

# **Revised TMDL Calculations**

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**Lake Okeechobee Technical Advisory Committee**

**Updates to May 3 Presentation**

**May 4, 2000**

**Refinements to Steady-State Model**

**Mass-Balance Data**

**Yearly Net Settling Rates**

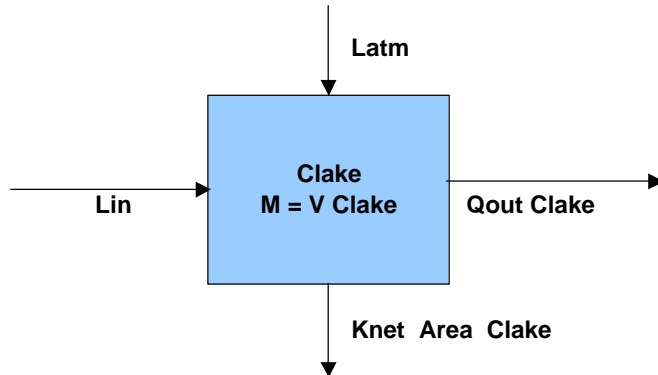
**Calibration Using Pelagic P Concentrations**

**Residuals Plots**

**Calibration Using Lake Outflow P Concentrations**

**Revised TMDL Calculations**

## Phosphorus Balance Model



**Dynamic Water Balance:**

$$dV/dt = Q_{in} + Q_{prec} - Q_{evap} - Q_{out}$$

**Dynamic Mass Balance:**

$$dM/dt = Linflow + Latmos - Qout\ Clake - Knet\ Area\ Clake$$

**Steady State Mass Balance:**

$$Lin + Latm = Q_{net\ Clake} + Knet\ Area\ Clake$$

**Model Calibration to 1973-1999 data: \***

$$Knet = (Lin + Latm - dM/dt) / (Area\ Clake) - Qout/Area$$

$$= 0.89\ m/yr \quad \text{at steady-state}$$

**Hydrologic Conditions for TMDL Calculations (1973-1999 Means):**

$$Q_{out} = 1.682\ e9\ m^3/yr$$

$$Q_{in} = 2.568\ e9\ m^3/yr$$

$$Area = 1.733\ e9\ m^2$$

**TMDL Calculation:**

|      |   |              |   |                   |   |             |
|------|---|--------------|---|-------------------|---|-------------|
| TMDL | = | Qout Ctarget | + | Knet Ctarget Area |   |             |
|      |   | Flushing     |   | Retention         |   | Total       |
|      | = | 67.3         | + | 61.8              | = | 129.1 mt/yr |

**Watershed Load:**

|     |   |           |   |      |   |            |
|-----|---|-----------|---|------|---|------------|
| Lin | = | TMDL      | - | Latm |   |            |
|     |   | 129.1     | - | 31.2 | = | 97.9 mt/yr |
| Cin | = | Lin / Qin |   |      | = | 38 ppb     |

\* Equation used to calculate Knet from observed data has been modified (relative to April 6 & May 3 analyses) to include change in mass term (dM/dt).

## Lake Mass Balance Data

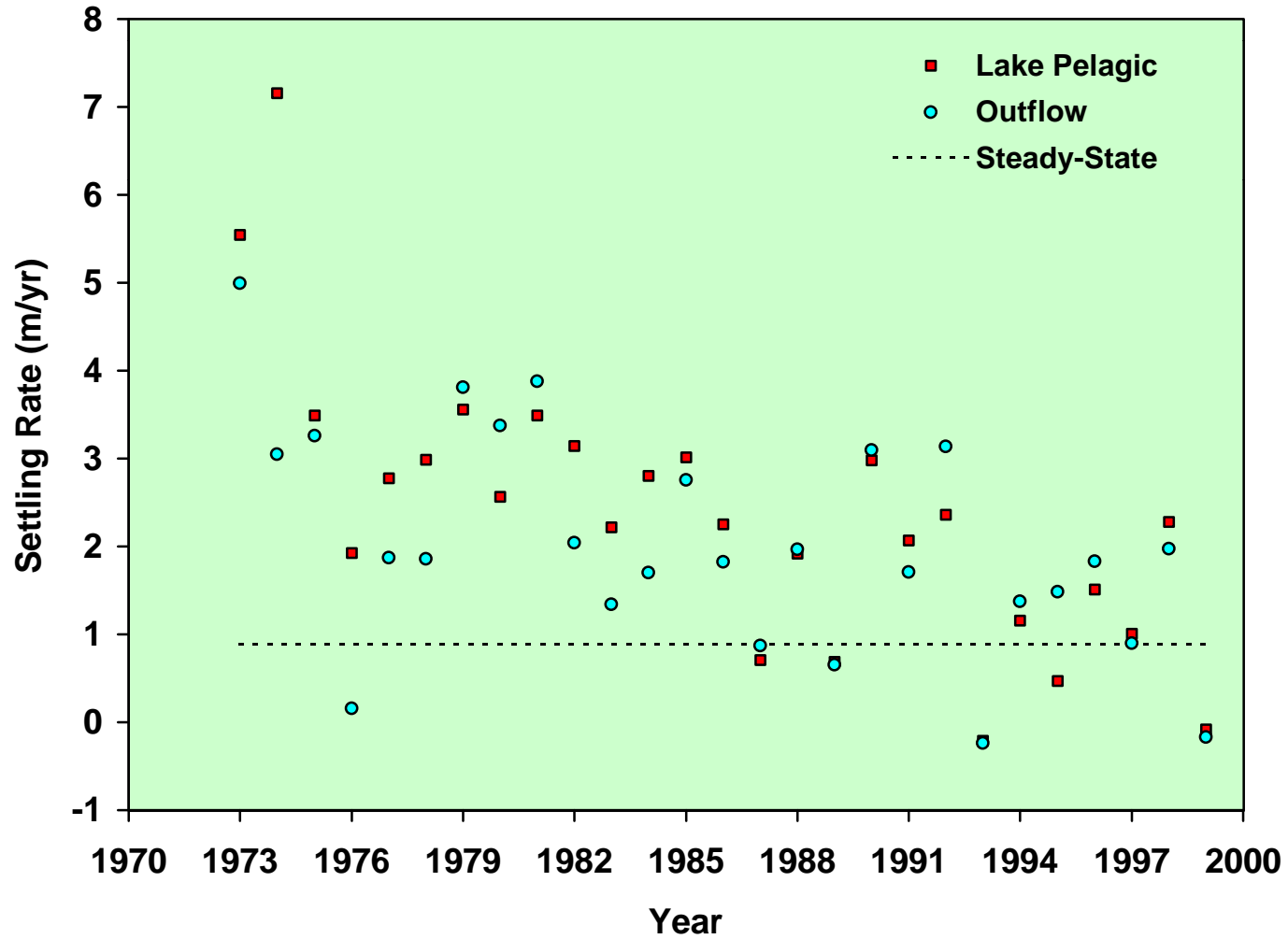
### Yearly Balances

| <u>Year</u> | <u>Surf L</u><br><u>mt/y</u> | <u>Atm L</u><br><u>mt/yr</u> | <u>Total L</u><br><u>mt/yr</u> | <u>Qin</u><br><u>E9m3</u> | <u>Qout</u><br><u>E9m3</u> | <u>dM/dt</u><br><u>mt/yr</u> | <u>Area</u><br><u>E9m2</u> | <u>Zmn</u><br><u>m</u> | <u>Lake P</u><br><u>ppb</u> | <u>Outfl P</u><br><u>ppb</u> | <u>K Lake</u><br><u>m/yr</u> | <u>K Outfl</u><br><u>m/yr</u> |
|-------------|------------------------------|------------------------------|--------------------------------|---------------------------|----------------------------|------------------------------|----------------------------|------------------------|-----------------------------|------------------------------|------------------------------|-------------------------------|
| 1973        | 434.4                        | 29.8                         | 464.2                          | 3.01                      | 0.76                       | -84.7                        | 1.656                      | 2.4                    | 55.2                        | 60.8                         | 5.54                         | 4.99                          |
| 1974        | 737.3                        | 30.4                         | 767.6                          | 3.63                      | 2.27                       | 75.5                         | 1.686                      | 2.5                    | 48.3                        | 93.5                         | 7.16                         | 3.04                          |
| 1975        | 297.0                        | 29.9                         | 327.0                          | 1.89                      | 1.08                       | -35.9                        | 1.664                      | 2.4                    | 52.7                        | 55.8                         | 3.49                         | 3.26                          |
| 1976        | 403.0                        | 30.2                         | 433.2                          | 2.40                      | 1.88                       | 136.4                        | 1.678                      | 2.4                    | 58.1                        | 138.0                        | 1.92                         | 0.16                          |
| 1977        | 332.6                        | 30.3                         | 362.9                          | 1.61                      | 0.76                       | 55.3                         | 1.686                      | 2.5                    | 56.6                        | 78.7                         | 2.77                         | 1.87                          |
| 1978        | 608.1                        | 32.7                         | 640.7                          | 3.24                      | 0.83                       | 200.0                        | 1.814                      | 2.9                    | 70.6                        | 105.0                        | 2.98                         | 1.86                          |
| 1979        | 900.9                        | 32.9                         | 933.8                          | 3.66                      | 2.41                       | 138.4                        | 1.826                      | 3.0                    | 89.3                        | 84.9                         | 3.56                         | 3.81                          |
| 1980        | 193.8                        | 32.6                         | 226.3                          | 1.22                      | 1.79                       | -352.3                       | 1.809                      | 2.9                    | 89.9                        | 73.3                         | 2.56                         | 3.37                          |
| 1981        | 324.0                        | 26.2                         | 350.3                          | 1.01                      | 0.94                       | -142.2                       | 1.458                      | 2.2                    | 81.7                        | 74.7                         | 3.49                         | 3.88                          |
| 1982        | 814.6                        | 29.1                         | 843.7                          | 3.86                      | 0.71                       | 364.8                        | 1.616                      | 2.7                    | 82.7                        | 119.5                        | 3.14                         | 2.04                          |
| 1983        | 594.6                        | 33.1                         | 627.8                          | 3.70                      | 3.33                       | -48.9                        | 1.842                      | 3.1                    | 91.3                        | 116.6                        | 2.22                         | 1.34                          |
| 1984        | 569.0                        | 33.1                         | 602.1                          | 2.38                      | 2.35                       | -164.7                       | 1.838                      | 3.0                    | 102.2                       | 139.9                        | 2.80                         | 1.70                          |
| 1985        | 371.0                        | 30.1                         | 401.0                          | 1.58                      | 1.30                       | -115.8                       | 1.670                      | 2.5                    | 81.6                        | 87.6                         | 3.02                         | 2.75                          |
| 1986        | 457.0                        | 31.4                         | 488.5                          | 1.81                      | 0.72                       | 194.4                        | 1.747                      | 2.6                    | 63.3                        | 75.4                         | 2.25                         | 1.82                          |
| 1987        | 460.3                        | 32.0                         | 492.4                          | 2.74                      | 1.06                       | 242.5                        | 1.781                      | 2.7                    | 107.7                       | 95.9                         | 0.71                         | 0.87                          |
| 1988        | 260.2                        | 32.9                         | 293.1                          | 1.86                      | 1.51                       | -267.1                       | 1.825                      | 2.9                    | 111.7                       | 109.9                        | 1.92                         | 1.97                          |
| 1989        | 314.9                        | 28.2                         | 343.1                          | 1.59                      | 1.60                       | 100.4                        | 1.565                      | 2.3                    | 90.5                        | 92.7                         | 0.69                         | 0.65                          |
| 1990        | 360.6                        | 26.8                         | 387.4                          | 1.67                      | 0.77                       | -155.1                       | 1.490                      | 2.2                    | 104.2                       | 100.8                        | 2.98                         | 3.10                          |
| 1991        | 409.8                        | 30.6                         | 440.4                          | 2.71                      | 0.39                       | 104.5                        | 1.699                      | 2.6                    | 86.1                        | 102.0                        | 2.07                         | 1.71                          |
| 1992        | 353.5                        | 32.8                         | 386.3                          | 2.05                      | 1.52                       | -116.1                       | 1.824                      | 2.9                    | 86.3                        | 69.4                         | 2.36                         | 3.14                          |
| 1993        | 258.2                        | 32.1                         | 290.2                          | 1.99                      | 2.33                       | 115.3                        | 1.781                      | 2.7                    | 89.4                        | 91.5                         | -0.21                        | -0.24                         |
| 1994        | 539.3                        | 32.2                         | 571.5                          | 3.89                      | 1.93                       | 201.5                        | 1.790                      | 2.8                    | 92.5                        | 84.2                         | 1.16                         | 1.38                          |
| 1995        | 642.7                        | 33.2                         | 675.8                          | 4.35                      | 4.69                       | 120.7                        | 1.842                      | 3.1                    | 100.0                       | 74.8                         | 0.47                         | 1.48                          |
| 1996        | 160.9                        | 32.7                         | 193.6                          | 1.57                      | 1.72                       | -347.0                       | 1.819                      | 2.8                    | 121.1                       | 107.2                        | 1.51                         | 1.83                          |
| 1997        | 427.4                        | 31.3                         | 458.7                          | 2.82                      | 0.73                       | 213.8                        | 1.741                      | 2.6                    | 98.7                        | 106.9                        | 1.01                         | 0.90                          |
| 1998        | 739.5                        | 32.9                         | 772.4                          | 4.46                      | 4.16                       | -201.3                       | 1.830                      | 3.1                    | 117.0                       | 125.4                        | 2.28                         | 1.97                          |
| 1999        | 626.1                        | 32.5                         | 658.6                          | 2.66                      | 1.85                       | 467.2                        | 1.805                      | 2.9                    | 113.0                       | 124.8                        | -0.08                        | -0.17                         |

### Cumulative Balances - Average from Year N to 1999, 1999 - N >= 3 Years

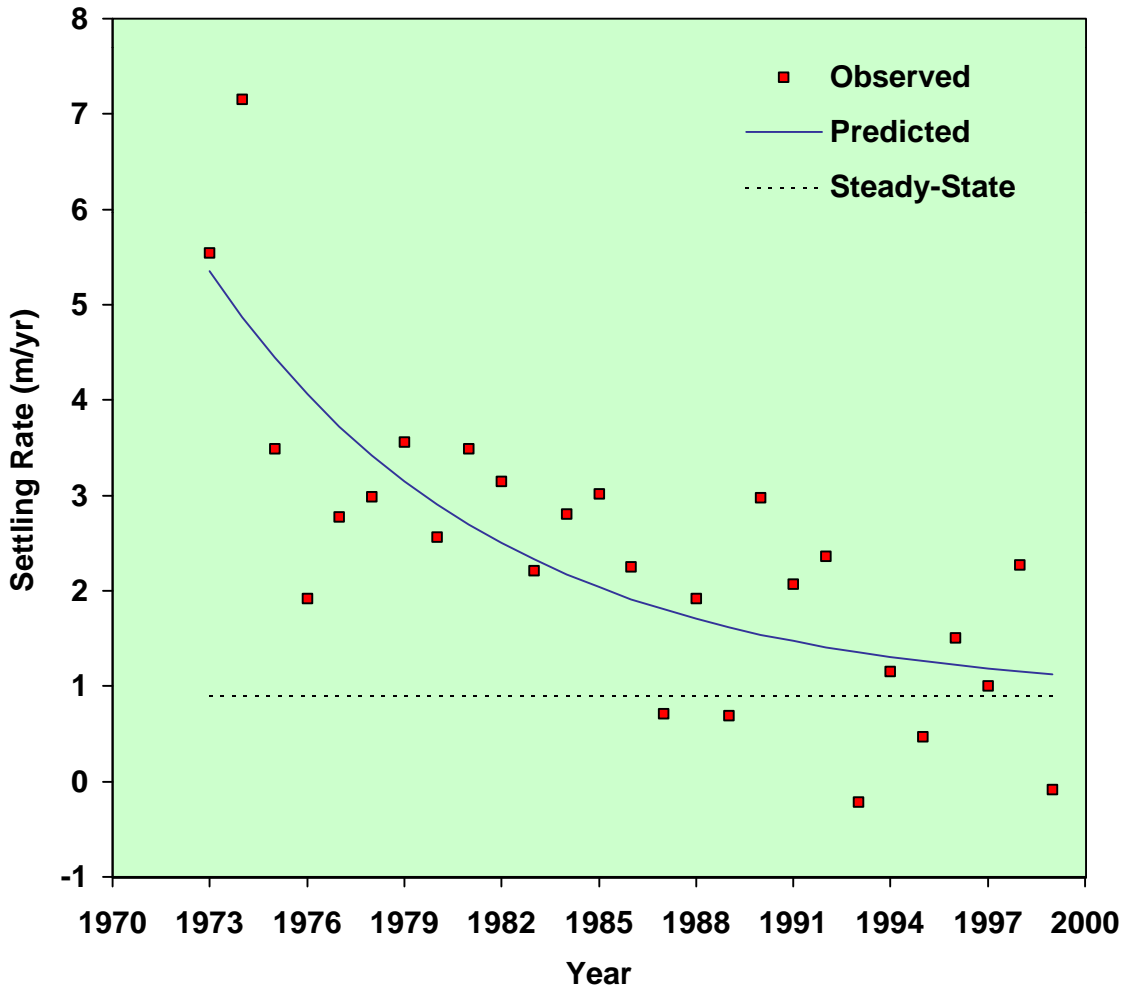
| <u>Year</u> | <u>Surf L</u><br><u>mt/y</u> | <u>Atm L</u><br><u>mt/yr</u> | <u>Total L</u><br><u>mt/yr</u> | <u>Qin</u><br><u>E9m3</u> | <u>Qout</u><br><u>E9m3</u> | <u>dM/dt</u><br><u>mt/yr</u> | <u>Area</u><br><u>E9m2</u> | <u>Zmn</u><br><u>m</u> | <u>Lake P</u><br><u>ppb</u> | <u>Outfl P</u><br><u>ppb</u> | <u>K Lake</u><br><u>m/yr</u> | <u>K Outfl</u><br><u>m/yr</u> |
|-------------|------------------------------|------------------------------|--------------------------------|---------------------------|----------------------------|------------------------------|----------------------------|------------------------|-----------------------------|------------------------------|------------------------------|-------------------------------|
| 1973        | 466.3                        | 31.2                         | 497.5                          | 2.57                      | 1.68                       | 25.91                        | 1.733                      | 2.7                    | 86.7                        | 95.9                         | 2.17                         | 1.87                          |
| 1974        | 467.5                        | 31.2                         | 498.8                          | 2.55                      | 1.72                       | 30.16                        | 1.736                      | 2.7                    | 87.9                        | 97.2                         | 2.08                         | 1.79                          |
| 1975        | 456.8                        | 31.3                         | 488.0                          | 2.51                      | 1.70                       | 28.35                        | 1.738                      | 2.7                    | 89.5                        | 97.4                         | 1.98                         | 1.74                          |
| 1976        | 463.4                        | 31.3                         | 494.7                          | 2.53                      | 1.72                       | 31.03                        | 1.741                      | 2.7                    | 91.1                        | 99.1                         | 1.94                         | 1.70                          |
| 1977        | 466.0                        | 31.4                         | 497.4                          | 2.54                      | 1.71                       | 26.45                        | 1.743                      | 2.7                    | 92.5                        | 97.4                         | 1.94                         | 1.79                          |
| 1978        | 472.1                        | 31.4                         | 503.5                          | 2.58                      | 1.76                       | 25.14                        | 1.746                      | 2.7                    | 94.1                        | 98.3                         | 1.90                         | 1.78                          |
| 1979        | 465.6                        | 31.4                         | 497.0                          | 2.55                      | 1.80                       | 16.81                        | 1.743                      | 2.7                    | 95.2                        | 98.0                         | 1.86                         | 1.78                          |
| 1980        | 443.9                        | 31.3                         | 475.2                          | 2.50                      | 1.77                       | 10.74                        | 1.738                      | 2.7                    | 95.5                        | 98.6                         | 1.78                         | 1.69                          |
| 1981        | 457.0                        | 31.2                         | 488.3                          | 2.56                      | 1.77                       | 29.84                        | 1.735                      | 2.7                    | 95.8                        | 100.0                        | 1.74                         | 1.62                          |
| 1982        | 464.4                        | 31.5                         | 495.9                          | 2.65                      | 1.82                       | 39.40                        | 1.750                      | 2.7                    | 96.6                        | 101.4                        | 1.66                         | 1.54                          |
| 1983        | 443.8                        | 31.6                         | 475.5                          | 2.58                      | 1.88                       | 20.26                        | 1.758                      | 2.7                    | 97.4                        | 100.3                        | 1.59                         | 1.51                          |
| 1984        | 434.4                        | 31.6                         | 466.0                          | 2.51                      | 1.79                       | 24.58                        | 1.753                      | 2.7                    | 97.8                        | 99.3                         | 1.55                         | 1.52                          |
| 1985        | 425.4                        | 31.4                         | 456.9                          | 2.52                      | 1.75                       | 37.19                        | 1.747                      | 2.7                    | 97.5                        | 96.6                         | 1.46                         | 1.48                          |
| 1986        | 429.3                        | 31.5                         | 460.9                          | 2.58                      | 1.78                       | 48.12                        | 1.753                      | 2.7                    | 98.7                        | 97.2                         | 1.37                         | 1.40                          |
| 1987        | 427.2                        | 31.6                         | 458.7                          | 2.64                      | 1.87                       | 36.87                        | 1.753                      | 2.7                    | 101.4                       | 98.9                         | 1.31                         | 1.37                          |
| 1988        | 424.4                        | 31.5                         | 455.9                          | 2.63                      | 1.93                       | 19.73                        | 1.751                      | 2.7                    | 100.9                       | 99.1                         | 1.37                         | 1.41                          |
| 1989        | 439.4                        | 31.4                         | 470.7                          | 2.70                      | 1.97                       | 45.81                        | 1.744                      | 2.7                    | 99.9                        | 98.2                         | 1.31                         | 1.35                          |
| 1990        | 451.8                        | 31.7                         | 483.5                          | 2.82                      | 2.01                       | 40.35                        | 1.762                      | 2.8                    | 100.8                       | 98.7                         | 1.35                         | 1.41                          |
| 1991        | 461.9                        | 32.3                         | 494.2                          | 2.94                      | 2.15                       | 62.07                        | 1.792                      | 2.8                    | 100.5                       | 98.5                         | 1.20                         | 1.25                          |
| 1992        | 468.4                        | 32.5                         | 500.9                          | 2.97                      | 2.37                       | 56.77                        | 1.804                      | 2.8                    | 102.2                       | 98.0                         | 1.10                         | 1.20                          |
| 1993        | 484.9                        | 32.4                         | 517.3                          | 3.11                      | 2.49                       | 81.47                        | 1.801                      | 2.8                    | 104.5                       | 102.1                        | 0.93                         | 0.99                          |
| 1994        | 522.6                        | 32.5                         | 555.1                          | 3.29                      | 2.51                       | 75.83                        | 1.804                      | 2.9                    | 107.0                       | 103.9                        | 1.09                         | 1.16                          |
| 1995        | 519.3                        | 32.5                         | 551.8                          | 3.17                      | 2.63                       | 50.69                        | 1.807                      | 2.9                    | 109.9                       | 107.8                        | 1.07                         | 1.12                          |
| 1996        | 488.5                        | 32.4                         | 520.8                          | 2.88                      | 2.11                       | 33.19                        | 1.799                      | 2.8                    | 112.4                       | 116.1                        | 1.24                         | 1.16                          |

# Yearly Net Settling Rates



$$K_{net} = (L_{in} + L_{atm} - dM/dt) / (\text{Area Clake}) - Q_{out}/\text{Area}$$

## Calibration of Net Settling Rate Using Lake Pelagic P Concentrations



Observed:  $K_{net} = (L_{in} + L_{atm} - dM/dt) / (\text{Area Clake}) - Q_{out}/\text{Area}$

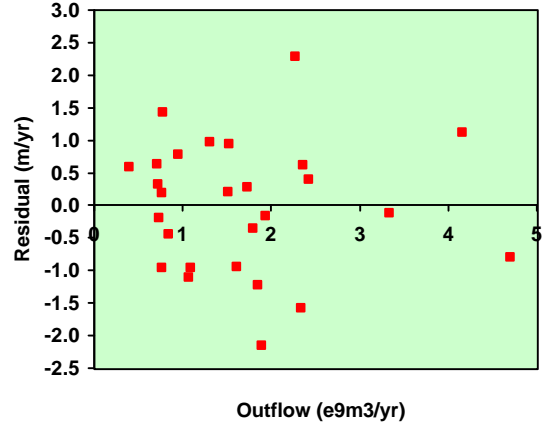
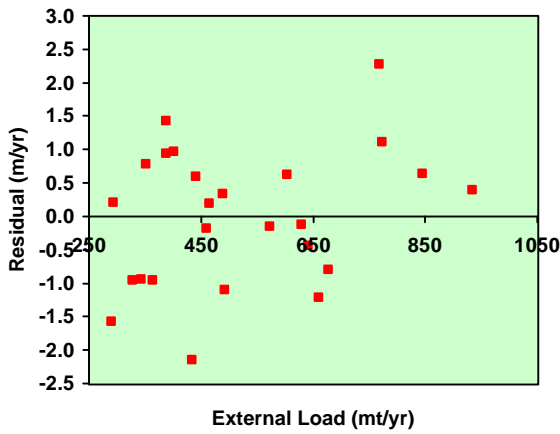
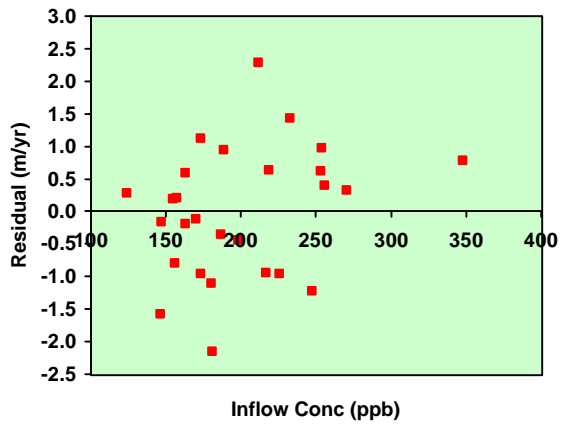
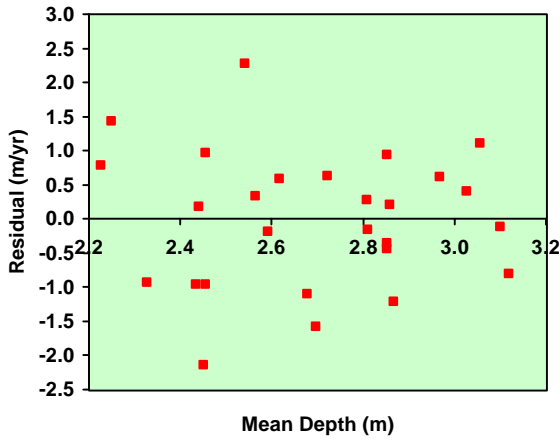
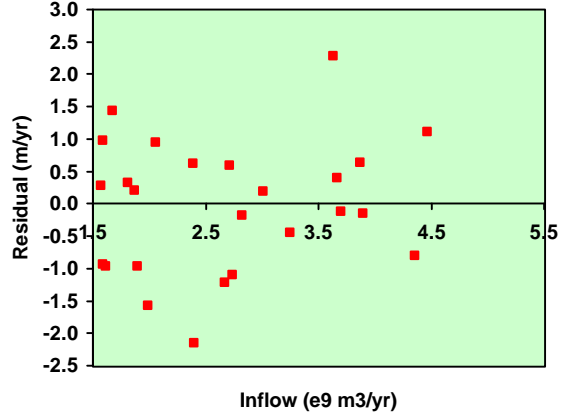
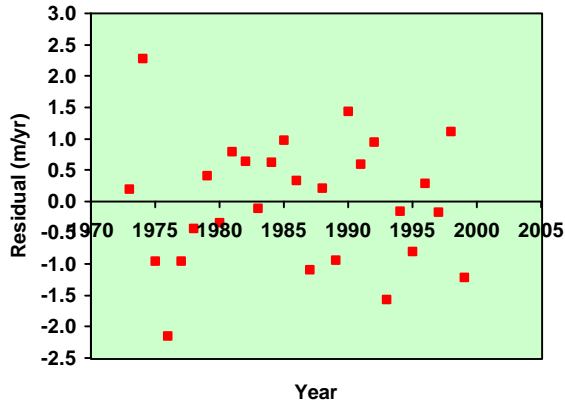
Model:  $K = K_{ss} + (K_o - K_{ss}) \exp(-b(t - 1973))$   
 $R^2 = 0.60$   
 $K_{ss} = 0.892 \text{ m/yr} = \text{Steady-State } K_{net}$   
 $K_o = 5.349 \text{ m/yr}$   
 $b = 0.113 \text{ 1/yr}$

$T_{90} = \text{Time for 90\% Response to New Steady State}$   
 $= -\ln(0.1) / b = 20.3 \text{ years}$

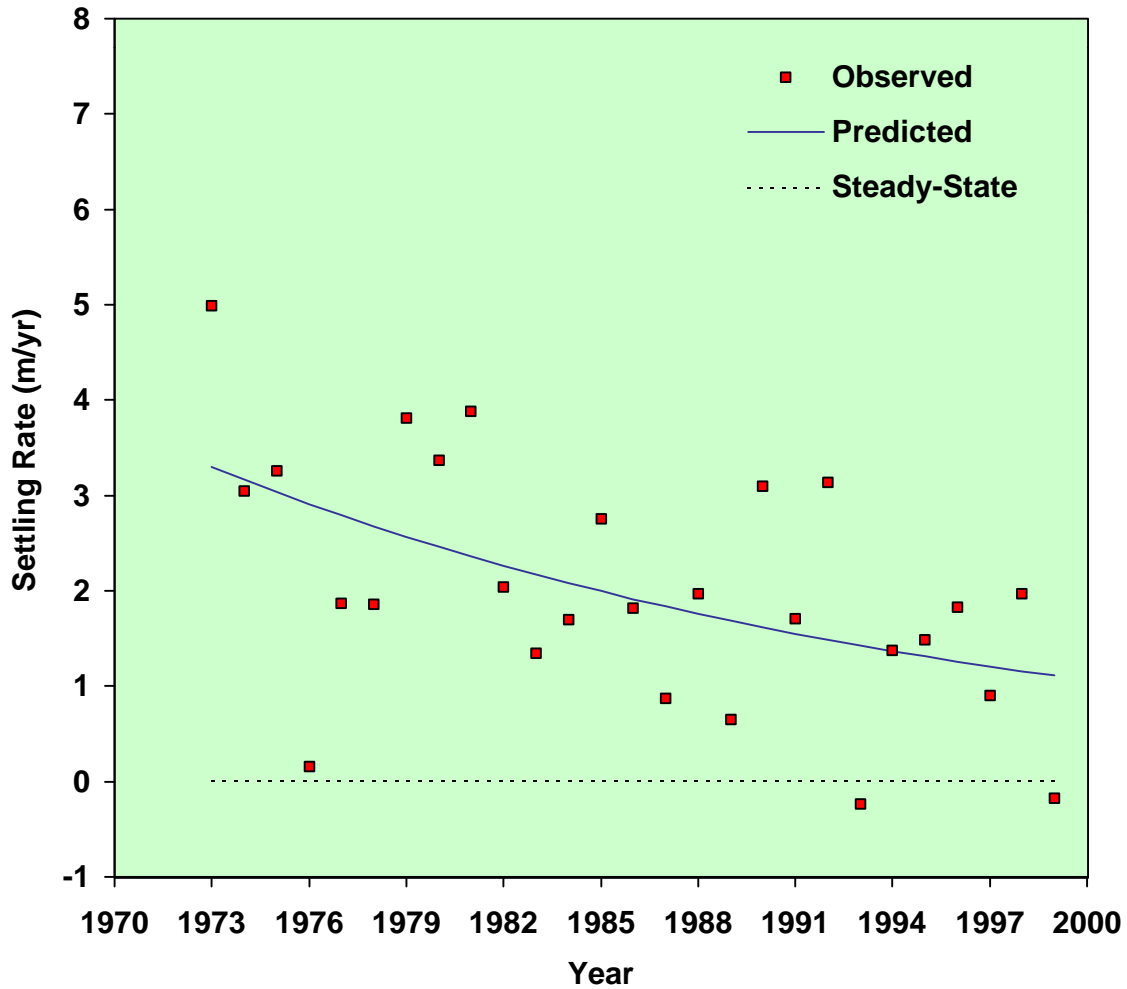
### Residuals Plots

### Observed - Predicted Knet

### Yearly Values



## Calibration of Net Settling Rate Using Lake Outflow P Concentrations



Observed:  $K_{net} = (Lin + Latm - dM/dt) / (Area \cdot Cout) - Q_{out}/Area$

Model:  $K = K_{ss} + (K_o - K_{ss}) \exp(-b(t - 1973))$   
 $R^2 = 0.27$   
 $K_{ss} = 0.004 \text{ m/yr} = \text{Steady-State } K_{net}$   
 $K_o = 3.302 \text{ m/yr}$   
 $b = 0.042 \text{ 1/yr}$

T90 = Time for 90% Response to New Steady State  
 $= -\ln(0.1) / b = 54.8 \text{ years}$

**Revised TMDL Calculations for Lake Okeechobee**  
**W. Walker, LOTAC, May 4, 2000**

TMDL = Qnet Ctarget + Knet Area Ctarget

|   |       |                              |  |
|---|-------|------------------------------|--|
| Target Conc (ppb)                               |       |                              |  |
| April   | 40    | LOTAC consensus              |  |
| Revised   | 40    | " "                          |  |
| Area (1000 km <sup>2</sup> )                    |       |                              |  |
| April   | 1.730 | 1973-1998 Mean               |  |
| Revised   | 1.733 | 1973-1999 Mean               |  |
| Rainfall P Load (mg/m <sup>2</sup> -yr)         |       |                              |  |
| April   | 20    | assumed                      |  |
| Revised   | 18    | LOTAC consensus              |  |
| Settling Rate (m/yr)                            |       |                              |  |
| April   | 1.22  | 1994-1998 mean               |  |
| Revised   | 0.89  | estimated steady-state value |  |
| Lake Outflow (E9 m <sup>3</sup> /yr)            |       |                              |  |
| April   | 1.676 | 1973-1998 mean               |  |
| Revised   | 1.682 | 1973-1999 mean               |  |
| TMDL (mtons/yr)                                 |       |                              |  |
| April   | 151   | mass-balance model           |  |
| Revised   | 129   | "                            |  |
| Watershed Inflow Volume (E9 m <sup>3</sup> /yr) |       |                              |  |
| April   | 2.564 | 1973-1998 mean               |  |
| Revised   | 2.568 | 1973-1999 mean               |  |
| Watershed Inflow Conc (ppb)                     |       |                              |  |
| April   | 46    | mass-balance model           |  |
| Revised   | 38    | "                            |  |