Phosphorus Biogeochemistry *in* SUBTROPICAL ECOSYSTEMS

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19 Long-Term Water Quality Trends in the Everglades

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19.1 ABSTRACT

Long-term water quality and hydrologic monitoring data have provided important bases for defining the Everglades nutrient-enrichment problem, developing interim water quality standards and regulations, designing control measures, and evaluating the effectiveness of control measures. Specific monitoring and data-reduction procedures for determining compliance with interim and long-term objectives are built into the Settlement Agreement (USA et al., 1991), EAA Regulatory Rule (SFWMD, 1992b), and Everglades Forever Act (State of Florida, 1994). These procedures provide measures of performance for the phosphorus control program that are important from ecological, management, and legal perspectives.

Interpretation of monitoring data with respect to long-term or anthropogenic impacts is facilitated by application of a model, which attempts to differentiate long-term, hydrologic, and random variance components. The model has been used to develop tracking procedures for several Everglades locations.

Variations in flow, phosphorus concentration, and phosphorus loads at major structures in the EAA and WCAs over the 1978 to 1996 period are summarized. The structure, calibration, and application of a model for tracking ENP Shark River Slough inflow P concentrations are described. Interpretations and limitations of tracking results are described.

19.2 INTRODUCTION

Eutrophication induced by anthropogenic phosphorus loads poses a long-term threat to Everglades ecosystems. Impaired water quality and substantial shifts in microbial

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and macrophyte communities have been observed in regions located downstream of agricultural discharges (Belanger et al., 1989; Nearhoof, 1992; Amador and Jones, 1993; Davis, 1994; Doren et al., 1997). This problem developed over a period of three decades following construction of the Central and Southern Florida Flood Control Project and drainage of wetland areas south of Lake Okeechobee to support intensive agriculture. As shown in Fig. 19.1, the Everglades Agricultural Area (EAA) is located between Lake Okeechobee and the Everglades Water Conservation Areas (WCAs).

In 1988, a lawsuit was filed by the federal government against the local regulatory agencies [Florida Department of Environmental Regulation and South Florida Water Management District (SFWMD)] for not enforcing water quality standards in Loxahatchee National Wildlife Refuge (LNWR) and Everglades National Park (ENP). The lawsuit ended in an out-of-court Settlement Agreement (SA) (USA et al., 1991) and federal consent decree in 1992.

The SA establishes interim and long-term requirements for water quality, control technology, and research. Generally, interim standards and controls are designed based on existing data and known technologies. The interim control program includes implementation of agricultural Best Management Practices (BMPs) and construction of wetland Stormwater Treatment Areas (STAs) to reduce phosphorus loads from the Everglades Agricultural Area (EAA) by approximately 80%, relative to a 1979 to 1988 baseline. Subsequently, SFWMD adopted the EAA Regulatory Rule (SFWMD,

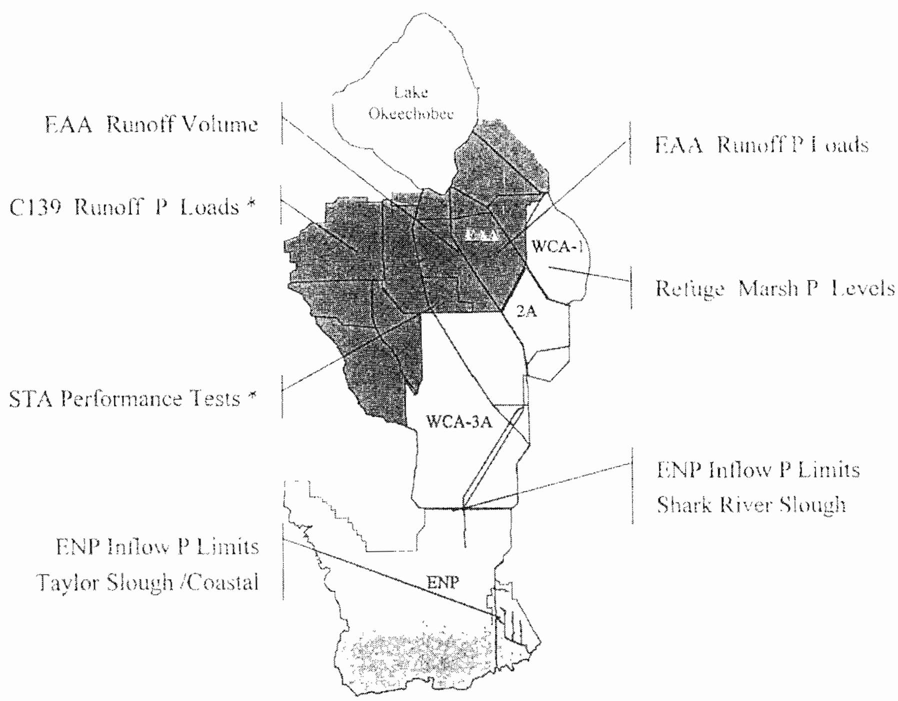

FIGURE 19.1 Regional map.

1992b; Whalen and Whalen, 1994), which requires implementation of BMPs in the EAA to achieve an annual-average phosphorus load reduction of at least 25%. The State of Florida (1994) passed the Everglades Forever Act, which defines a construction project and funding mechanism for STAs. Interim phosphorus standards will apply after interim control technologies are in place (1999 to 2006 for LNWR and 2003 to 2006 for ENP Shark Slough inflows). Long-term standards (>2006) and control technologies will be developed over a period of several years and require a substantial research effort to develop supporting data (Lean et al., 1992).

Long-term water quality and hydrologic monitoring data have provided important bases for defining the Everglades nutrient-enrichment problem, developing interim water quality standards and regulations, designing control measures, and evaluating the effectiveness of control measures. Specific monitoring and data-reduction procedures for determining compliance with interim and long-term objectives are built into the Settlement Agreement, EAA Regulatory Rule, and Everglades Forever Act. The procedures provide measures of performance for the control program that are important from ecological, management, and legal perspectives.

Interpretation of monitoring data with respect to long-term or anthropogenic impacts is facilitated by application of a model that attempts to differentiate long-term, hydrologic, and random variance components. The model has been used to develop tracking procedures for several Everglades locations (Fig. 19.1):

1. ENP Inflow P Limits (2 Basins) (USA et al., 1991, SFWMD, 1992a)
2. LNWR Marsh P Levels (USA et al., 1991, SFWMD, 1992a)
3. EAA Basin P Load Reductions (SFWMD, 1992b)
4. EAA Basin Runoff/BMP Replacement-Water Calculation (SFWMD, 1994)
5. C139 Basin Runoff and P Load (Walker, 1995a)
6. STA Performance Tests (Walker, 1996, FDEP, 1997)

Each procedure was developed within the constraints of historical data to accomplish a specific objective. They share a model structure that is generally applicable in situations where historical monitoring data are to be used as a frame of reference for interpreting current and/or future monitoring data. This would be the case when the management goal is to restore the system to its historical condition, to prevent degradation beyond its current condition, or to require improvement relative to its historical or current condition.

This chapter summarizes long-term variations in flow, total phosphorus concentration, and total phosphorus loads at major structures surrounding in the EAA and WCAs over the 1978 to 1996 period. The structure, calibration, and application of the model for tracking ENP Shark River Slough inflow P concentrations are described. Interpretations and limitations of model results are discussed.

19.3 DATA SOURCES

Water quality data summarized below have been collected by South Florida Water Management District (Germain, 1994) between 1978 and 1996. Hydrologic data collected by SFWMD, Corps of Engineers, U.S. Geologic Survey, and Everglades National Park have been extracted from SFWMD's DBHYDRO data base (SFWMD, 1996). Total phosphorus loads have been calculated using an algorithm that is similar to that described in the EAA Regulatory Rule (SFWMD, 1992b).

19.4 DATA SUMMARIES

Current and future control efforts target total phosphorus loads entering the WCAs from the EAA. Figures 19.2 and 19.3 show annual variations in discharge volume and flow-weighted mean phosphorus concentration, respectively, at major structures between Lake Okeechobee and ENP for Water Years 1978 through 1996. Variations in EAA rainfall and WCA water levels over the same period are shown in Fig. 19.4. An October to September Water Year is used for consistency with the tracking procedure for ENP inflow P limits (see below). Values are summarized for six locations. The term "EAA –> WCAs" primarily represents EAA runoff but also includes lake releases passing through the EAA and runoff from a portion of the C-139 basin. Although the S10s are outflow structures from WCA-1, discharges through these structures are heavily influenced by EAA runoff that is pumped into WCA-1 at S6 and flows along the southern perimeter of WCA-1 to the S10s.

Although minor WCA inflows and outflows are not represented, Figs. 19.2 and 19.3 provide general pictures of temporal and spatial gradients over the 19-year period. Temporal variations in flow and concentration at each location reflect variations in management, climate, and sampling/analytical error. Sorting out these factors is difficult; it is useful, however, to summarize predominant patterns in the data and describe potential causal mechanisms.

Patterns in the flow time series (Fig. 19.2) include the following:

1. Lower flows from EAA to the lake after 1985. These reflect implementation of the Interim Action Plan (IAP), which was designed to reduce P loads to the lake. This was accomplished by reducing backpumping from the EAA to the lake and increasing pumping from the EAA to the WCAs. Although IAP was adopted in 1979, full implementation did not occur until 1986.
2. Higher flows south of the EAA after 1991. These reflect (a) diversion of EAA runoff away from the lake [IAP (1)], (b) increased regulatory releases from Lake Okeechobee (especially in 1993), and (c) high rainfall in recent years (Fig. 19.4).

In each year between 1992 and 1996, discharges from the EAA to the WCAs exceeded the range experienced in 1978 to 1991. The 1995 discharge into ENP Shark Slough (S12s + S333) exceeded the 1978 to 1991 maximum by a factor of 2.5. Record high water levels were experienced in WCA-3A (Fig. 19.4) and ENP during this period. As demonstrated below, these conditions complicate the interpretation of recent water quality data.

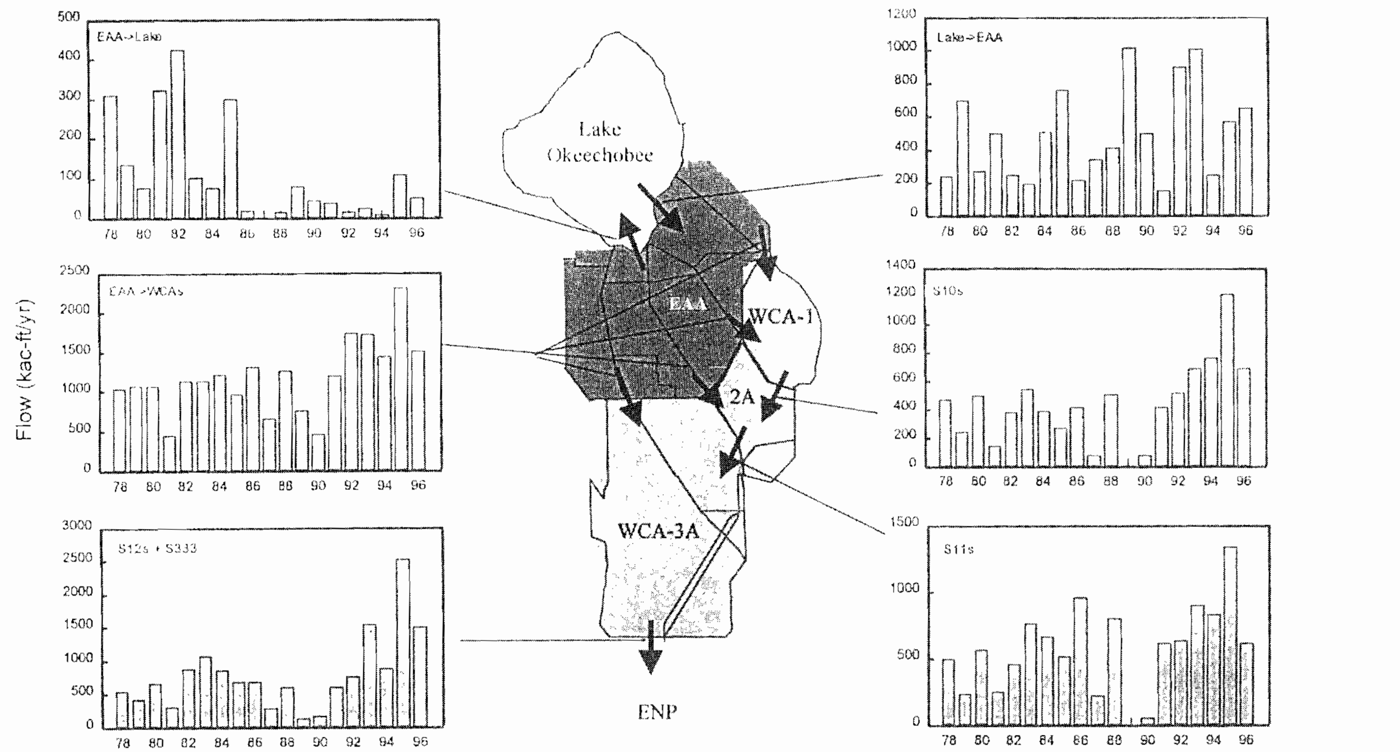

FIGURE 19.2 Flows expressed in 1000 acre-ft per year (kac-ft/yr), October–September water years. Lake –> EAA = discharge from lake to the EAA (structures S354, S351, and HGS5). EAA –> Lake = discharge from EAA to the lake (S2, S3, and S352). EAA –> WCAs = discharge from EAA to the WCAs (S5A, S6, S7, S150, S8, S200, and G250). S10s = discharge WCA-1 to WCA-2A (S10A, B, C, D, and E). S11s = discharge from WCA-2A to WCA-3A (S11A, B, and C). S12s + S333 = discharge from WCA-3A to ENP Shark Slough (S12A, B, C, D, and S333).

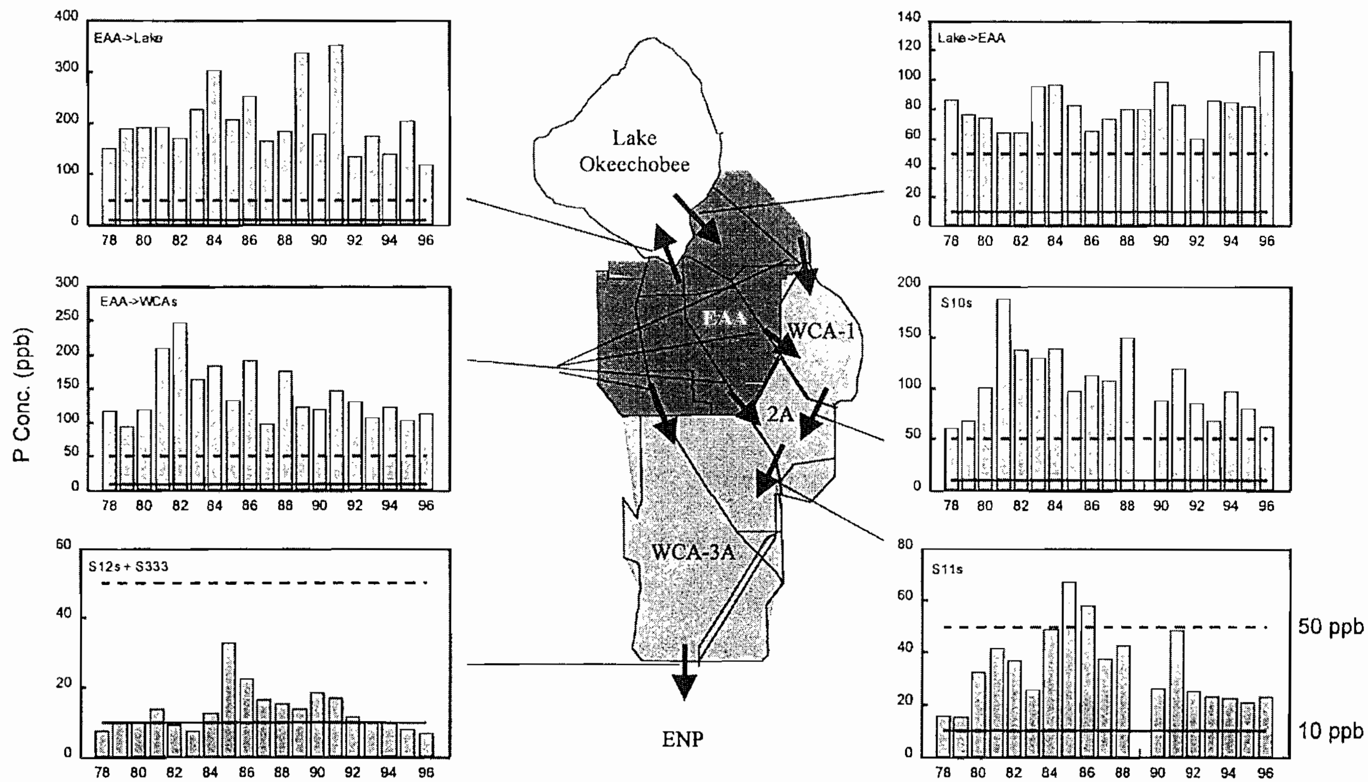

FIGURE 19.3 Annual flow-weighted mean phosphorus concentrations at major structures, 1978–1996. Concentrations expressed in parts per billion (ppb). October–September water years, horizontal dashed lines show 50-ppb design target for interim phosphorus control measures. Structure flows are defined in Fig. 19.2.

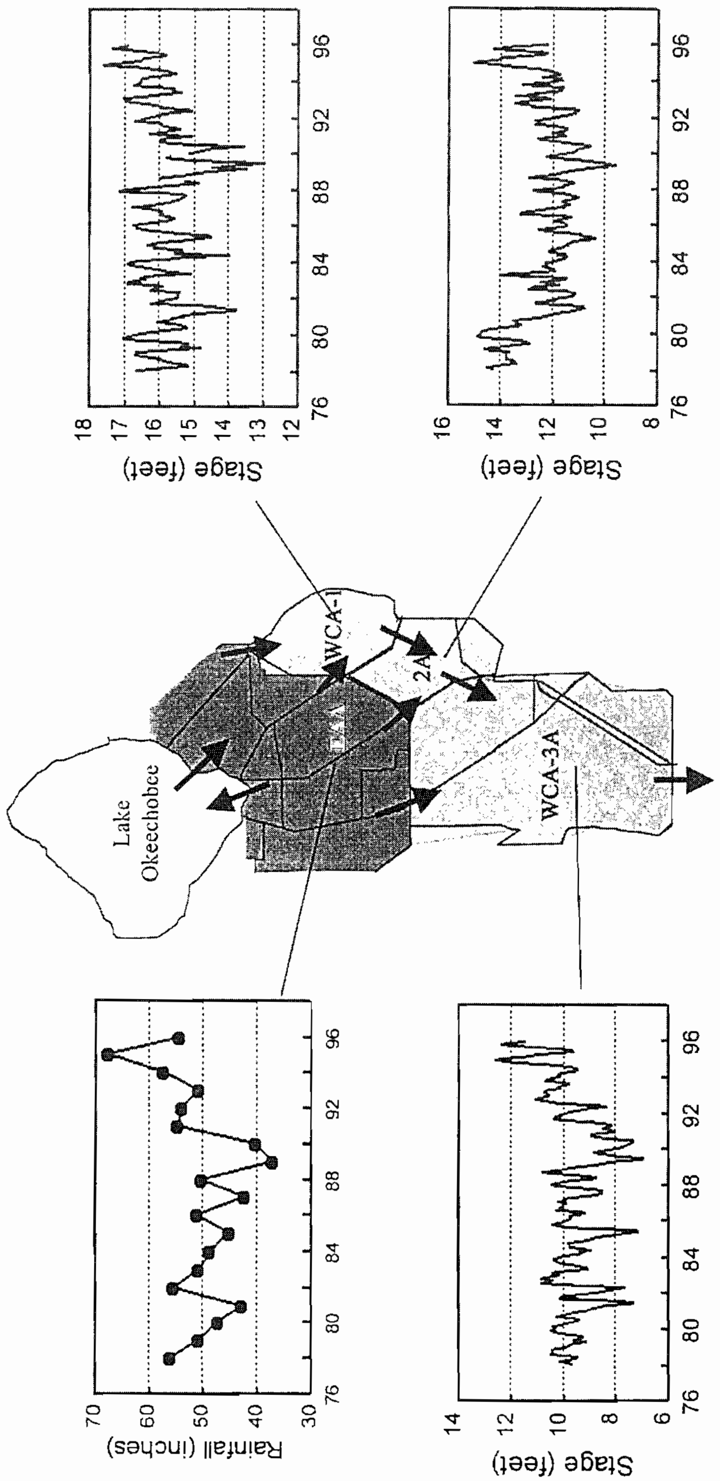

FIGURE 19.4 EAA Rainfall and WCA Stages, 1978–1996. EAA annual rainfall in inches, WCA monthly stages in feet (NGVD).

Total phosphorus concentrations (Fig. 19.3) are shown in relation to the 50-ppb interim control target established in the SA and EFA and the 10-ppb default long-term standard established in the EFA. Predominant patterns in the phosphorus concentration time series include:

1. Increasing concentrations in early years south of the EAA. These may reflect IAP, growth in agricultural land use, variations in water management (WCA regulation schedules, flow distribution), and long-term nutrient enrichment impacts on the WCAs.
2. Decreasing concentrations in later years south of the EAA. These may reflect control measures implemented after 1991, shifts in agricultural crops (away from vegetables), changes in water management, and control measures implemented after 1991.
3. Higher phosphorus concentrations at ENP inflows (S12s + S333) in Water Years 1985 and 1986. These reflected unusual operating conditions in which the structures were left open and WCA-3A stage was lowered. By decreasing contact between canal flows and adjacent marsh, this condition facilitated transport of phosphorus-rich runoff and lake releases through WCA canals to ENP inflow structures.

Of particular interest is the extent to which benefits of control measures implemented after 1991 are reflected in the concentration data. One such measure is adoption of the EAA Regulatory Rule (requiring a 25% reduction in EAA phosphorus load) in 1992. For the five-year period between May 1992 and April 1997, the EAA basin tracking procedure (SFWMD, 1992b) indicates an average load reduction of 46% relative to the May 1979–April 1988 base period and adjusted for variations in rainfall. The Everglades Nutrient Removal Project (ENR), a pilot-scale wetland treatment system in operation since August 1994 (Guardo et al., 1995; SFMWD, 1997), removed an additional 9% of the (post-BMP) EAA runoff phosphorus load that occurred between August 1994 and April 1997.

Precontrol (1978 to 1991) and postcontrol (1992 to 1996) averages for flow, phosphorus concentration, and phosphorus load are summarized in Fig. 19.5. With the exception of discharges from the Lake to the EAA, phosphorus concentration decreased at each location. Although this pattern is consistent with beneficial impacts of control measures, other mechanisms (in particular, higher flows and stages in the WCAs) may have also contributed to the apparent water quality improvements. Despite the apparent reductions relative to the 1978 to 1991 period, and regardless of the precise causal mechanisms, phosphorus concentrations in discharges from the EAA to the WCAs averaged approximately 100 ppb, twice the interim control target of 50 ppb established in the SA and used in designing Stormwater Treatment Areas (Walker, 1995).

Average phosphorus loads south of the EAA were slightly higher in the 1992 to 1996 period, because increases in flow (driven primarily by higher rainfall) more than offset the reductions in concentration. The decrease in loads from EAA to the Lake and corresponding increase in loads from the EAA to the WCAs reflect changes in water management (IAP).

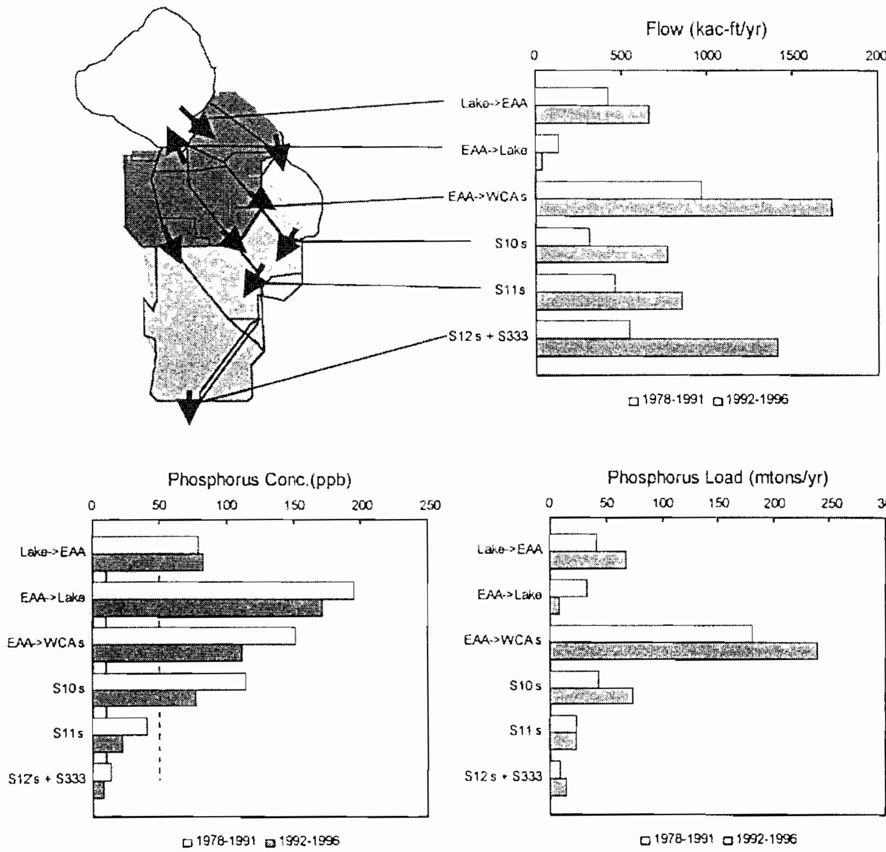

FIGURE 19.5 Comparison of 1979–1991 with 1992–1996 conditions at major structures.

19.5 TRACKING MODEL

Detection of trends or shifts in the long-term mean resulting from management activities or other anthropogenic factors is of primary concern to water-quality management. Interpretation of long-term data sets and establishment of interim standards at various Everglades locations (Fig. 19.1) have been facilitated by application of a general model that attempts to differentiate long-term, hydrologic, and random variance components. Explicit consideration of variability is the key to formulating a valid tracking procedure. The model has the following general form:

$$\text{Response} = \text{R Temporal Effect} + \text{Hydrologic Effect} + \text{Random Effect} \qquad (1)$$

The response is the measurement to be tracked (e.g., concentration or load, averaged over appropriate spatial and temporal scales, linear or log-transformed). The *temporal effect* represents a long-term trend or step-change in the historical data (if present); this may reflect anthropogenic influences (e.g., land development, new point-source discharges, control measures, etc.). Theoretically, the temporal term could also reflect effects of long-term hydrologic or natural variations occurring over time scales that are too long to be identifiable within the period of record for the Response measurement. The *hydrologic effect* represents correlations of the Response with other measured variables, such as flow, water level, and/or rainfall (if present), as identified in the time frame of the analysis. The *random effect* is essentially an error term that represents all other sources of variance, including sampling error, analytical error, and variance sources not reflected in the temporal or hydrologic terms. While no attempt is made to differentiate precise causal mechanisms, explicit consideration of the above variance components provides better resolution and, hopefully, leads to more accurate interpretations of long-term data sets (e.g., Fig. 19.3) than can be achieved with a simple time-series analysis.

As demonstrated below, inclusion of temporal and hydrologic terms increases the statistical power (reduces risk of Type I and Type II errors) when the model is used for setting standards. These terms can be excluded in situations where long-term trends are not present or where significant correlations between the response variable and hydrologic variables cannot be identified. In such a situation, the response would be treated as a purely random variable and the model would be identical to that described by Smeltzer et al., (1989) for tracking long-term variations in lake water quality. The model can be expanded to include multiple hydrologic effects, interactions between temporal and hydrologic effects, as well as other deterministic terms. *Seasonal effects* (if present) can be considered by adding another term or eliminated by defining the response as an annual statistic (average, median, etc.).

The model is not constrained to any particular mathematical form. For example, hydrologic effects can be predicted by a simulation model, provided that uncertainty associated with such predictions *(random effects)* can be quantified. Everglades applications invoke relatively simple, multiple-regression models that provide direct estimates of parameter uncertainty. The hydrologic term provides a basis for adjusting historical and future monitoring data back to an average hydrologic condition, so that changes in the long-term mean (typically reflecting anthropogenic influences) can be tracked and not confused with random climatologic variability (e.g., wet-year vs. dry-year differences).

19.6 CALIBRATION TO SHARK RIVER SLOUGH

SA interim standards for ENP Shark River Slough were designed to provide a long-term-average, flow-weighted mean concentration equivalent to that present between March 1, 1978 and March 1, 1979, the legally-established base period consistent with ENPs designation as an Outstanding Florida Water (OFW). Analysis of monitoring data collected between December 1977 and September 1989 at five inflow structures (S12A, B, C, D, and S333) revealed significant increasing trends in phosphorus concentrations (Walker, 1991). To reduce possible influences of season and shifts in the flow distribution across the five inflow structures, the annual-average, flow-weighted mean concentration across all five structures was selected as a response variable and basis for the interim standard. Annual values for Water Years 1978 to 1990 (October-September) were used to calibrate a regression model of the following form:

$$C - C_m = b_1(T - T_m) + b_2(Q - Q_m) + E \qquad (2)$$

where C = observed annual, flow-weighted-mean concentration total phosphorus (ppb), T = water year (October–September), Q = basin total flow (1000 acre-ft/yr), E = random error term, and $_m$ = subscript denoting average value of C, T, or Q in the calibration period.

Alternative Water Year definitions were investigated. The October to September definition was selected, because it provided the best data fit. Prior to calibration, biweekly concentration data used to calculate annual flow-weighted means were screened for outliers from a log-normal distribution while accounting for correlations between concentration and flow (Snedocor and Cochran, 1989); a single sample was rejected on this basis. Data from Water Years 1985 and 1986 were excluded from the calibration because of unusual operating conditions, which promoted discharge of high-phosphorus canal flows (vs. marsh sheet flows) through the inflow structures. The flow-weighted mean concentrations were 33 and 21 ppb, respectively, as compared with a range of 7 to 18 in other Water Years. These unusual operating conditions are not expected to be repeated.

When data from individual sampling dates are analyzed, total P concentrations in ENP Shark River Slough inflows are negatively correlated with water level in upstream WCA-3A (Walker, 1991). Similar negative correlations with water level are found at other structure and marsh sampling stations in the WCAs (Walker, 1995). At enriched marsh sites, P concentration tends to increase at low stage; this is thought to reflect (a) peat oxidation and subsequent P release from the soils into the water column during and following droughts, and (b) practical difficulties associated with obtaining representative marsh water samples at low stage. Higher water levels are thought to promote phosphorus uptake in the WCAs by increasing wetted area, increasing water residence time, and increasing the hydraulic exchange between canals and adjacent marsh areas. Lower stages tend to promote phosphorus transport through the WCAs by increasing the relative proportion of canal flow vs. marsh sheet flow.

When the data are analyzed on an annual basis, negative correlations with both WCA-3A stage ($r = -0.63$) and basin total flow ($r = -0.68$) are observed. The latter is used for hydrologic adjustment in the tracking procedure, because it provides a slightly better fit of the data. It is likely that flow is a partial surrogate for water-level effects. Consideration of both flow and stage does not improve the fit.

Table 19.1 lists calibration data and results. The model explains 80% of the variance in the historical data set with a residual standard error of 1.87 ppb. The fit is illustrated in Fig. 19.6. Figure 19.6a plots observed and predicted concentrations against time. The 80% prediction interval (10th, 50th, and 90th percentiles) is shown in relation to the observed data. Both regression slopes are significant at $p < 0.05$. The partial regression concept (Snedocor and Cochran, 1989) can be applied to elucidate temporal, hydrologic, and random variance components.

TABLE 19.1
Derivation of Interim Phosphorus Standards for ENP Shark River Slough Inflows

		Flow-Weighted-Mean Total P Concentration					
Water Year	Basin flow, kac-ft/yr	Observed, ppb	Predicted, ppb	Flow-adjusted, ppb	Detrended, ppb	50% target, ppb	90% limit, ppb
78	522.8	6.7	8.4	6.7	7.0	8.4	11.7
79	407.0	9.8	9.6	9.2	9.5	9.0	12.3
80	649.2	10.6	9.0	11.2	9.7	9.6	11.1
81	291.7	12.4	11.3	11.4	11.0	10.2	12.9
82	861.3	8.4	9.2	10.0	6.3	10.8	10.1
83	1061.3	7.0	8.9	9.5	4.4	11.4	9.4
84	842.8	12.0	10.5	13.4	8.7	12.0	10.2
87	276.6	15.9	14.9	14.8	10.9	13.8	13.0
88	585.5	15.6	14.1	15.9	10.0	14.4	11.4
89	116.9	13.5	16.9	11.6	7.3	15.0	14.0
90	148.2	18.1	17.3	16.3	11.2	15.6	13.8
Mean	523.9	11.8	11.8	11.8	8.7	8.7	11.8

Variables

C = Observed TP (ppb)

Q = Observed Flow (kac-ft/yr)

T = Water Year (October-September)

E = Random Error (ppb)

b_1, b_2 = Regression Slopes

SE = Regression Standard Error of Estimate (ppb)

m = Subscript Denoting Mean Value

Regression model

$C = C_m + b_1 (T - T_m) + b_2 (Q - Q_m) + E = 11.8 + 0.5932 (T - 83.7) - 0.00465 (Q - 523.9) + E$

Regression results

$R^2 = 0.80$ SE = 1.873 ppb $C_m = 11.8$ ppb $T_m = 83.7$

$Q_m = 523.9$ kac-ft/yr $b_1 = 0.5932$ $Var(b_1) = 0.02366$ $b_2 = -0.00465$

$Var(b_2) = -0.0046$ $Cov(b_1,b_2) = 0.00013$ $t_{\alpha,dof} = 1.397$ n = 11

C_Q = Flow-adjusted TP $= C + b_2 (Q_m - Q) = C - 0.00465 (523.9 - Q)$

C_T = Detrended TP (adjusted to $T_o = 78.5$) $= C + b_1 (T_o - T) = C + 0.5932 (78.5 - T)$

Target $= C_m + b_1 (78.5 - T_m) + b_2 (Q - Q_m) = 11.16 - 0.00465$ Q

Limit = Target + S $t_{\alpha,dof} = 11.16 - 0.00465\,Q + 1.397\,S$

$S = [SE^2 (1 + 1/n) + Var(b_1) (T_o - T_m)^2 + Var(b_2) (Q_c - Q_m)^2 + 2\,Cov(b_1,b_2) (T_o - T_m)(Q_c - Q_m)]^{0.5}$
$= [6.377 - 0.00591\,Q + 0.00000436\,Q^2]^{0.5}$

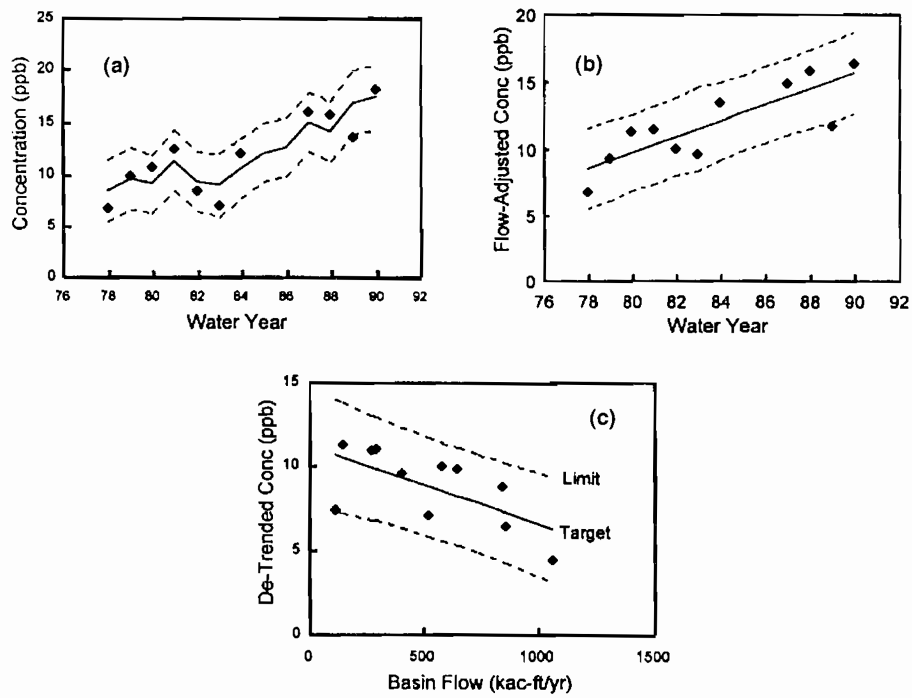

FIGURE 19.6 Model calibration to ENP Shark River Slough inflows, (a) observed, (b) adjusted to mean flow, and (c) adjusted to 1978–1979 conditions. October–September Water Years. Lines = 80% prediction intervals, squared = observed flow-weighted means.

The concentration measured in any year (C) can be adjusted back to an average flow condition (Q_m) using the following equation for flow-adjusted concentration (C_Q):

$$C_Q = C + b_2(Q_m - Q) \tag{3}$$

Figure 19.6b plots observed and predicted flow-adjusted concentrations against time. The long-term trend is more readily apparent in this display because effects of flow variations have been filtered out.

Similarly, the concentration measured in any year can be adjusted back to any base period (T_0) using the following equation for a time-adjusted or detrended concentration (C_T):

$$C_T = C + b_1(T_0 - T) \tag{4}$$

A base period (T_0) of 78.5 represents the 1978 to 1979 OFW time frame, as defined above. Figure 19.6c plots observed and predicted time-adjusted concentrations against flow. With the long-term trend removed in above manner, the negative correlation between concentration and flow is apparent. Figure 19.6c shows the predicted relationship between concentration and flow if the long-term mean were equivalent to that present in 1978 to 1979.

The model can be used to evaluate the likelihood that current monitoring results (C_c, Q_c) are equivalent to the 1978 to 1979 base period while accounting for hydrologic and random variations. This is accomplished using the following terms, which characterize the prediction interval for a 1978 to 1979 time frame under a given flow condition:

$$\text{Target} = (C_m + b_1(T_o - T_m) + b_2)(Q^c - Q_m) \tag{5}$$

$$\text{Limit} = \text{Target} + St_{\alpha dof} \tag{6}$$

where Target = 50th percentile of prediction interval = predicted mean (ppb), Limit = 90th percentile of prediction interval (ppb), S = standard error of predicted value (ppb), t = one-tailed student's t statistic, α = significance level = 0.10, and dof = degrees of freedom.

In Fig. 19.6c, the target and limit lines correspond to the 50th and 90th percentile predictions, respectively. The required parameter estimates and variance/covariance terms are derived from a standard multiple regression analysis (Snedocor and Cochran, 1989). If the current long-term flow-weighted mean is less than the 1978 to 1979 long-term mean (adjusted for hydrologic effects), there would be less than a 50% chance that the observed yearly mean (C_c) would exceed the target and less than a 10% chance that C_c would exceed the limit. The difference between the target and limit reflects the magnitude of the random effects term and uncertainty in model parameter estimates (b_1, b_2, C_m).

19.7 TYPE I AND TYPE II ERRORS

Under the terms of the settlement agreement, an exceedence of the limit in any year would trigger further scientific investigations which, in turn, may lead to implementation of additional phosphorus control measures. The significance level for the compliance test (0.10) represents the maximum Type-I error rate (probability of exceeding the limit if the future and 1978 to 1979 long-term means are exactly equal). Unless a model can be constructed to explain all of the variance in the data, there is no way to design a compliance test without explicitly adopting a maximum Type-I error. In this case, the 0.10 value was arrived at by negotiation and with the understanding that results of the test would be interpreted by a scientific panel in light of the inherent risk of Type I error.

Type II error (failure to detect an exceedence or excursion from the standard) is another unavoidable feature of compliance tests. In this case, a Type II error would occur when the actual long-term mean exceeds the 1978 to 1979 flow-adjusted mean but the measured annual value is still below the limit. Risk of Type II error depends on the specified maximum Type I error (10%), model error variance (random effects term), and the degree of excursion from the objective.

Figure 19.7 illustrates Type I and Type II error concepts. The probability that the measured annual mean exceeds the limit is plotted against the difference

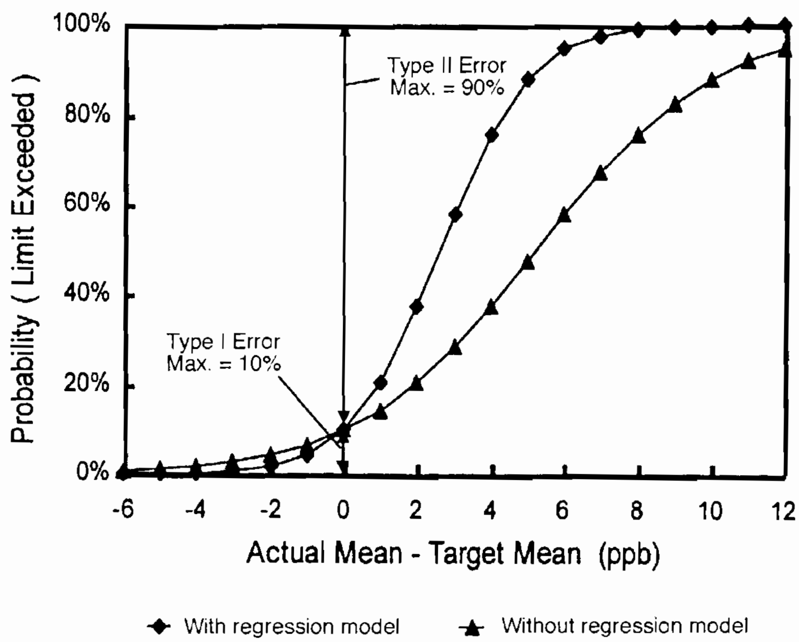

FIGURE 19.7 Type I and Type II error.

between the actual long-term mean and the objective (1978 to 1979 long-term mean). Probabilities are calculated using standard statistical procedures (Snedecor and Cochran, 1989; Walker, 1989). Type I errors (false exceedences) may occur when the actual long-term mean is below the objective. The risk of Type I error equals the probability shown on the left-hand side in Fig. 19.7 and has maximum value of 10% (by design). Type II errors (failure to detect exceedences) may occur when the actual mean exceeds the target. The risk of Type II error equals 100% minus the probability shown on the right-hand side of Fig. 19.7 and has a maximum value of 90%. As deviation from the target increases, risks of Type I and Type II errors decrease.

Probability curves are shown for two values of residual standard error in Fig. 19.7. Without applying the regression model, the random effects term in the model would have a standard deviation of 3.73 ppb (= standard deviation of annual flow-weighted means in the calibration period). With the regression model, the standard deviation is reduced to 1.87 ppb. Removing variance associated with trend and flow increases the probability of exceeding the limit when the long-term mean exceeds the objective. For example, if the true long-term mean were 5 ppb above the objective, the probability of an exceedence (measured annual value above limit) would be ~90% with the regression model, but only ~50% without the regression model. Risk of Type I error when the actual mean is below the objective is also lower with the regression model. The regression approach thus enables a more powerful compliance test than would result from treating the calibration data set as a random time series.

19.8 TRACKING RESULTS FOR SHARK RIVER SLOUGH

Figure 19.8 shows monitoring results for the Water Years 1991 to 1996 (six years following the 1978 to 1990 calibration period). Although interim standards will not be enforced until 2003, the procedure is useful for tracking responses to control measures implemented over the 1991 to 2002 period. As discussed above, these include the EAA Regulatory Program (1992) and ENR project (1994).

Figure 19.8a shows observed values before and after the calibration period in relation to the 80% prediction interval derived from the regression model (Table 19.1). Values in Fig. 19.8a reflect both long-term trend and flow variations. Observed values in 1992 to 1996 fall near the lower boundary of the 80% prediction interval (10th percentile).

Figure 19.8b shows flow-adjusted concentrations [Eq. (3)] in relation to the 80% prediction interval. The prediction interval extrapolates the increasing trend in the 1978 to 1990 data to the later years. Flow-related variations are filtered from this time series, so that observed and predicted values reflect variations in the long-term mean. The width of the prediction interval increases in later years, primarily as a result of higher flow regimes. The plot suggests that the increasing trend present during the calibration period has been arrested in recent years.

Figure 19.8c plots concentrations against flow in relation to the 80% prediction interval for 1978 to 1979 conditions. Observed values during the 1978 to 1990 calibration period have been adjusted to the 1978 to 1979 time frame [Eq. (4)]. The middle and upper values in the prediction interval correspond to the target and limit values at any flow. Compliance with the interim standards (when they are in effect) will require that the observed (unadjusted) flow-weighted means fall below the limit line in every year.

Under provisions of the settlement agreement, the maximum flow during the calibration period (1061 kac-ft/yr) is used to calculate the limit in years when the observed flow exceeds that value. This essentially prevents extrapolation of the regression beyond the calibration range. The dashed line in Fig. 19.8c shows the limit calculated according to this procedure. It is debatable whether this procedure provides a better estimate of the 90th percentile at high flows than the extrapolated (solid) line. The distribution of observed values after 1991 is such that the determination of "compliance" (if the standard were in effect) would be influenced only in the case of the extreme high-flow year (1995). In the remaining years, the system would have been in compliance in two out of five years (1994 and 1996), regardless of which limit line is used.

19.9 DISCUSSION

Extremely wet conditions experienced in recent years relative to the calibration period impose significant limitations on tracking results. As shown in Figs. 19.2 and 19.8, basin flows exceeded the maximum value experienced in the calibration period (1061 kac-ft/yr) in three out of six Water Years after 1990 (1993, 1995, and 1996). In these years, the model is being extrapolated beyond the range of the calibration data set. The extrapolation is particularly large in Water Year 1995, when the average

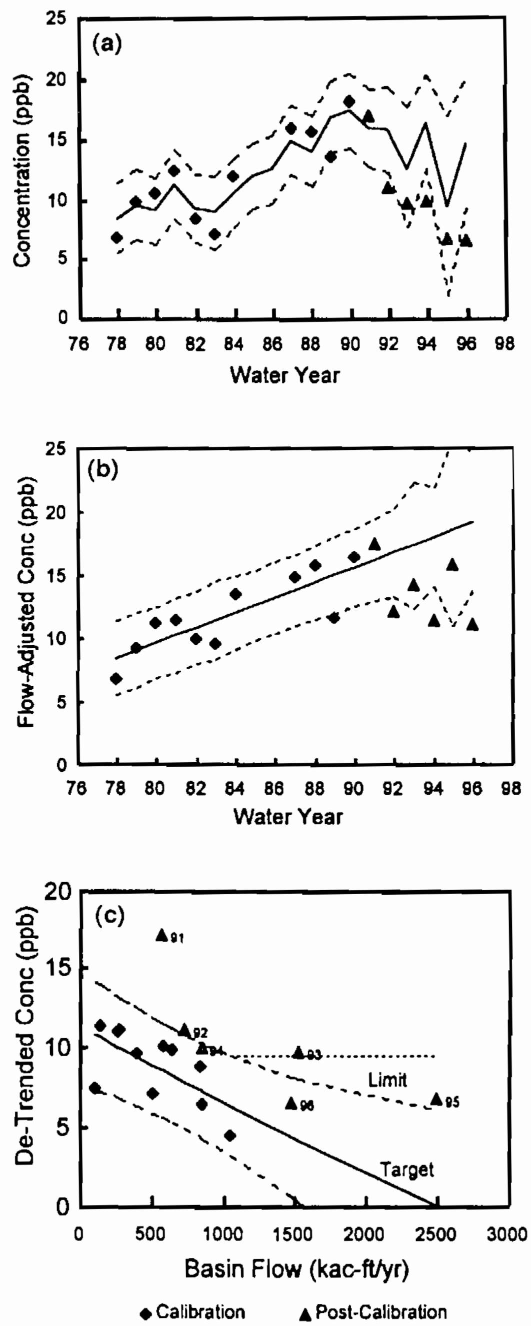

FIGURE 19.8 Model application to ENP Shark River Slough inflows, (a) observed, (b) adjusted to mean flow, and (c) adjusted to 1978–1979 conditions (calibration period), observed (1992–1996). October–September Water Years. Diamonds = observed flow-weighted means (1991–1996), lines = 80% prediction intervals.

flow exceeded the calibration maximum by approximately 2.5-fold. When the model is applied to these high-flow regimes, prediction uncertainty increases, as reflected by the wider prediction intervals in later years (Figs. 19.8a, 19.8b) and/or higher flows (Fig. 19.8c).

When recent data within the calibrated flow range are considered (WY 1992, 1994), Fig. 19.8b suggests that the increasing trend in the long-term mean present prior to 1991 has been arrested. Despite signs of improvement, it is unlikely that the interim control objective for ENP Shark Slough inflows has been achieved, since the flow-adjusted means in recent years are consistently above the 1978 to 1979 flow-adjusted mean (~ 8 ppb, Fig. 19.8b). Observed concentrations in 1992 to 1996 cluster around the limit line in Fig. 19.8c. If the interim objective were achieved, the observed values would be expected to cluster around the target line (center of 1978 to 1979 distribution).

Results for 1992 to 1996 do not fully reflect the benefits of existing controls. In particular, full implementation of BMPs in the EAA was not required until January 1996. Several years of monitoring under average and dry conditions will provide a more reliable assessment of ENP inflow water quality conditions in relation to interim objectives established in the settlement agreement and a basis for tracking responses to existing and future control efforts.

19.10 CONCLUSIONS

1. Interpretation of long-term data sets is facilitated by a model that explicitly considers temporal, hydrologic, and random variance components. The model for tracking phosphorus concentrations at inflows to ENP Shark River Slough explains 80% of the variance in the 1978 to 1990 calibration data using with terms representing long-term trend and correlation with basin annual flow.
2. Under terms of the state/federal settlement agreement, the model provides a basis for establishing interim control limits designed to achieve water quality conditions equivalent to those experienced in 1978 to 1979, while accounting for hydrologic and random variations.
3. Application of the model to recent data suggests that the increasing trend in the long-term mean present during the calibration period was arrested in postcalibration years (1992 to 1996). This response may reflect benefits of phosphorus-control measures implemented during this period (BMPs in the Everglades Agricultural Area and operation of the Everglades Nutrient Removal Project).
4. Further reductions in concentration will have to occur before ENP inflow concentrations are consistently in compliance with the interim objective established in the settlement agreement. Such reductions may occur as the system responds to full implementation of existing controls and to future controls.
5. Results for some recent years are limited by extremely wet conditions requiring extrapolation of the tracking model beyond the calibrated flow range.

6. Future monitoring under average and dry conditions will provide a more reliable assessment of ENP inflow water quality conditions in relation to interim objectives and a basis for tracking responses to existing and future controls.

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