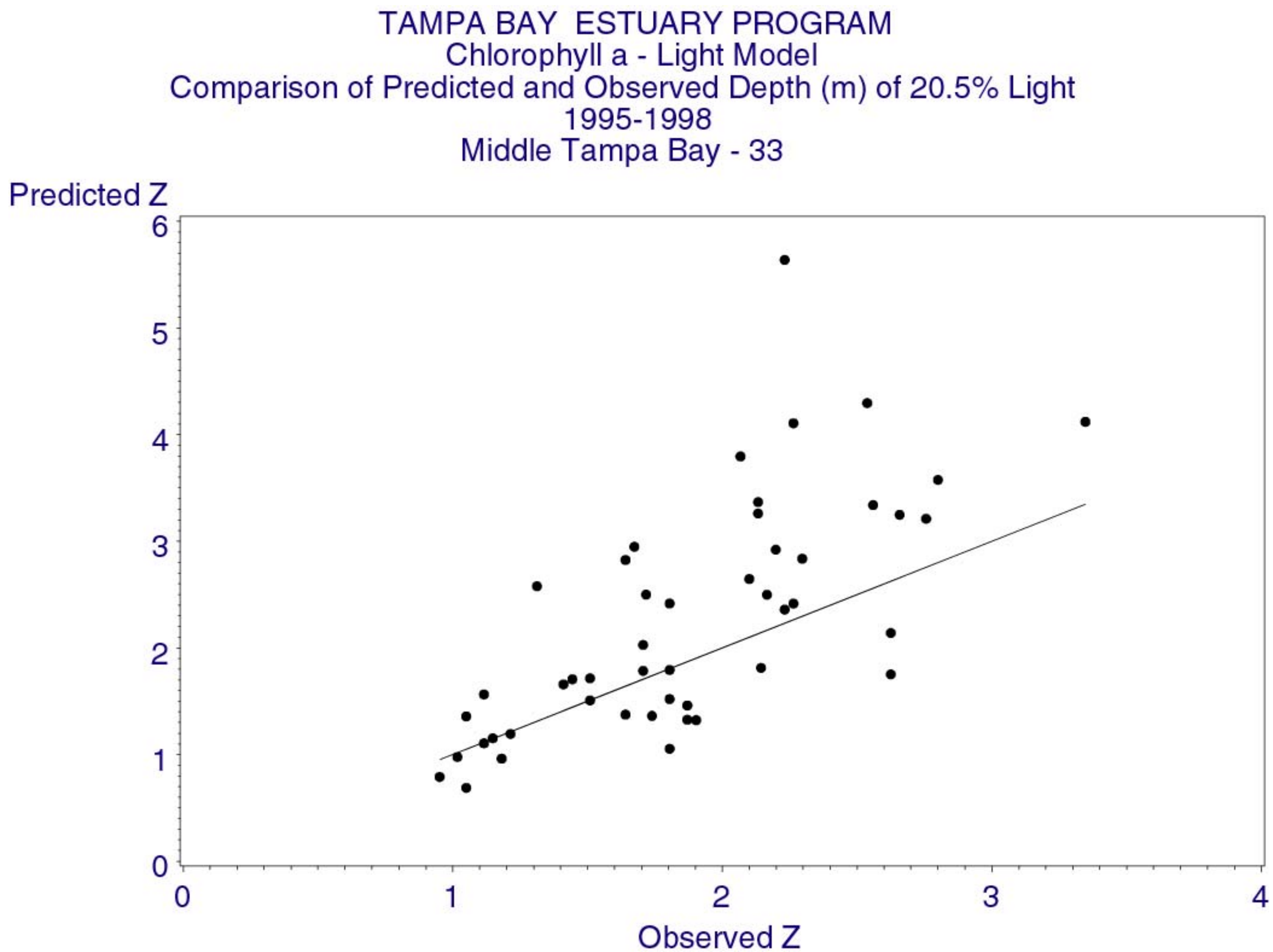

Figure 3-11. Relationship between observed and predicted depth of 20.5% light attenuation, Middle Tampa Bay 33.

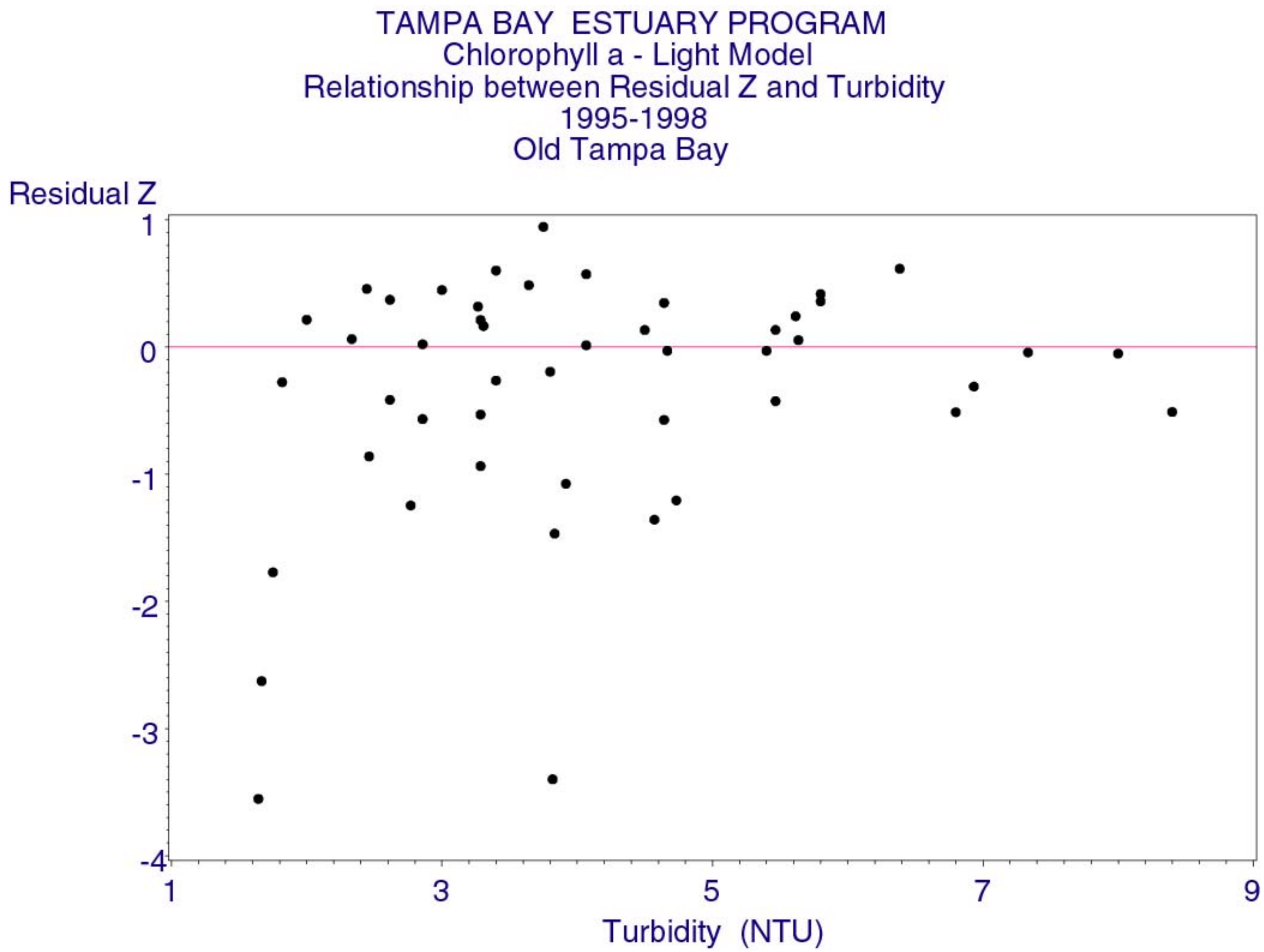

Figure 3-12. Relationship between turbidity and residuals of the depth of 20.5% light attenuation, Old Tampa Bay.

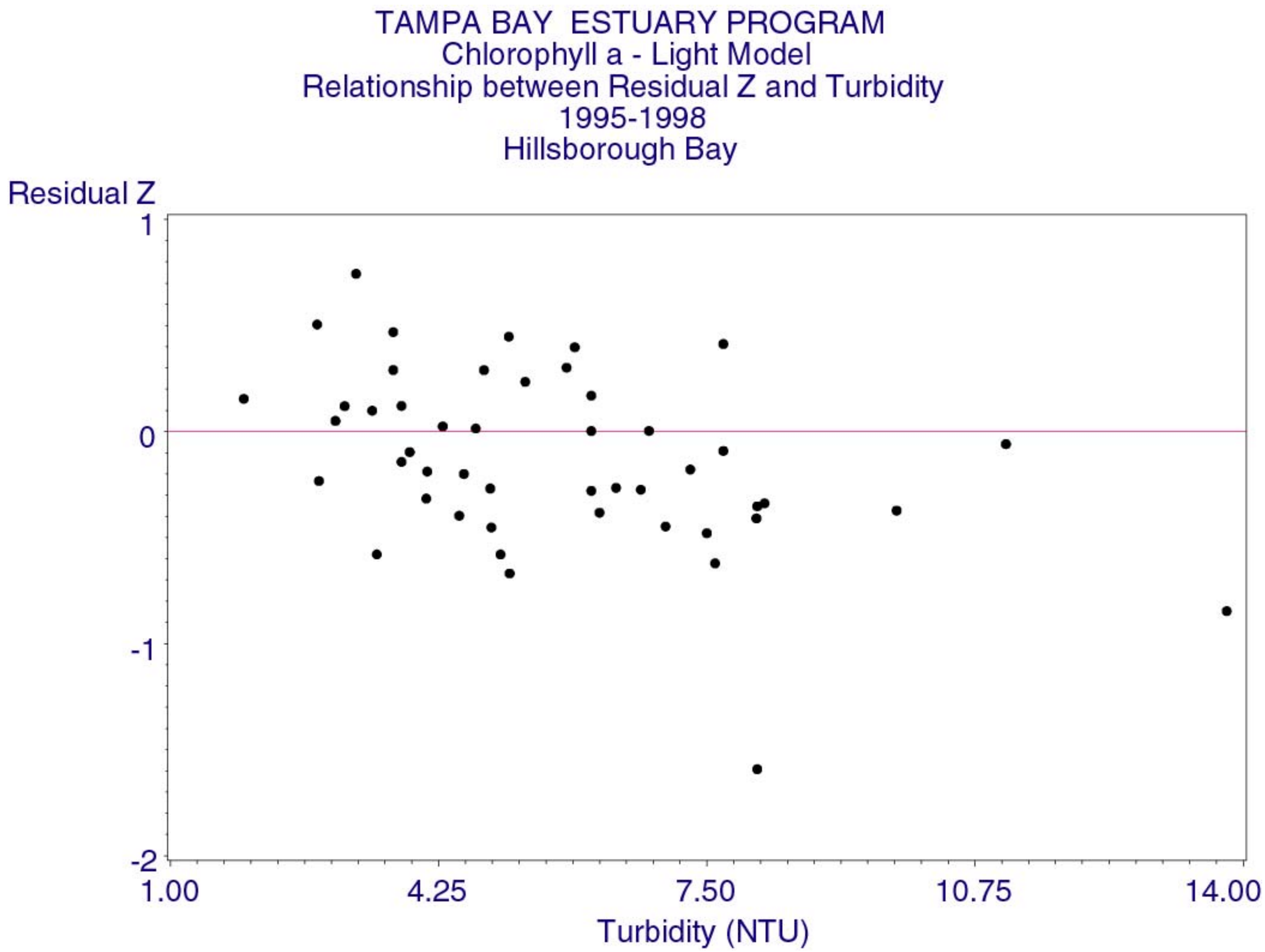

Figure 3-13. Relationship between turbidity and residuals of the depth of 20.5% light attenuation, Hillsborough Bay.

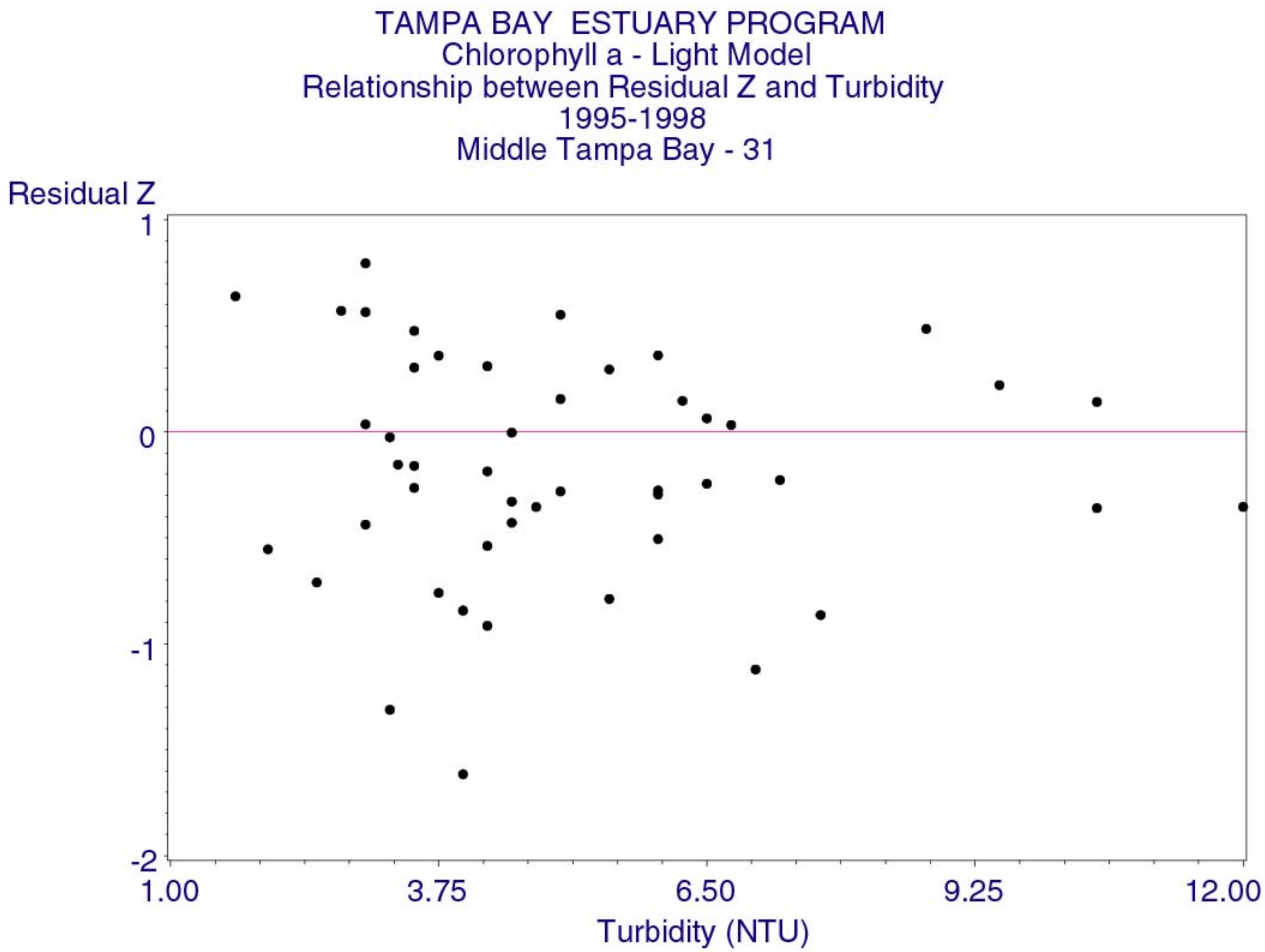

Figure 3-14. Relationship between turbidity and residuals of the depth of 20.5% light attenuation, Middle Tampa Bay 31.

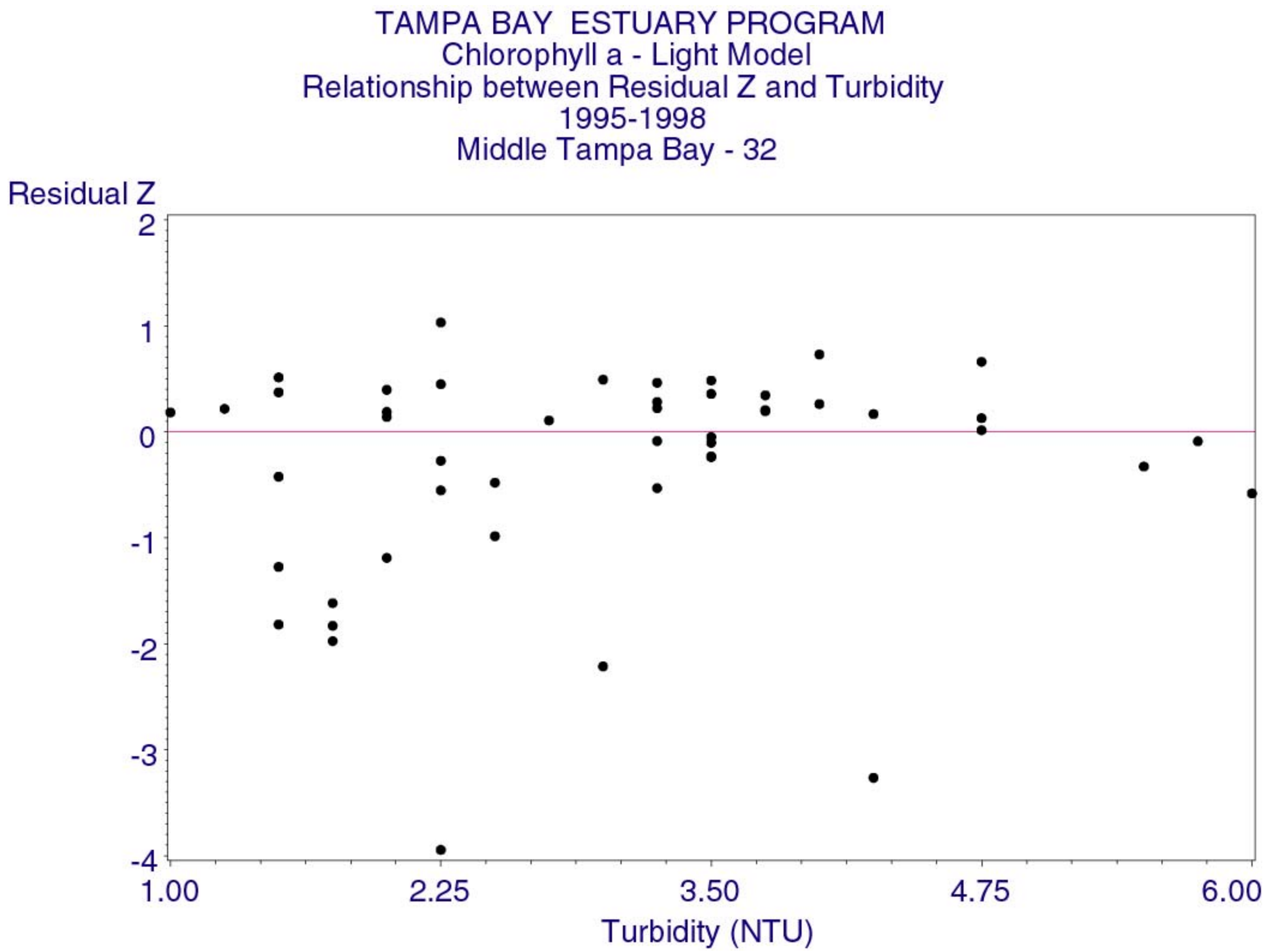

Figure 3-15. Relationship between turbidity and residuals of the depth of 20.5% light attenuation, Middle Tampa Bay 32.

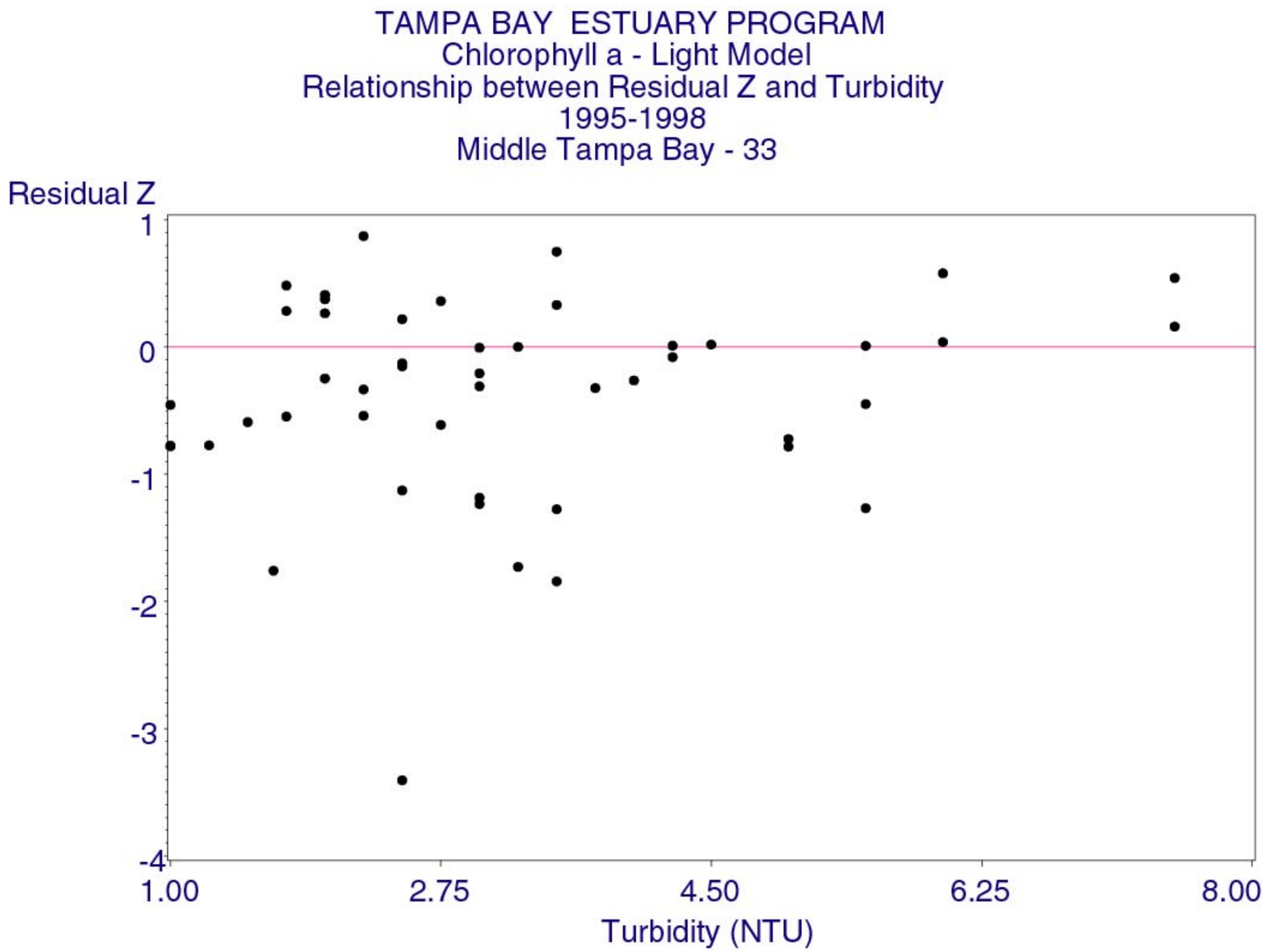

Figure 3-16. Relationship between turbidity and residuals of the depth of 20.5% light attenuation, Middle Tampa Bay 33.

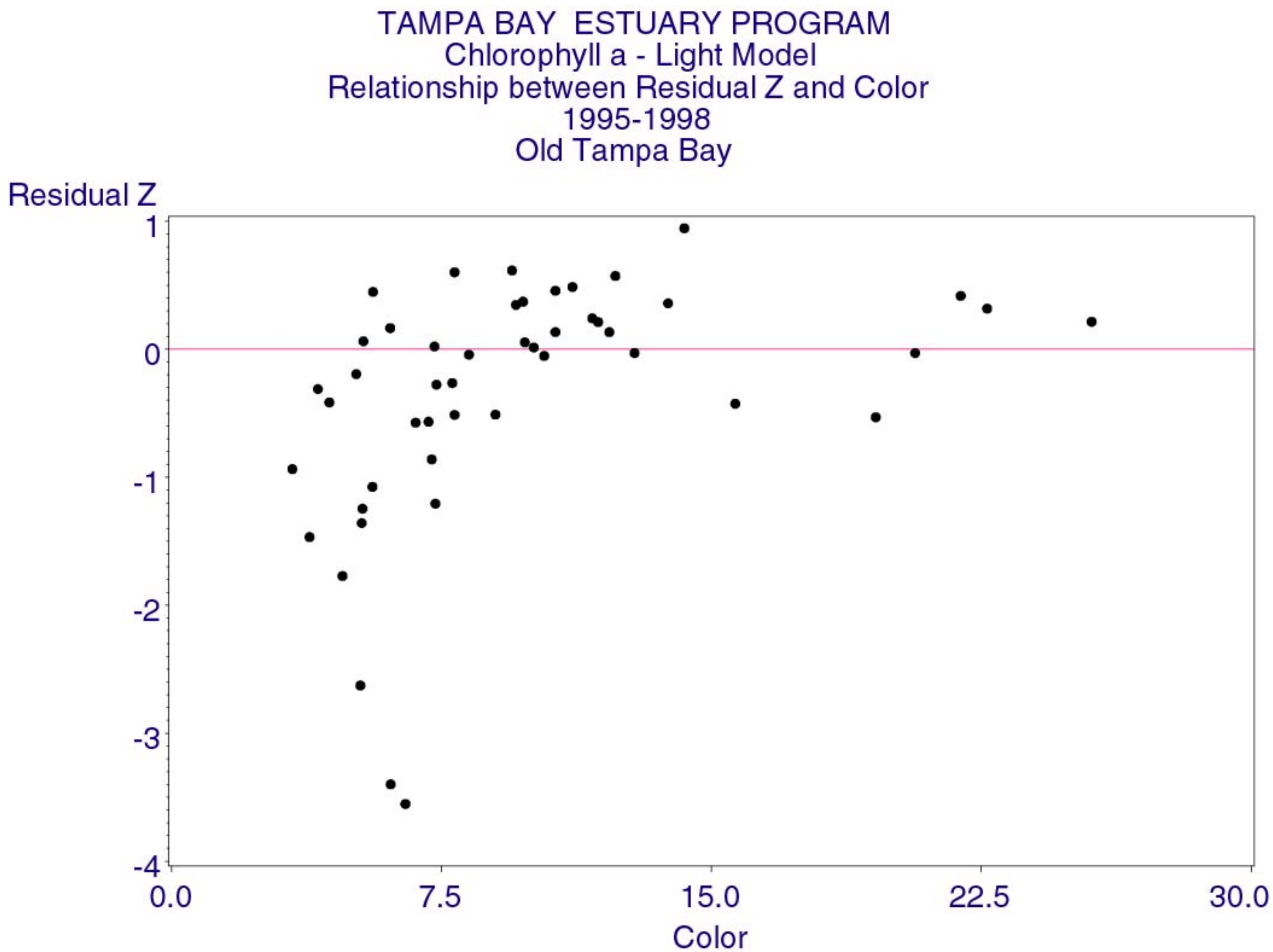

Figure 3-17. Relationship between color and residuals of the depth of 20.5% light attenuation, Old Tampa Bay.

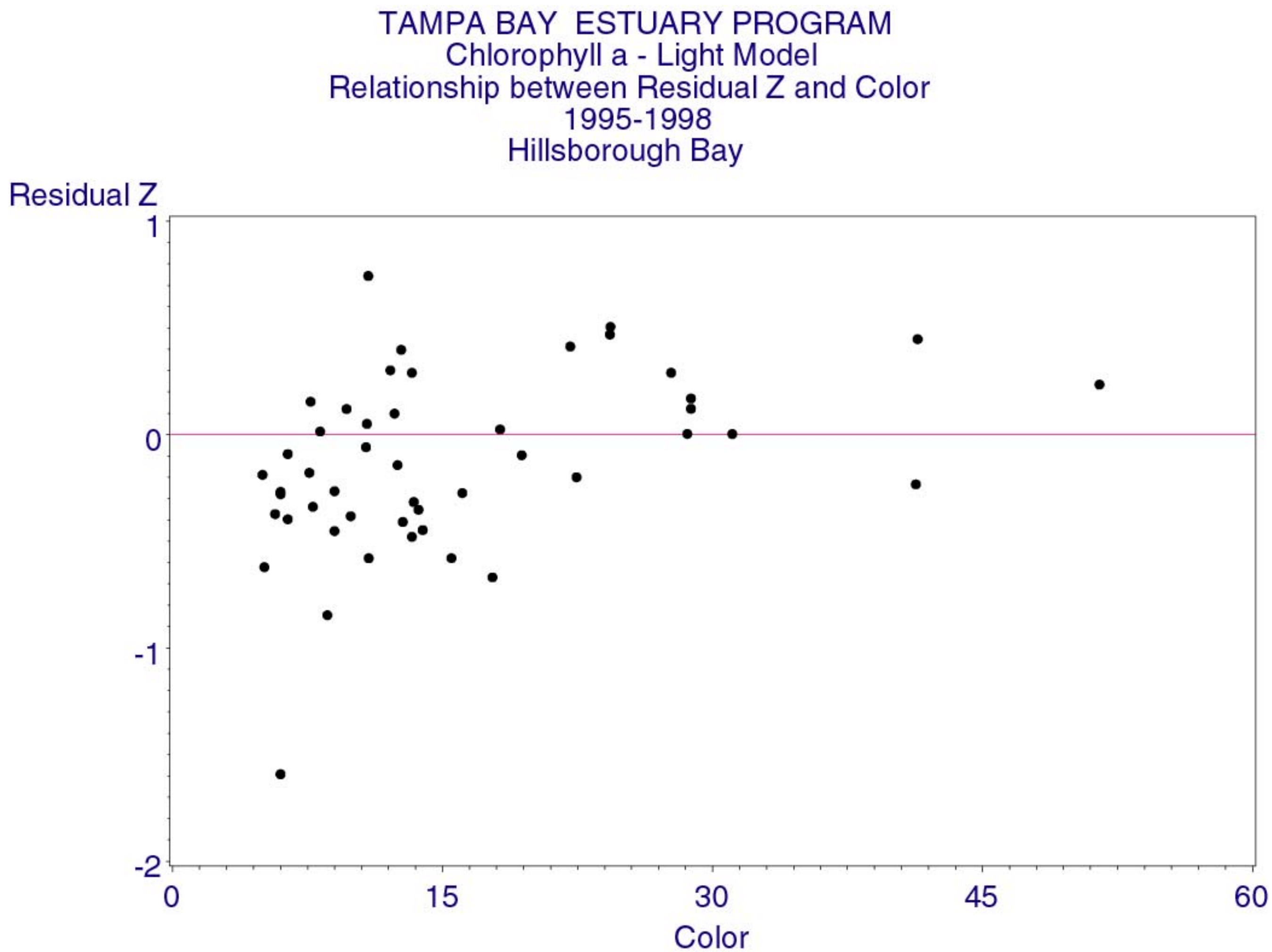

Figure 3-18. Relationship between color and residuals of the depth of 20.5% light attenuation, Hillsborough Bay.

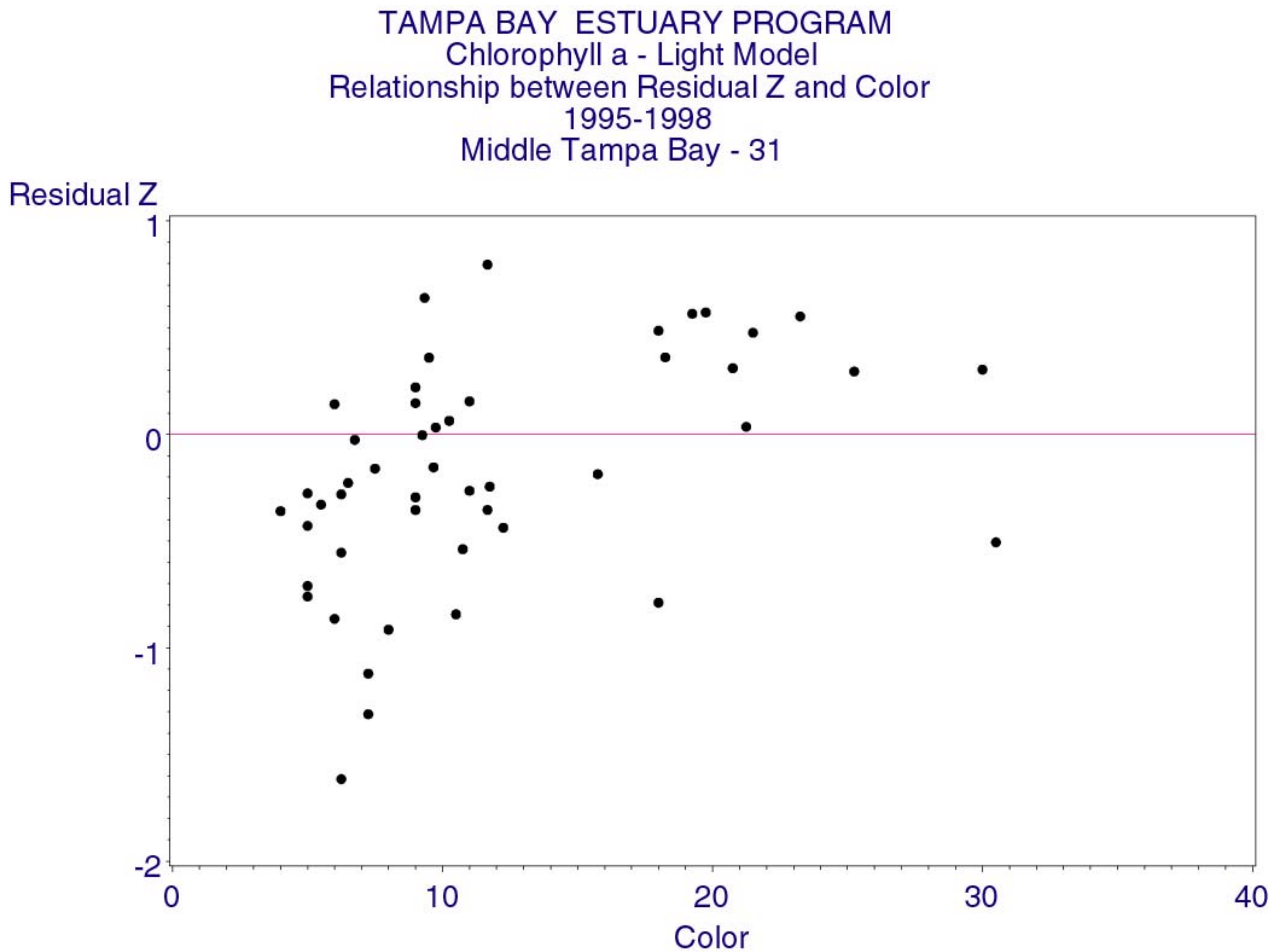

Figure 3-19. Relationship between color and residuals of the depth of 20.5% light attenuation, Middle Tampa Bay 31.

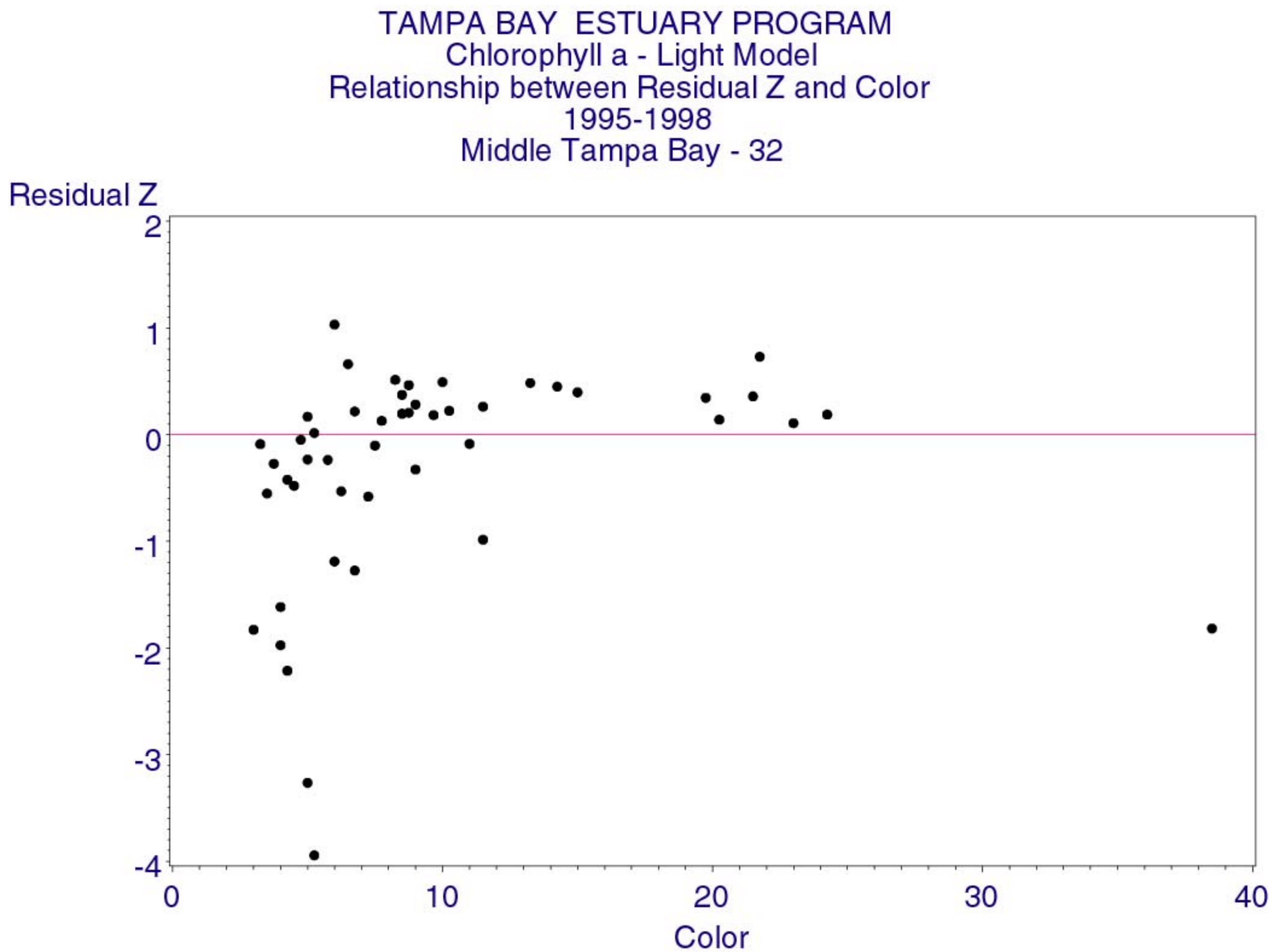

Figure 3-20. Relationship between color and residuals of the depth of 20.5% light attenuation, Middle Tampa Bay 32.

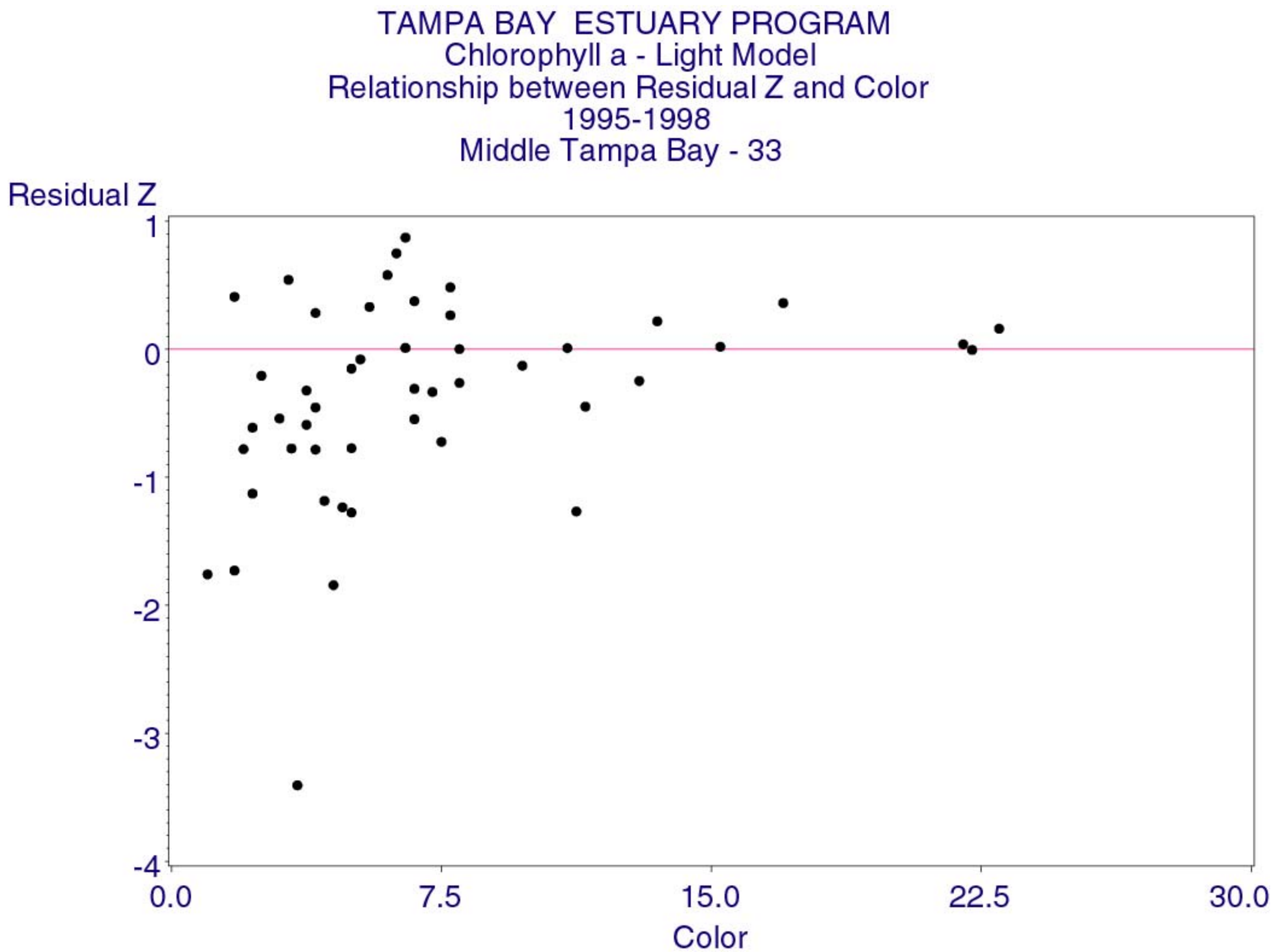

Figure 3-21. Relationship between color and residuals of the depth of 20.5% light attenuation, Middle Tampa Bay 33.

4 DISCUSSION AND CONCLUSIONS

The re-evaluation of the chlorophyll a – light attenuation model is one component of the overall examination of the nitrogen management strategy adopted by the Tampa Bay Estuary Program. The objective of this report is to re-evaluate the empirical relationship between chlorophyll a concentrations and light attenuation using the water quality data collected since 1994 by the Environmental Protection Commission of Hillsborough County (EPCHC).

In general, the chlorophyll a – light model explains the observed variation in light attenuation as a function of chlorophyll a concentrations. However, there appears to be some bias in the predicted Z values at low chlorophyll a concentrations. Specifically, the depth to which 20.5% of the incident light penetrates was somewhat shallower during the 1995-1998 period than had been predicted by the model based on the 1986-1994 data. The bias is expressed at both monthly and annual time scales.

To put the observed bias in the Z values in perspective, the differences in the mean annual Z values were converted to units of Secchi disc depth. Secchi disc depth is the specific indicator employed by the current monitoring program to evaluate spatial and temporal trends in light attenuation. The EPCHC measures Secchi disc depth at 0.5 foot intervals. The mean differences by bay segment in the mean annual Z values for the 1995-1998 period were:

- Old Tampa Bay – 13 inches
- Hillsborough Bay – 5 inches
- Middle Tampa Bay 31 – 8 inches
- Middle Tampa Bay 32 – 15 inches
- Middle Tampa Bay 33 – 17 inches.

Clearly, the difference in predicted and observed mean annual Secchi disc depths consistent with the Z values would be measurable given the existing monitoring program. Analysis of the Secchi disc depths observed in each bay segment show that the mean annual Secchi disc depths have decreased during the 1995-1998 period compared to those of the 1986-1994 period. This decrease is on the same order as those listed above.

Additional analyses were performed to evaluate possible reasons for the observed differences in the relationship between the 1986-1994 period and the 1995-1998 period. A regression model based on data from the extended time period of 1986 through 1998 was examined and the regression coefficients from this model were compared to those from the original model based on 1986-1994 data. Neither the monthly-specific intercept estimates nor the slope estimates from these two models were significantly different.

Another evaluation examined changes in the methods employed to collect and/or analyze the chlorophyll samples between the two periods. Mr. Tom Cardinale, EPCHC, provided information relating to any changes in equipment and methods employed during the sampling record. No relevant differences in either field or laboratory methods were reported.

A hypothesis that might explain the observed bias is a change in phytoplankton community structure that could result in changes in light attenuation per unit of algal biomass. Phytoplankton community composition data have been collected by the City of Tampa Bay Study Group since 1978, and can be used to test this hypothesis. Preliminary indications point toward a shift in community dominance in Hillsborough Bay from blue-green algae prior to 1995 to diatoms in the succeeding period.

Based on the outcome of these analyses, no readily apparent cause for the small bias in the chlorophyll a – light attenuation relationship could be found, but it may be that changes in phytoplankton community composition have contributed to this bias. It is recommended that the empirical relationships between chlorophyll a concentrations and light attenuation developed from the 1986-1994 water quality data continue to be employed as part of the model suite relating external nitrogen loads to light attenuation. Continued monitoring and analysis of the ambient chlorophyll a concentrations and water clarity is needed to ensure factors other than algal biomass are not contributing significantly to water clarity in the bay.

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