Milton Reservoir

Reservoir Water-Quality Assessment
Weld County, Colorado

Prepared for:
The Barr– Milton Watershed Association

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Final Report

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The aerial photograph of Milton Reservoir (Figure 1) is used with permission from and complements of Weld County (http://maps.merrick.com/Website/Weld).

Abbreviations

AF – acre-foot
EPA - Environmental Protection Agency
FRICO - Farmers Reservoir Irrigation Company
ft – feet
g - gram
HA – hectare
IY – irrigation year
m – meter
mg - milligram
l – liter
lbs - pounds
mg - milligram
MWRD - Metro Wastewater Reclamation District
N – nitrogen
n - number of data points
NA – Not Applicable
NED – Not Enough Data
N:P - Nitrogen to Phosphorus Ratio
P – phosphorus
R^2 – coefficient of determination
SACWSD - South Adams County Water and Sanitation District
SU – standard unit
TKN - Total Kjeldahl Nitrogen
µg – microgram
µS - micro Siemens
USGS - US Geological Survey

INTRODUCTION

Milton Reservoir (Figure 1) is a reservoir located on the high plains of Colorado about 36 miles northeast of Denver. Its elevation is approximately 4,800 feet above mean sea level. Precipitation in the area is 15.8 inches per year. The main source of water to the reservoir is the Platte Valley Canal (Figure 2). The reservoir also receives flow from the Beebe Seep. Water is released from the reservoir to the Gilmore Canal. It is owned and managed by the Farmer's Reservoir Irrigation Company (FRICO).

Milton Reservoir has four designated use classifications: agriculture, aquatic life warm, recreation, and water supply. The reservoir is currently on the State's 303(d) list for exceeding the upper pH limit of 9.0.

This reservoir water-quality assessment includes 1) in-reservoir data analysis, 2) inflow and outflow data analysis, 3) a water balance, and 4) a nutrient balance and 5) a comparison with other reservoirs in the same geographic area. A discussion of observed water-quality dynamics within the reservoir is also included.

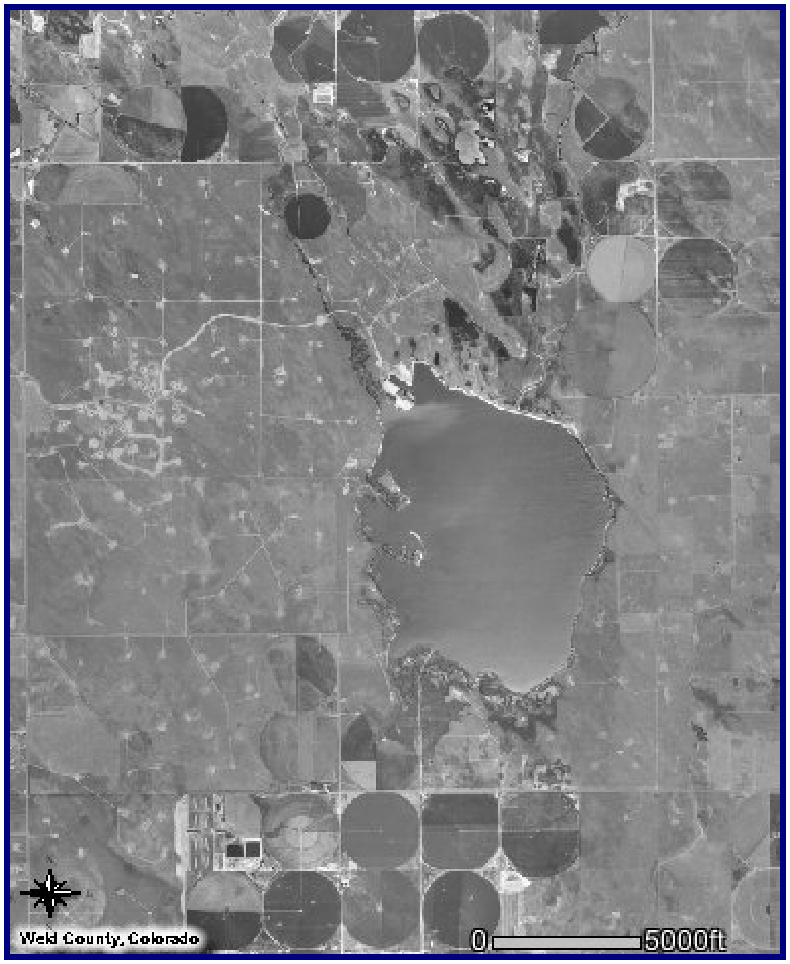

Figure 1. Milton Reservoir – Areal Photograph

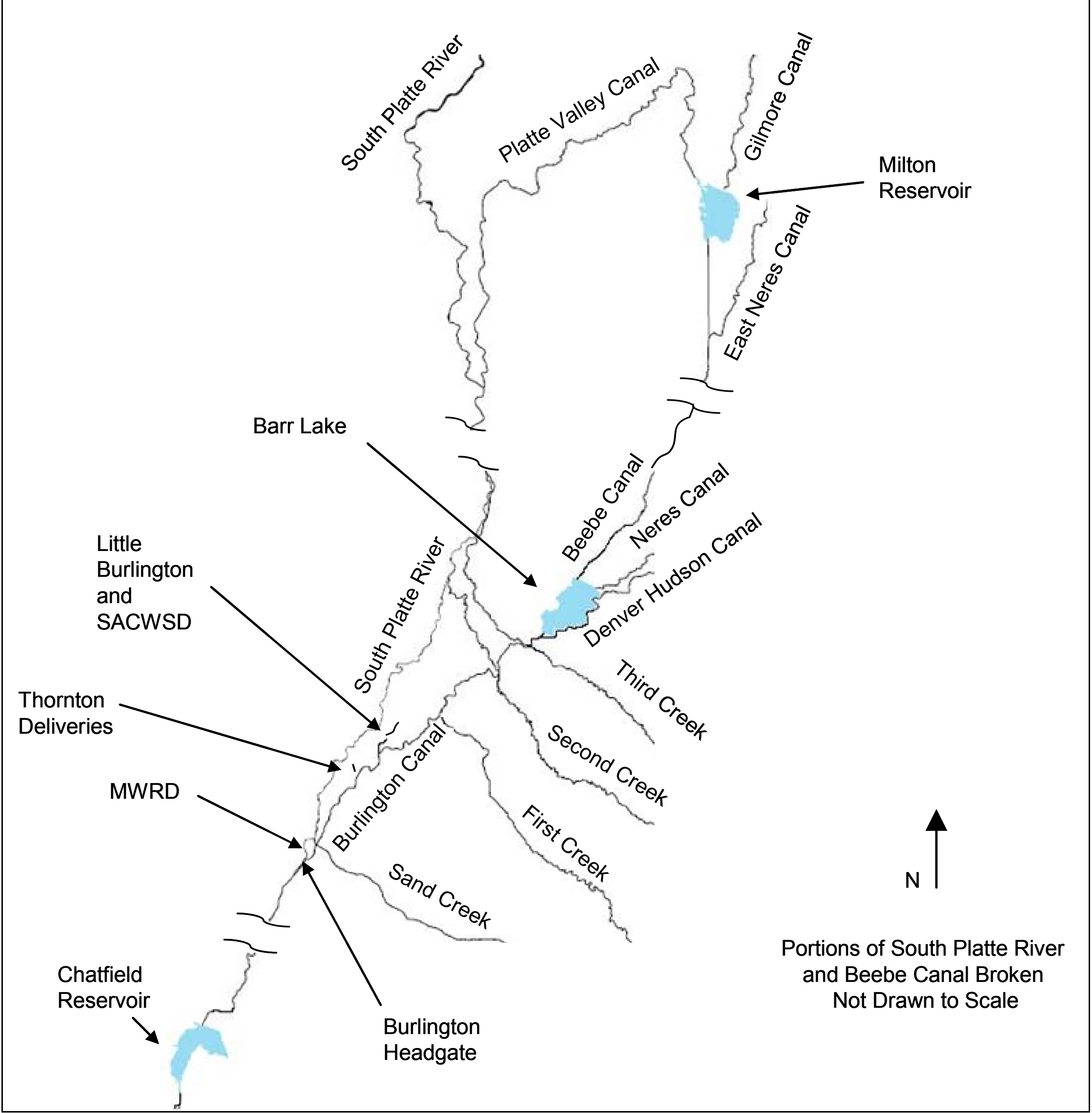

Figure 2. Map of Milton Reservoir and Environs

DATA – SOURCES AND TREATMENT

Data from several sources were used for this analysis (Table 1). With respect to water-quality data, results reported as being below the detection limit were treated as being at one-half the detection limit. In addition, when data for duplicate samples were available, the average of the sample and the duplicate were used in the analysis.

Table 1. Data Sources

Data Description	Source
Monthly Surface Water Flows into Milton Reservoir (11/68-10/04)	D. Helton Consulting (Rink, 2008a)
Monthly Reservoir Release Flows (11/68-10/04)	D. Helton Consulting (Rink, 2008a)
In-Reservoir Water Quality (6/02[1]-10/05)	Lundt, 2006b
Algal Species (2002-2004)	Lundt, 2004
Inflow / Outflow Water Quality (1/95-12/05)	Mountain River Associates (Lundt, 2005b
Elevation - Area - Capacity Table	D. Helton Consulting (Rink, 2008a)
Reservoir Contents (11/68-10/04)	D. Helton Consulting (Rink, 2008a)
Sediment Phosphorus Data	Lundt, 2005a
Water-Quality for Other Lower South Platte Reservoirs	Sprague, 2002a

Most annual computations for this report are based on an irrigation year – November 1 through October 31, and are designated using 'IY'. For example, IY04 represents November 1, 2003 through October 31, 2004.

Overall trend analyses were conducted for in-reservoir water-quality constituents as well as inflow (Platte Valley Canal and the Beebe Seep) water quality. The Mann-Kendall Methodology (Gilbert, 1987) was used. Although the Mann-Kendall test for trend can be performed on a small sample (4 <= n < = 10), a larger sample size is suggested (n >= 20) (EPA, 2000). Therefore, data were analyzed for trends only if there were at least 20 data points. Trends are described in the subsequent sections of this report and are reported with a 95% confidence interval ($\alpha = 0.05$) to determine whether a trend is significant.

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[1] In-reservoir water-quality sampling started in June 2002. Therefore, there are no data for the first seven months of the 2000 irrigation year.

Only significant trends are reported. Note that trend analyses were conducted using recent available water-quality data (2002-2004 for the in-reservoir data and 1998-2005 for the inflow / outflow data). Data from the 1970's were not included due to 1) very few historical data points and 2) the gap in data between the 1970's and 2001.

Monthly data for many components of the water balance were developed by D. Helton Consulting (Rink, 2008a). Most of the data values were from FRICO and Department of Water Resources records and in some cases, data were filled in by Mr. Helton to provide a complete monthly time series for the water balance (Helton, 2008). These data were provided to AMEC Earth & Environmental specifically for the water nutrient balance efforts and it was assumed that the data were the best datasets available to characterize the system. No attempts were made to verify the values received.

Overall, there were very few historical water-quality records for Milton Reservoir. Therefore, this study focuses on recent water-quality data.

RESERVOIR DATA ANALYSIS

Comparison of Sampling Sites

Water-quality samples were taken from three locations within Milton Reservoir (Figure 3). An analysis was completed to determine if the results from the three sites were statistically different from each other. The chi-square test for homogeneity (EPA, 1998) was used at a 95% confidence level ($\alpha = 0.05$).

The analysis looked at several constituents and compared data at the bottom of the reservoir (hypolimnion) and compared data near the surface (epilimnion) of the reservoir. The results are summarized in Table 2.

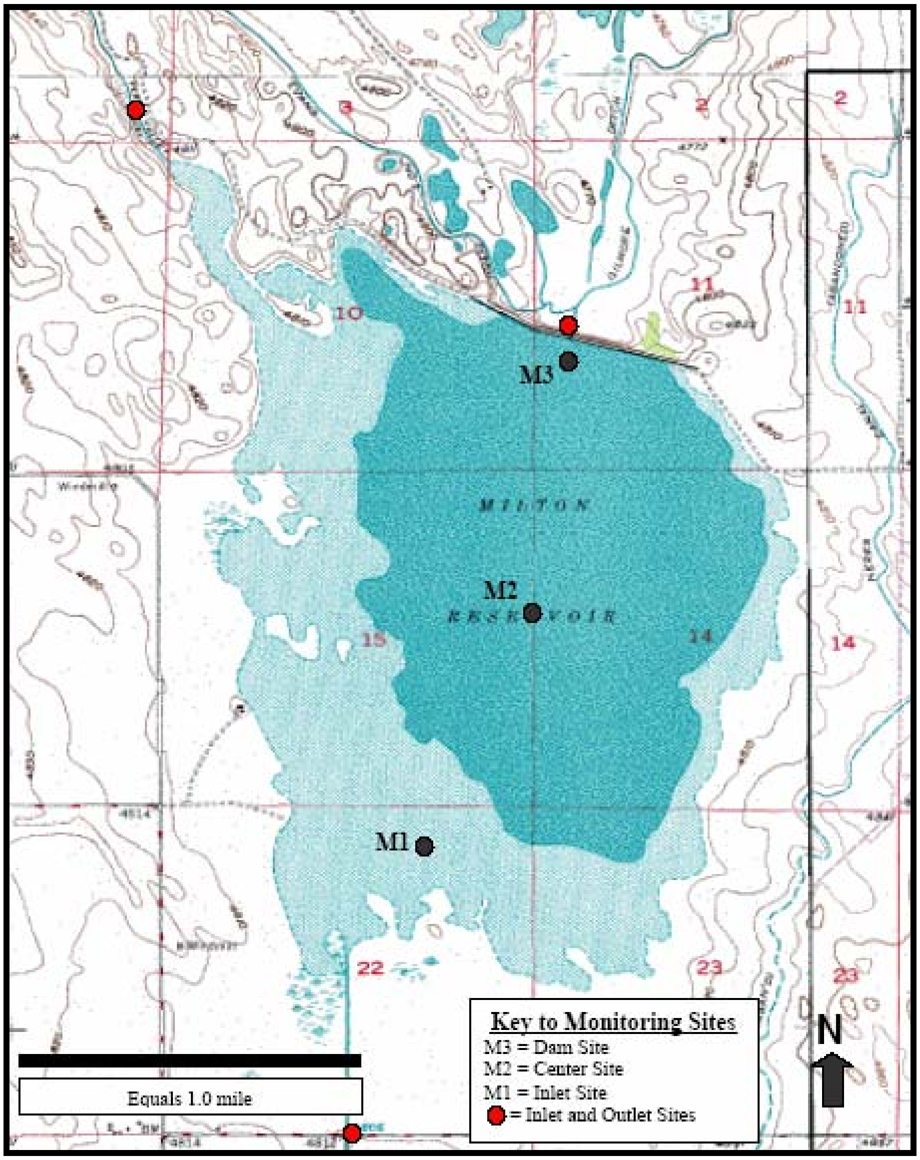

Figure 3. Milton Reservoir Sampling Sites **(Map Credit: S. Lundt, MWRD)**

With respect to chlorophyll *a*, total organic carbon, Secchi-disk depth, total suspended solids, total phosphorus, orthophosphate, nitrate + nitrite, ammonia, and Total Kjeldahl Nitrogen (TKN) in the epilimnion, the analysis indicates that data taken from sampling sites M1, M2, and M3 are not statistically different. For the hypolimnion, the analysis results indicate no statistical differences with respect to total organic carbon, and all of the nutrient species with the exception of total phosphorus and orthophosphate. Since the overall analysis indicates that the three sites are statistically homogeneous, data from the site near the dam (M3) was used for the discussion in the rest of this report. This site also had more data records associated with it over sites M1 and M2.

Table 2. Comparison of In-Reservoir Sampling Sites M1, M2, and M3

Constituent	Epilimnion (Surface Layer)	Hypolimnion (Bottom Layer)
Chlorophyll *a*	No Difference	NA
Secchi-Disk Depth	No Difference	No Difference
Total Organic Carbon	No Difference	NED
Total Suspended Solids	No Difference	No Difference
Total Phosphorus	No Difference	Difference
Orthophosphate	No Difference	Difference
Total Kjeldahl Nitrogen	No Difference	No Difference
Nitrate + Nitrite	No Difference	No Difference
Ammonia	No Difference	No Difference

NA = Not Applicable
NED = Not Enough Data

Physical Data

Morphometry

The morphometry of Milton Reservoir at full pool is summarized in Table 3. The reservoir is relatively shallow. Note that the reservoir is seldom at full pool as noted in Figure 4 and its contents dropped considerably during the dry year of 2002. Note that Figure 4 shows the gage height over time. The actual depth is approximately 11 feet less than the gage height (Rink, 2008c). The relationships between gage height, reservoir surface area, and reservoir contents are shown in Figure 5.

Table 3. Milton Reservoir Morphometry at Full Pool*

Parameter	Value (British Units)	Value (Metric Units)
Gage Height	37.4 ft	11.4 m
Depth		
Mean	11.5 ft	3.5 m
Maximum	26.4 ft	8.05 m
Surface Area	2,082 Acres	843 HA
Contents	24,029 AF	29.6x10^6 m^3

* Full Pool defined as maximum contents 1985-2005

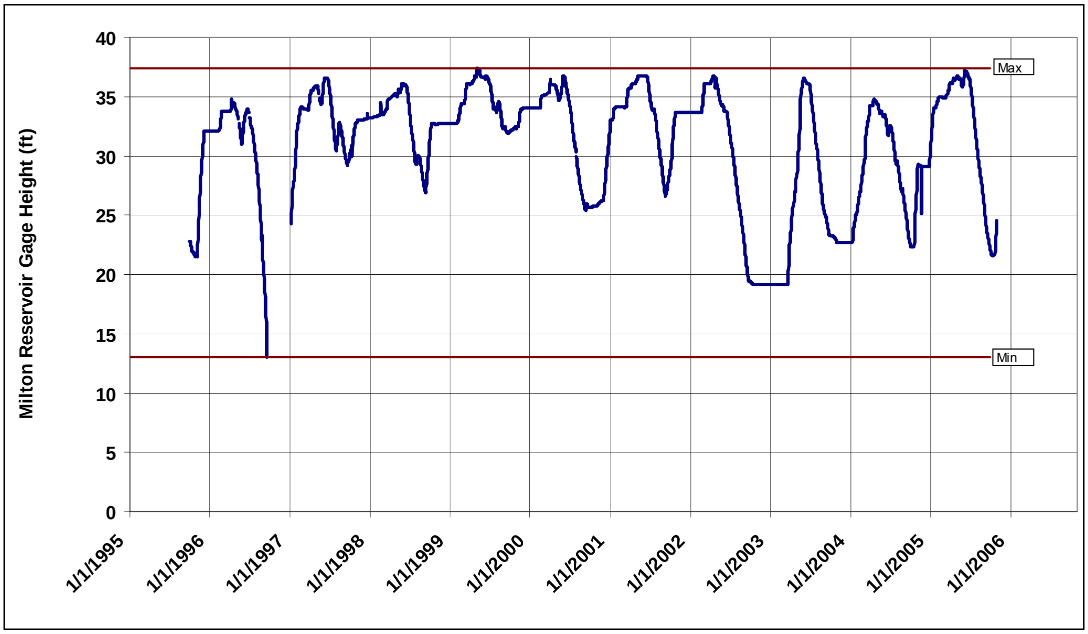

Figure 4. Historical Gage Height for Milton Reservoir (Note that the actual depth is approximately 11 feet less than the gage height.)

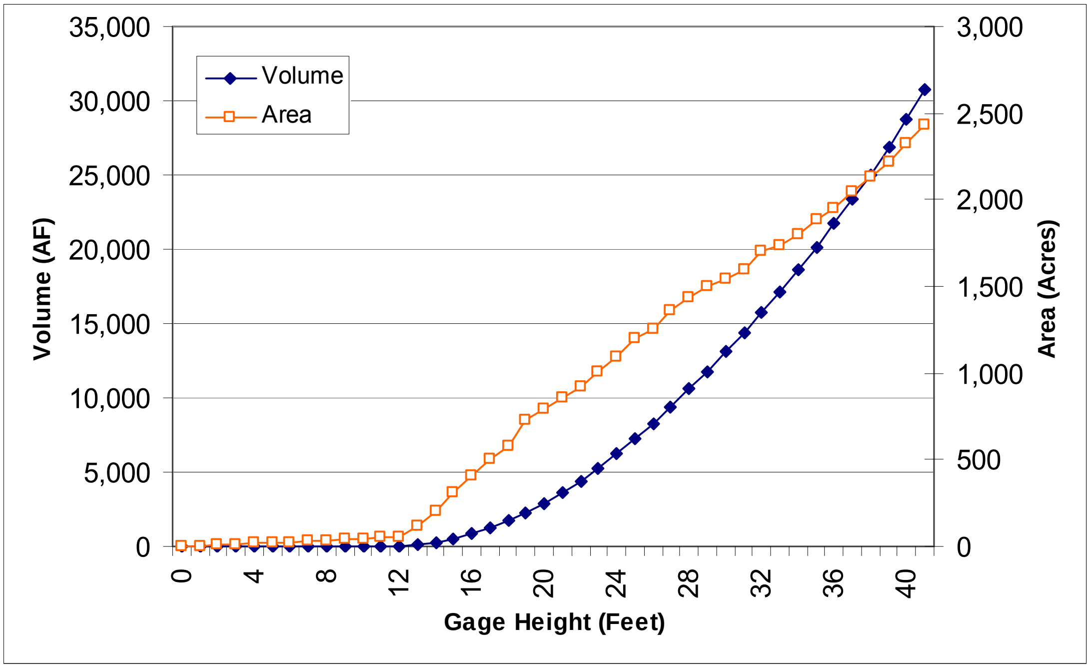

Figure 5. Area and Volume versus Gage Height for Milton Reservoir

Hydrology

Monthly inflow and outflow data were analyzed for patterns and magnitude. Monthly diversions from the South Platte River into the Platte Valley Canal for delivery to Milton Reservoir were developed by D. Helton Consulting (Rink, 2008a). Ditch losses of 20% were assumed by D. Helton Consulting to estimate the flow into the reservoir (Leonard Rice Engineers, 2005). Annual inflows and outflows are summarized in Table 4.

Table 4. Milton Reservoir Hydrology for IY69-IY04 (AF/Year)

	Inflow (Platte Valley Canal and Beebe Canal)	Reservoir Release to Gilmore Canal
Average Irrigation Year Flow	27,839	33,328
Maximum Annual Flow / Irrigation Year	50,796 (1997)	48,210 (1996)
Minimum Annual Flow / Irrigation Year	7,998 (2000)	23,940 (1979)

Figure 6 shows the inflow and outflow for a composite year. This plot was developed by averaging hydrographs from 1969 through 2004. Although the data are somewhat smoothed by the averaging process, the major features of the reservoir's hydrology can be seen. In general, the inflows are higher in the beginning of the year and drop back in the summer months. Inflows increase somewhat at the end of the year. The bulk of the outflow occurs between May and September. The highest outflows occur in July.

Reservoir contents for a composite year are displayed in Figure 7. Contents generally peak in April-May and are at lowest levels in August-September. The hydraulic residence time based on releases and average contents for each irrigation year are shown in Table 5.

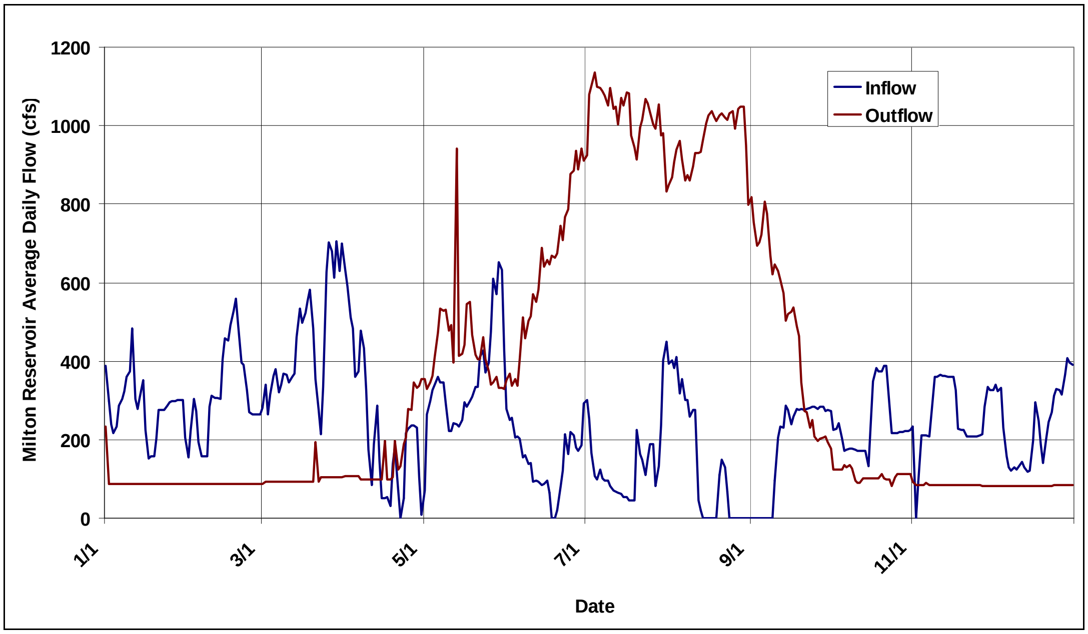

Figure 6. Inflow and Outflow for Milton Reservoir for a Composite Year Representing the Average of 1969 through 2004

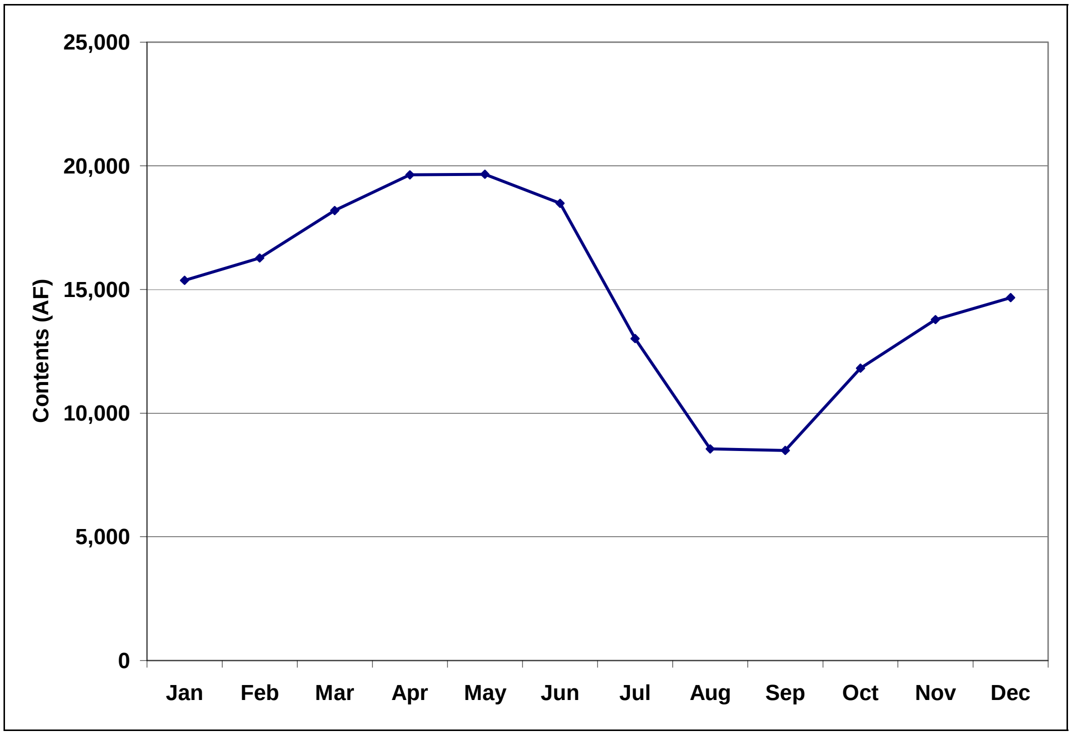

Figure 7. Milton Reservoir Contents for a Composite Year Representing the Average of IY68 through IY04

Table 5. Hydraulic Residence Times by Irrigation Year

Year	Hydraulic Residence Time (months)
IY00	7.0
IY01	8.4
IY02	7.0
IY03	4.1
IY04	5.4
Average (IY00-IY04)	6.4

Field Data

Field data include water temperature, dissolved oxygen, pH, and Secchi-disk depth. The first three constituents are taken every half meter throughout the water column.

Water Temperature

Recent surface and bottom temperatures are displayed in Figure 8. Temperatures peak in August of each year at about 26°C. Surface temperatures rose to over 28°C in 2003. Temperatures at the bottom do not differ greatly from surface temperatures throughout the year. In lakes and reservoirs that strongly stratify, the temperature at the bottom does not increase in the summertime. This is not the case with Milton Reservoir. There is some level of mixing between the upper layer and the bottom layer throughout the year. This is caused by wind mixing when the reservoir is shallow and is also influenced by releasing water from the bottom layer at the dam outlet.

Trend analysis on recent data (2002-2005) shows no trend over time for water temperature at the surface or at the bottom of the reservoir.

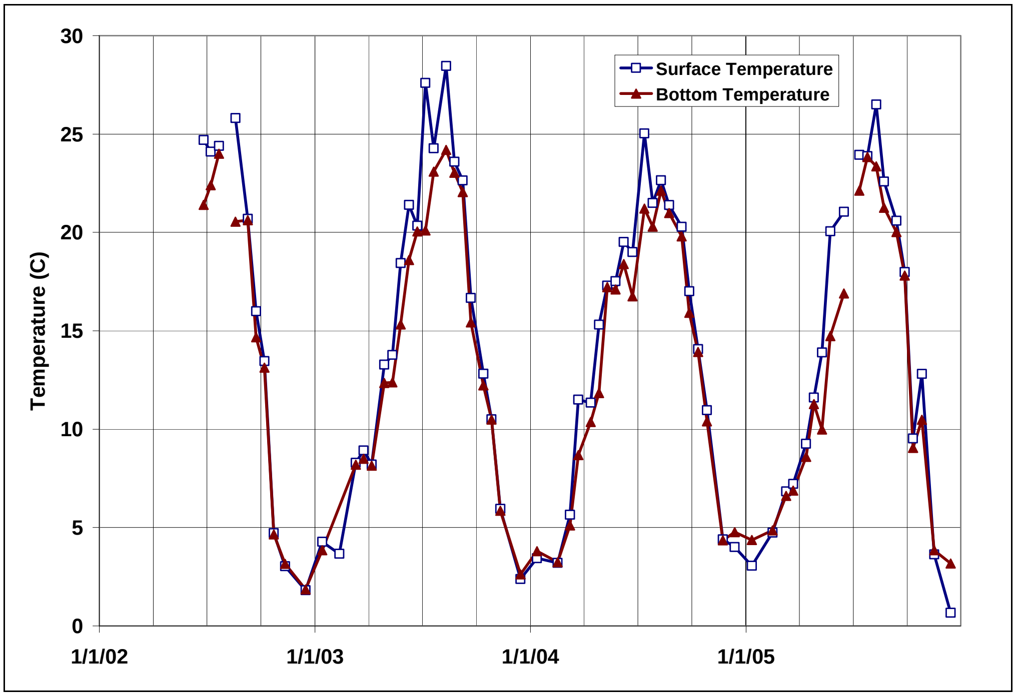

Figure 8. Surface and Bottom Temperatures in Milton Reservoir (Station M3)

A subset of temperature profile data for 2004 is displayed in Figure 9. Some level of stratification occurs in June and into July. During July and August, the reservoir releases increase (Figure 5) resulting in a decrease in reservoir depth (Figure 3). A more shallow depth coupled with bottom-level reservoir releases help to breakup the level of stratification achieved earlier.

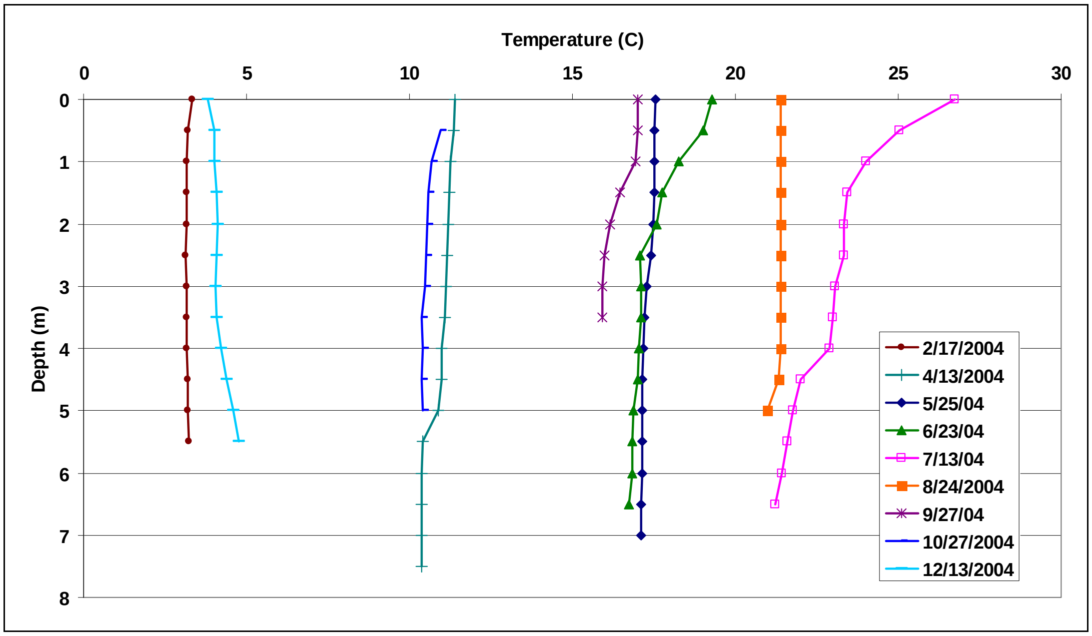

Figure 9. 2004 Temperature Profiles in Milton Reservoir (Station M3)

Dissolved Oxygen

Recent and historical surface and bottom layer dissolved oxygen concentrations are displayed in Figure 10. Oxygen depletion occurs near the bottom of the reservoir in the summer when the lake is temporarily stratified. Bottom dissolved oxygen concentrations are higher in the winter when the reservoir is well mixed and cooler. Dissolved oxygen near the surface is erratic, most likely due to the mixing patterns in the reservoir and the changing algal populations. Algae release dissolved oxygen when they are photosynthesizing. The trend analysis on recent data (2002-2005) shows no trend over time for dissolved oxygen for both the surface and bottom of the reservoir.

Dissolved oxygen profiles in the reservoir for 2004 are shown in Figure 11. The profiles show a sharp decrease in oxygen at the bottom in the summer when the reservoir has higher contents. When dissolved oxygen concentrations drop to below 2 mg/l, the release of constituents such as manganese, phosphorus, and ammonia can occur.

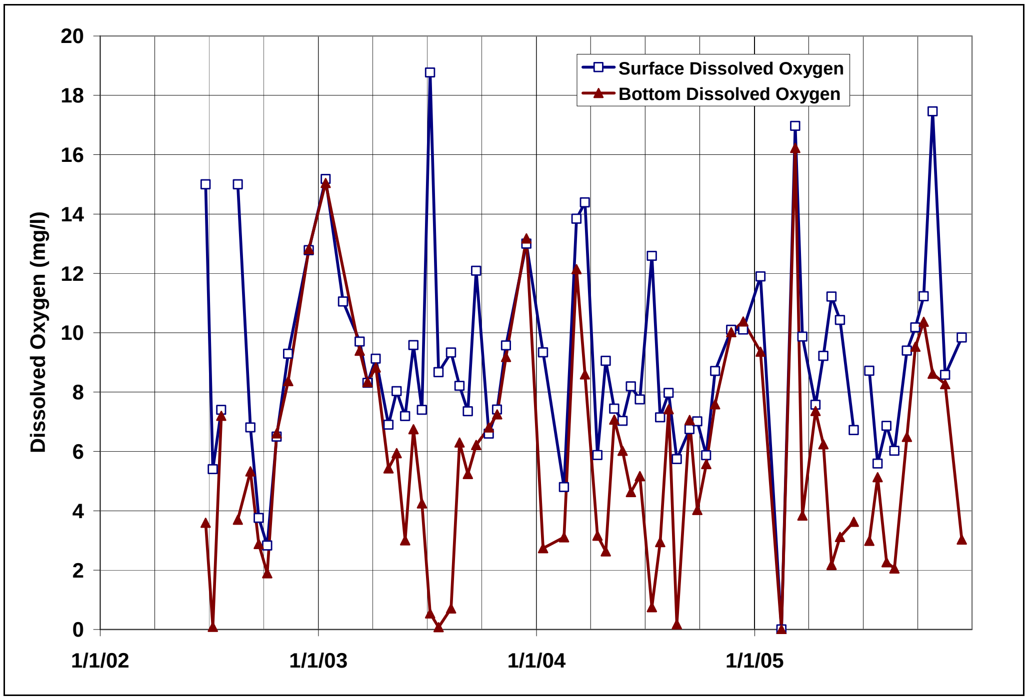

Figure 10. Surface and Bottom Dissolved Oxygen Concentrations in Milton Reservoir (Station M3)

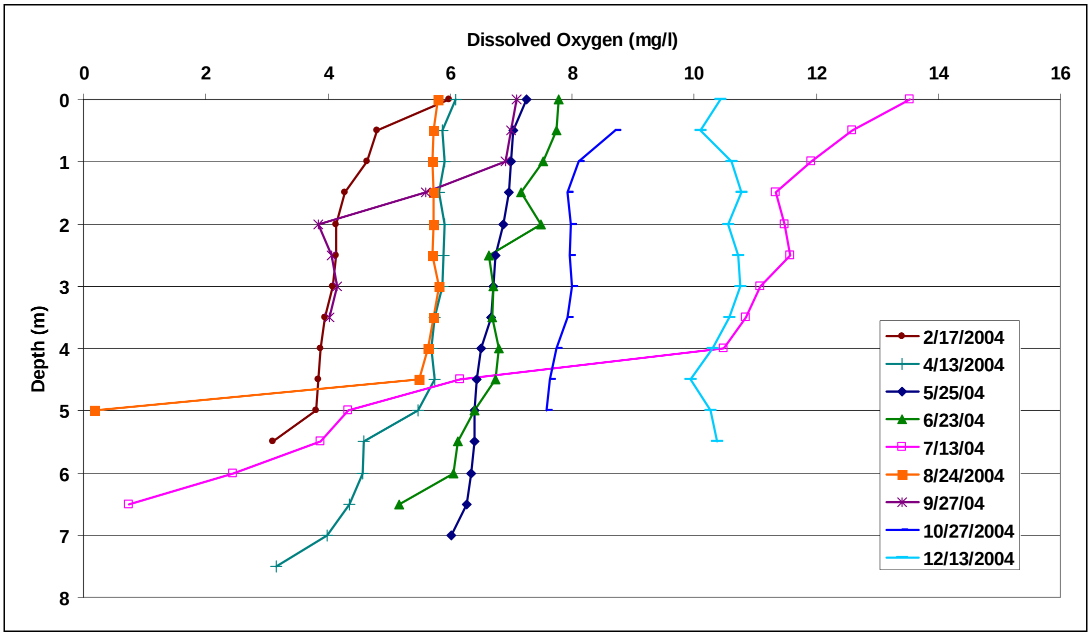

Figure 11. 2004 Dissolved Oxygen Profiles in Milton Reservoir (Station M3)

pH

Surface and bottom layer pH are displayed in Figure 12. pH values peak in summer around July of each year. The upper standard for pH (9.0) is exceeded every year during the recent period. The pH standard is not exceeded between the months of February though June. The duration of high pH was longer in 2003 and 2005 versus 2002 and 2004. In 1975, the reservoir pH was at the upper standard in August (EPA, 1977).

pH profiles in the reservoir for 2004 are shown in Figure 13. There is not much variation with depth. The trend analysis on recent data (2002-2005) shows an increase in pH over time at the surface and at the bottom of the reservoir.

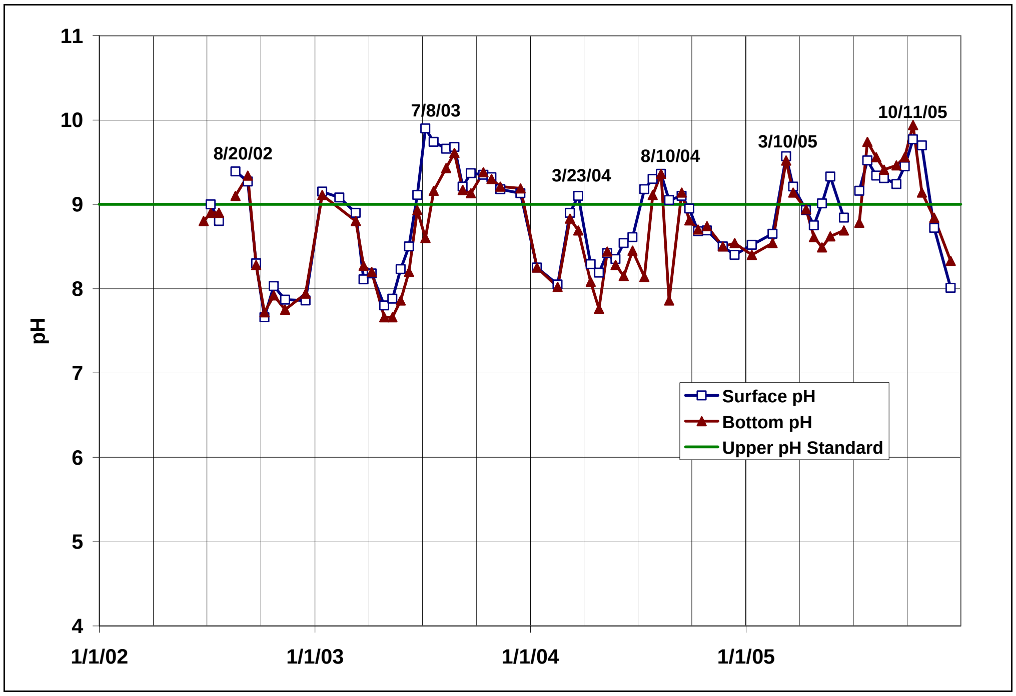

Figure 12. Surface and Bottom pH in Milton Reservoir (Station M3)

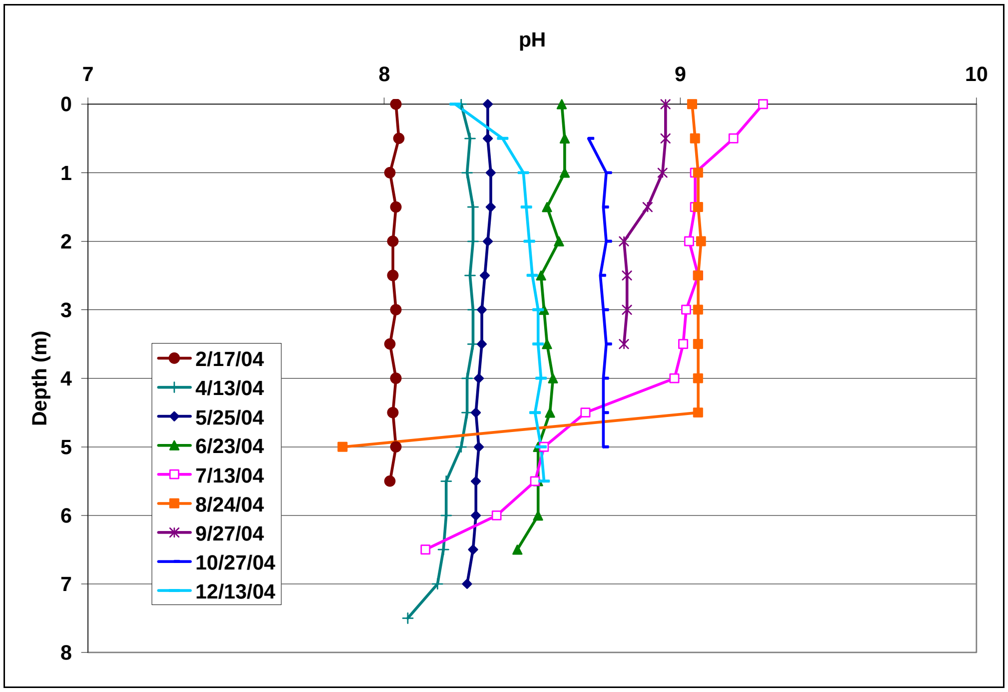

Figure 13. 2004 pH Profiles in Milton Reservoir (Station M3)

Secchi-Disk Depth

Secchi-disk depth is a measure of water clarity. The higher the value, the greater the clarity. Secchi-disk depths are presented in Figure 14. The average for 2002-2005 is 2.1 meters while the average summer average (June to September) is 1.9 meters. The data show a range of 0.3 to 6.6 meters. The pattern varies year to year. The lake was unusually clear during the winter of 2003-2004.

The trend analysis on recent data (2002-2005) shows no statistical trend in Secchi-disk depth over time.

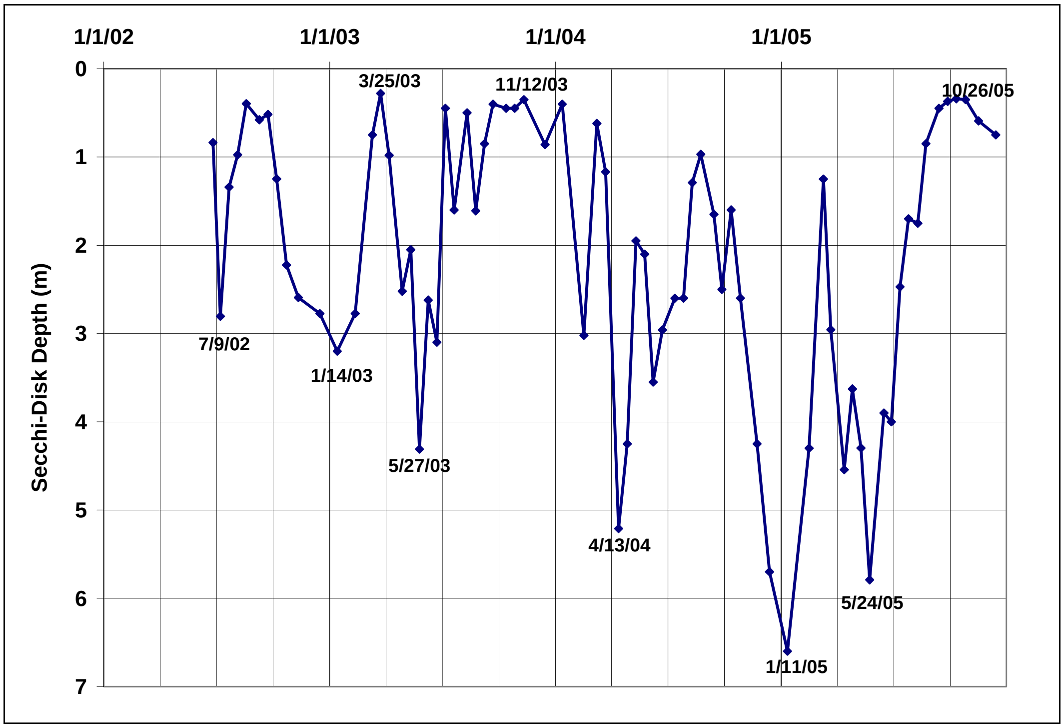

Figure 14. Secchi-Disk Depth in Milton Reservoir (Station M3)

Nutrients

Phosphorus

In-reservoir phosphorus data over the period 2002 - 2005 are shown in Figures 15 and 16. The average total phosphorus concentration over the period is 538 µg/l for the surface layer and 540 µg/l for the bottom layer. The maximum concentration is 1,230 µg/l (surface layer in the summer of 2004). The bulk of the total phosphorus is in the form of orthophosphate (the bioavailable form) as opposed to organic phosphorus. This is also the case for the primary inflow into the lake, the Platte Valley Canal (see Figure 21). Concentrations of the surface layer and bottom layer are similar much of the time. There is no specific pattern although the concentrations tend to peak in July / August. There was an unusual decline in phosphorus from November 2002 – March 2003. For both layers, the trend analysis shows that total phosphorus and orthophosphate are increasing over the time period of 2002 to 2005.

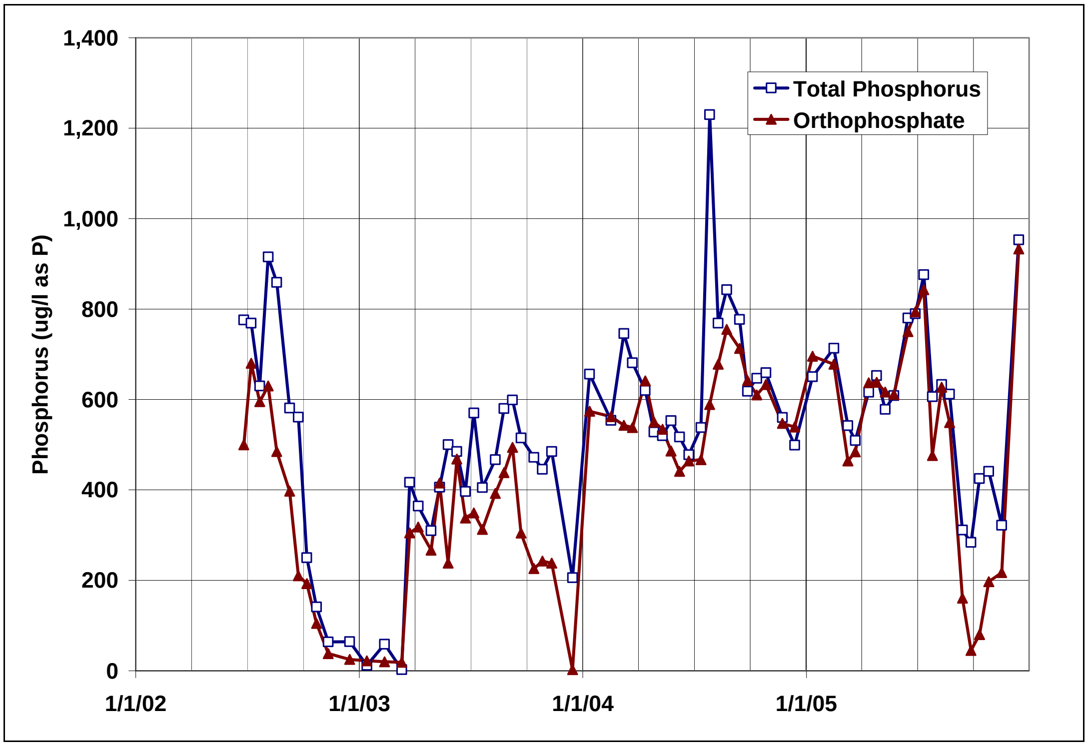

Figure 15. Phosphorus Concentrations Near the Surface of Milton Reservoir

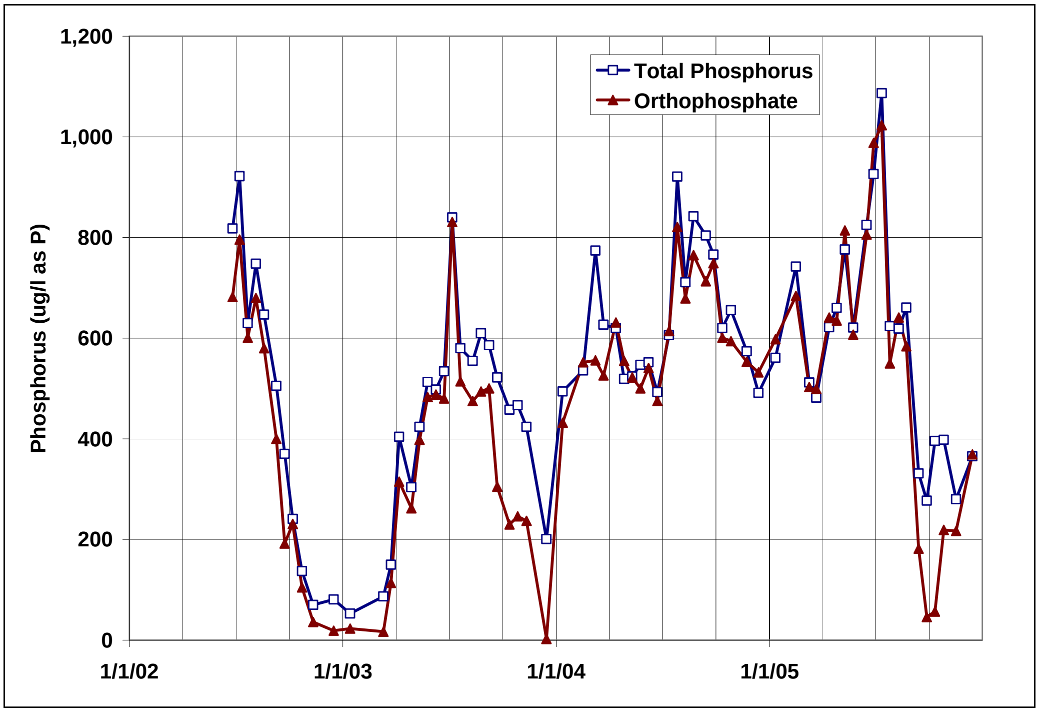

Figure 16. Phosphorus Concentrations Near the Bottom of Milton Reservoir

Nitrogen

In-reservoir nitrogen data over the period 2002 - 2005[2].are shown in Figures 17 and 18. The average total nitrogen concentration over the period is 3,551 µg/l for the surface layer and 3,329 µg/l for the bottom layer. The maximum concentration is 7,130 µg/l (surface layer). Concentrations of total nitrogen are typically higher in the spring. For both layers, the trend analysis shows that total nitrogen and ammonia have no trend over time. Nitrate + nitrite concentrations show an increasing trend near the surface but no trend near the bottom.

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[2] Note that one of the dischargers to the South Platte River recently upgraded its facility. The Littleton/Englewood Wastewater Treatment Plant installed a nitrate removal system in 2007 (Rink, 2008e).

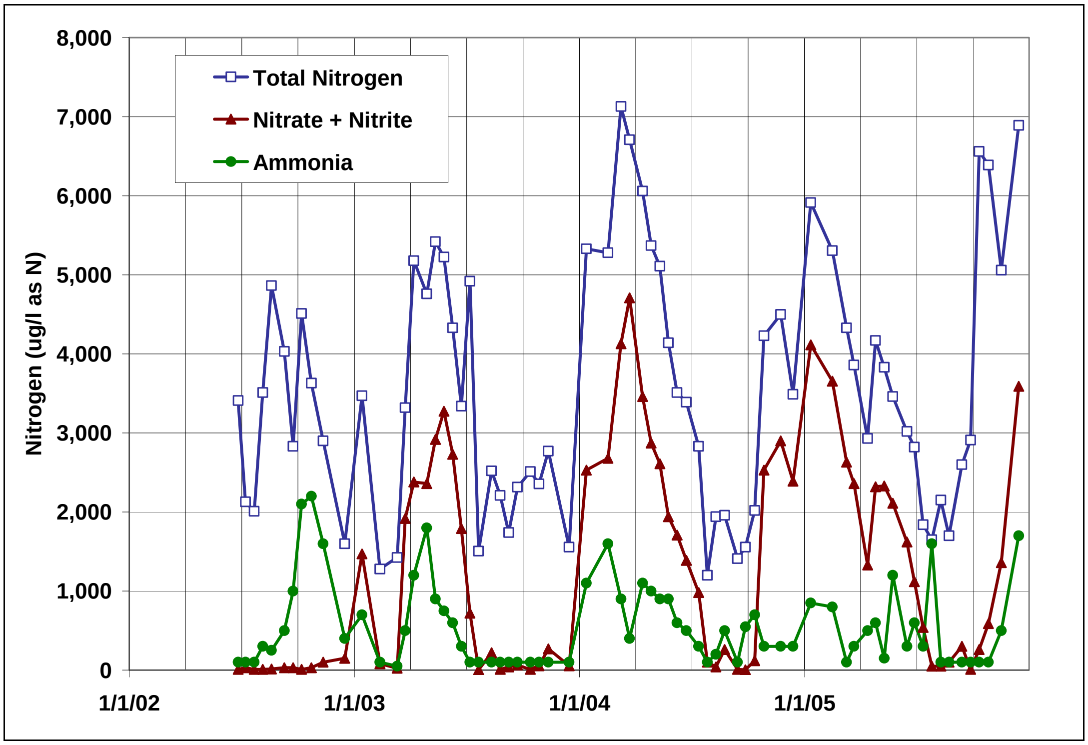

Figure 17. Nitrogen Concentrations Near the Surface of Milton Reservoir

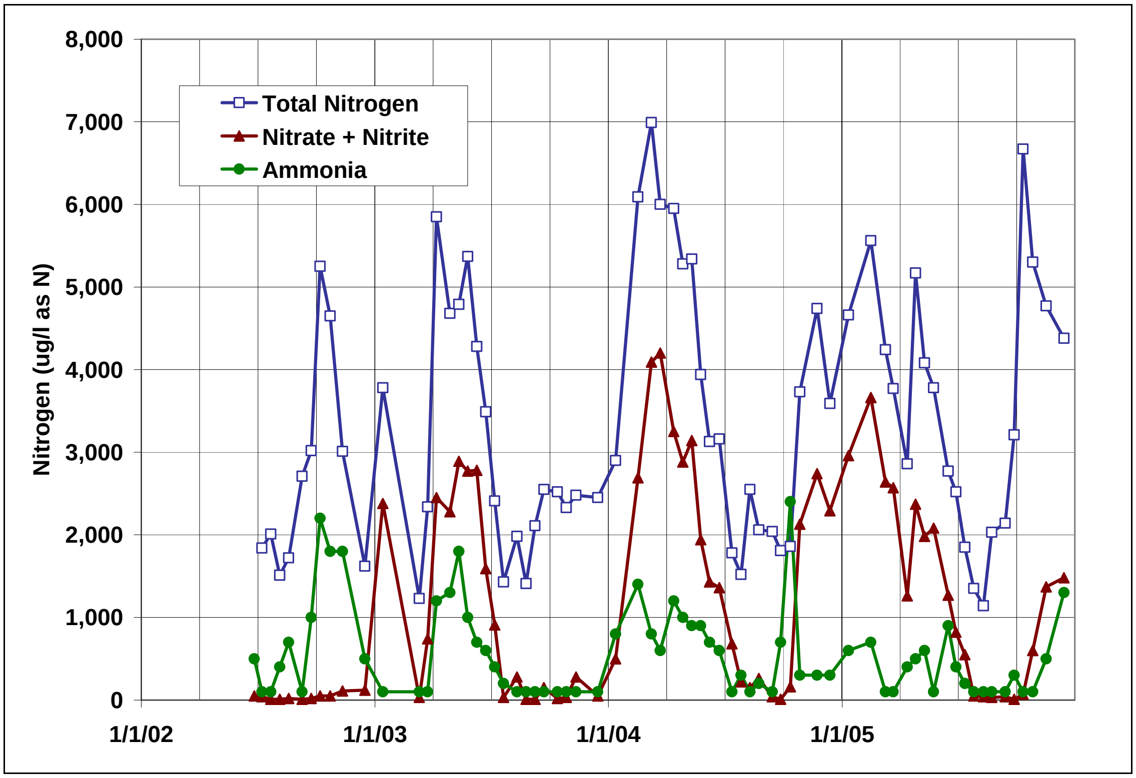

Figure 18. Nitrogen Concentrations Near the Bottom of Milton Reservoir

Algae and Zooplankton

Chlorophyll *a* measurements serve as a measure of the concentration of suspended algae or phytoplankton. These data are displayed in Figure 19.

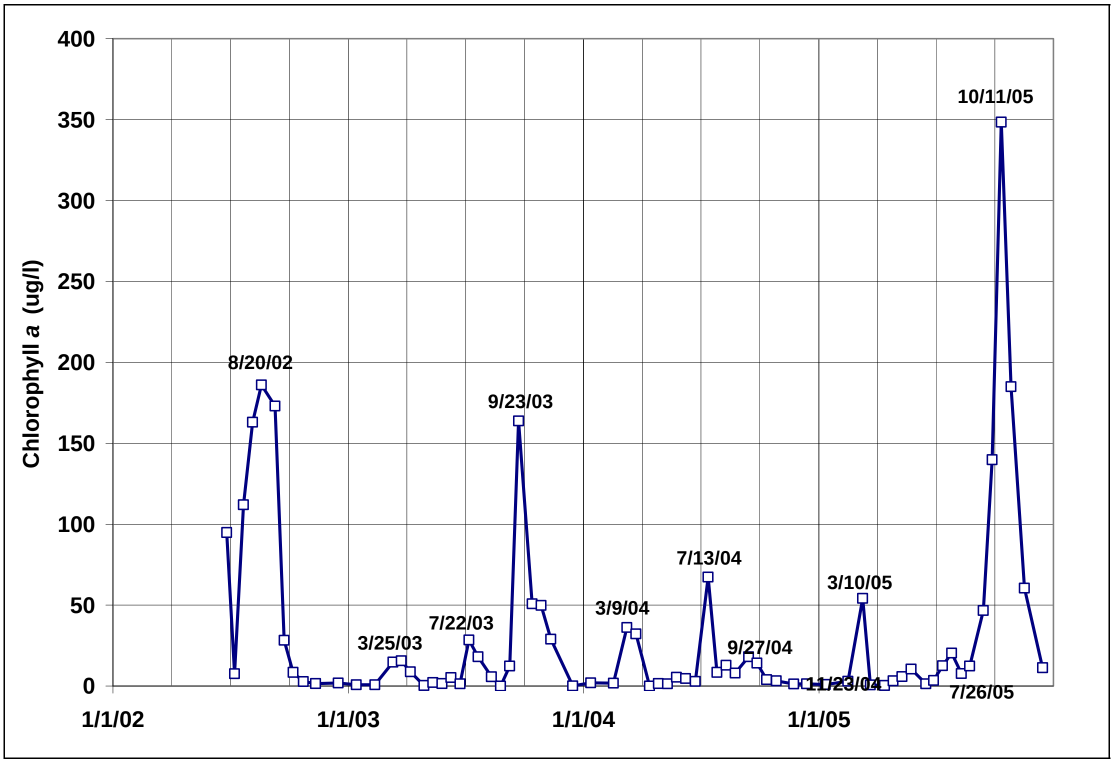

Figure 19. Chlorophyll *a* Concentrations in Milton Reservoir

The mean concentration over the period is 33.5 µg/l while the mean summer (June-September) concentration is 27 µg/l. The peak concentration of almost 350 µg/l occurred in October of 2005. In general, chlorophyll *a* concentrations peak in March, July and again in September / October. The trend analysis indicated no significant trend over the period 2002-2005.

Using Carlson's Trophic State Index (Carlson and Simpson, 1996), the observed growing season chlorophyll *a* concentrations place the reservoir in a eutrophic - hypereutrophic state.

Phytoplankton species data were received for the period July 2002 - August 2004. Blue-green species were dominant for portions of the year. The most dominant blue-green species were *Microcystis*, *Aphanizomenon* and *Aphanocapsa*. *Microcystis* and *Aphanocapsa* do not fix nitrogen but *Aphanizomenon* does. These species are often found in highly enriched reservoirs and lakes. Note that when the blue-green algae species are present, they often dominate the reservoir (Figure 20).

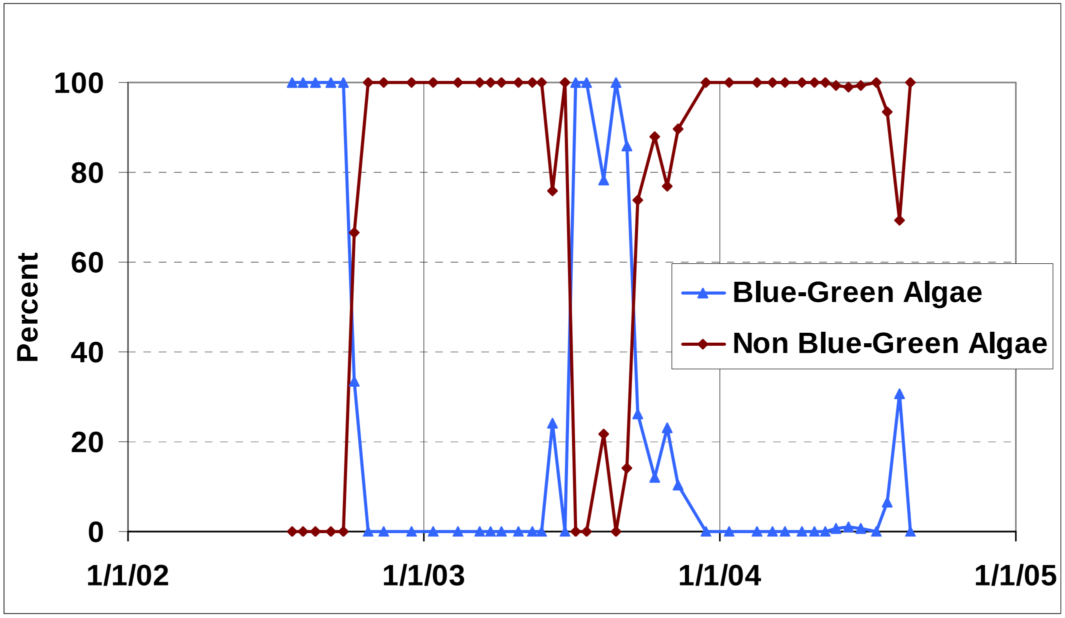

Figure 20. Dominant Algal Species Over Time

Some zooplankton data were available for this analysis but were not analyzed due to the number of data records and the suspected quality of the data (Lundt, 2006a).

Reservoir Data Analysis Summary

Milton Reservoir is a eutrophic - hypereutrophic plains reservoir. It is shallow and exhibits signs of temporary stratification in the summer before the reservoir is drawn down near the end of the summer. It has many of the signs of a highly enriched system:

- High nutrient concentrations;
- Low clarity;
- High levels of chlorophyll *a;*
- Blue-green algae dominating during portions of the year; and
- Dissolved oxygen depletion at the bottom of the reservoir.

Trends over the period 2002-2005 and mean concentrations of several constituents are displayed in Table 6. The results are mixed. Concentrations of some nutrients (phosphorus and nitrate + nitrite) are increasing, although there is no significant trend in chlorophyll a concentrations. It is difficult to draw conclusions on long term trends due to the lack of sufficient historical data.

Table 6. Milton Reservoir Trend Summary and Mean Concentrations (2002-2005)

Constituent	Mean (Surface / Bottom)	Trend
Total Phosphorus (µg/l)	538 / 540	Increasing
Orthophosphate (µg/l)	440 / 476	Increasing
Total Nitrogen (µg/l)	3,551 / 3,328	No Trend
Total Kjeldahl Nitrogen (µg/l)	2,303 / 2,183	Decreasing (Surface) No Trend (Bottom)
Nitrate + Nitrite (µg/l)	1,248 / 1,145	Increasing (Surface) No Trend (Bottom)
Ammonia (µg/l)	549 / 550	No Trend
Chlorophyll *a* (µg/l)	33.5	No Trend
Secchi-Disk Depth (m)	2.1	No Trend
pH (SU)	8.9* / 8.7*	Increasing
Dissolved Oxygen (mg/l)	9.1 / 5.8	No Trend
Temperature (°C)	14.5 / 13.5	No Trend
Total Organic Carbon (mg/l)	10.0 / 10.3	Decreasing (Surface) No Trend (Bottom)
Specific Conductance (µS/cm)	1,086 / 1,083	Decreasing
Total Suspended Solids (mg/l)	14.4 / 10.2	No Trend (Surface) Not Enough Data (Bottom)

* Although we recognize that calculating the mean of observed pHs introduces a bias as compared to –log (mean [H+]), the mean of the observed pHs is presented as a useful value to the reader.

INFLOW / OUTFLOW DATA ANALYSIS

There is a longer data set for inflow and outflow water-quality data than for in-reservoir data. This monitoring program for Milton Reservoir inflow and outflow began in 1998 (Mountain River Associates, 2001).

Phosphorus

Inflow concentrations of phosphorus from the Platte Valley Canal and Beebe Canal are displayed in Figures 21 and 22. For the Platte Valley Canal, the average total phosphorus concentration is 918 µg/l while the peak is 1,820 µg/l. For the Beebe Canal, the average is 415 µg/l while the peak is 2,740 µg/l. By contrast, the average total phosphorus concentration in the South Platte River below Chatfield Reservoir is 38 µg/l.

In general, concentrations in the Platte Valley Canal are higher during the winter and spring. Concentrations in the Beebe Canal are somewhat erratic. Most of the total phosphorus is in the form of orthophosphate. For both the Platte Valley Canal and the Beebe Canal, total phosphorus and orthophosphate have been statistically increasing since 1998. In general, the overall total phosphorus concentrations are higher in the Platte Valley Canal inflow to Milton Reservoir.

Outflow concentrations are shown in Figure 23. Again, most of the phosphorus is in the form of orthophosphate. Inflow and outflow concentrations are shown in Figure 24 for total nitrogen for comparison purposes.

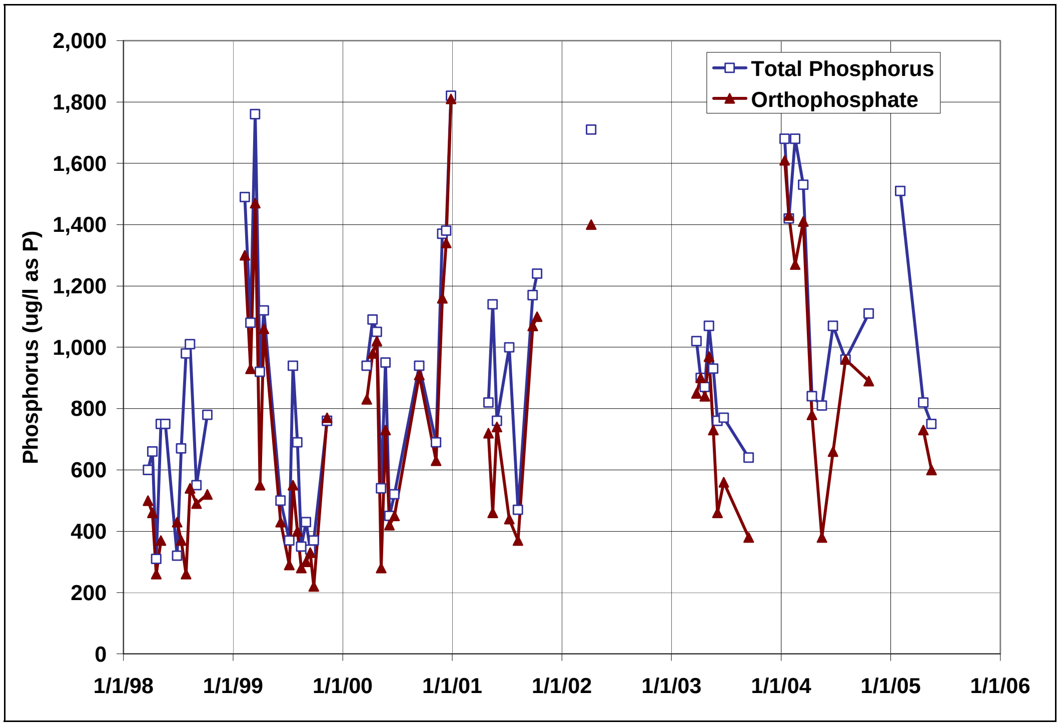

Figure 21. Phosphorus Concentrations in the Platte Valley Canal Inflow to Milton Reservoir

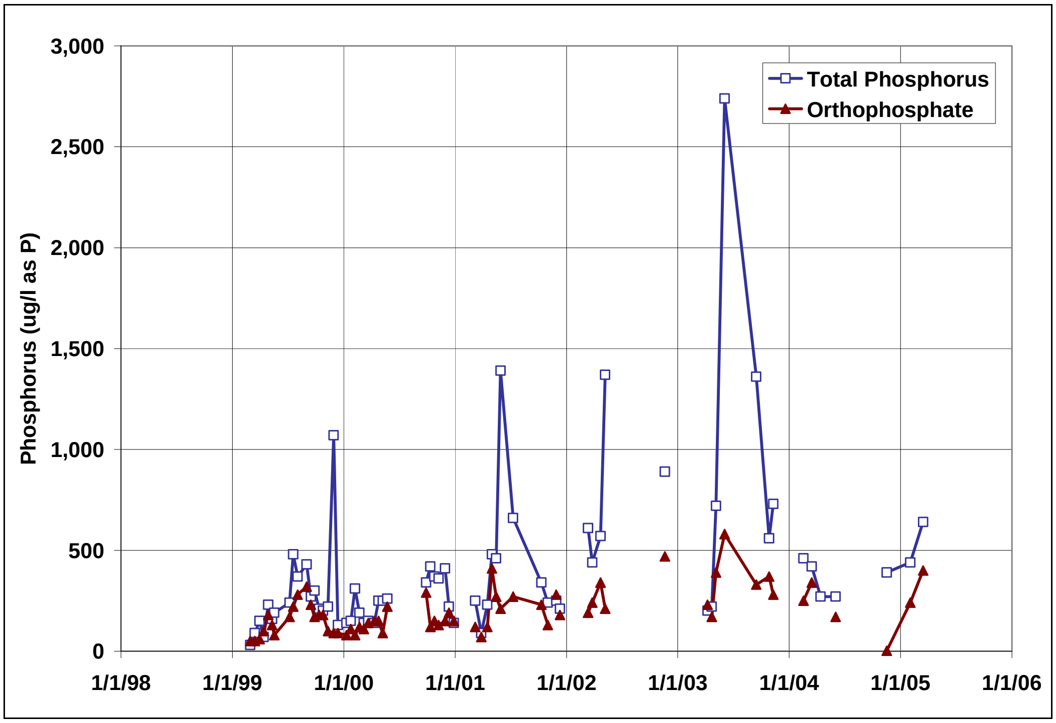

Figure 22. Phosphorus Concentrations in the Beebe Canal Inflow to Milton Reservoir

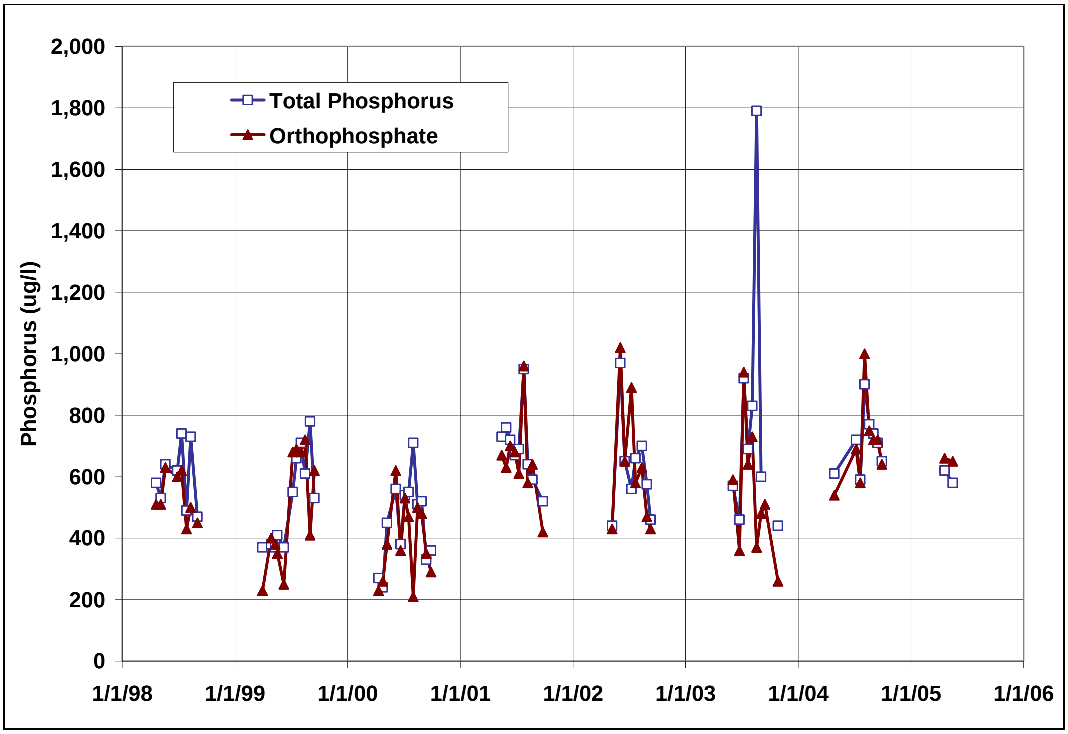

Figure 23. Phosphorus Concentrations in the Outflow from Milton Reservoir

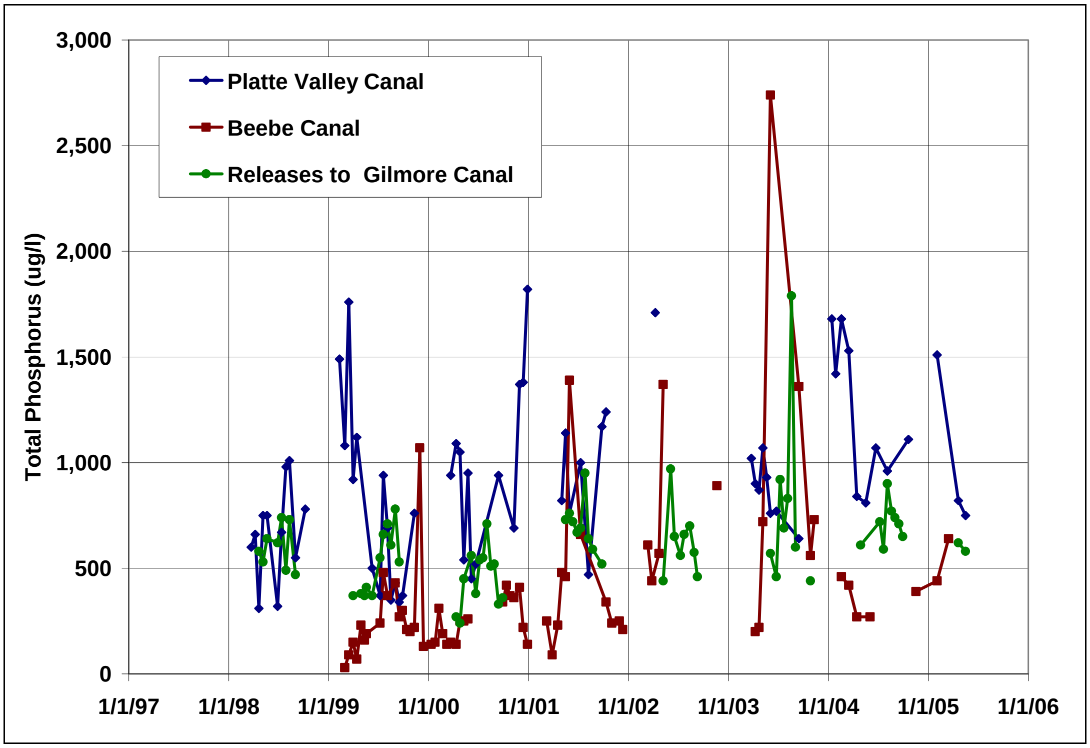

Figure 24. Total Phosphorus Concentrations in the Inflow to Milton Reservoir (via the Platte Valley Canal and the Beebe Canal) and the Release to the Gilmore Canal

Nitrogen

Inflow concentrations of nitrogen are displayed in Figures 25 -27[3]. In general, concentrations for the Platte Valley Canal exceed those in the Beebe Canal. For the Platte Valley Canal, the mean total nitrogen concentration is 6,086 µg/l and peaks at 13,370 µg/l. For the Beebe Canal, the mean concentration is 4,165 µg/l while the maximum is 11,900 µg/l. By contrast, the average total nitrogen concentration in the South Platte River below Chatfield Reservoir is 428 µg/l. Concentrations in the Platte Valley Canal are typically elevated in the late winter - early spring.

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[3] See footnote on page 17.

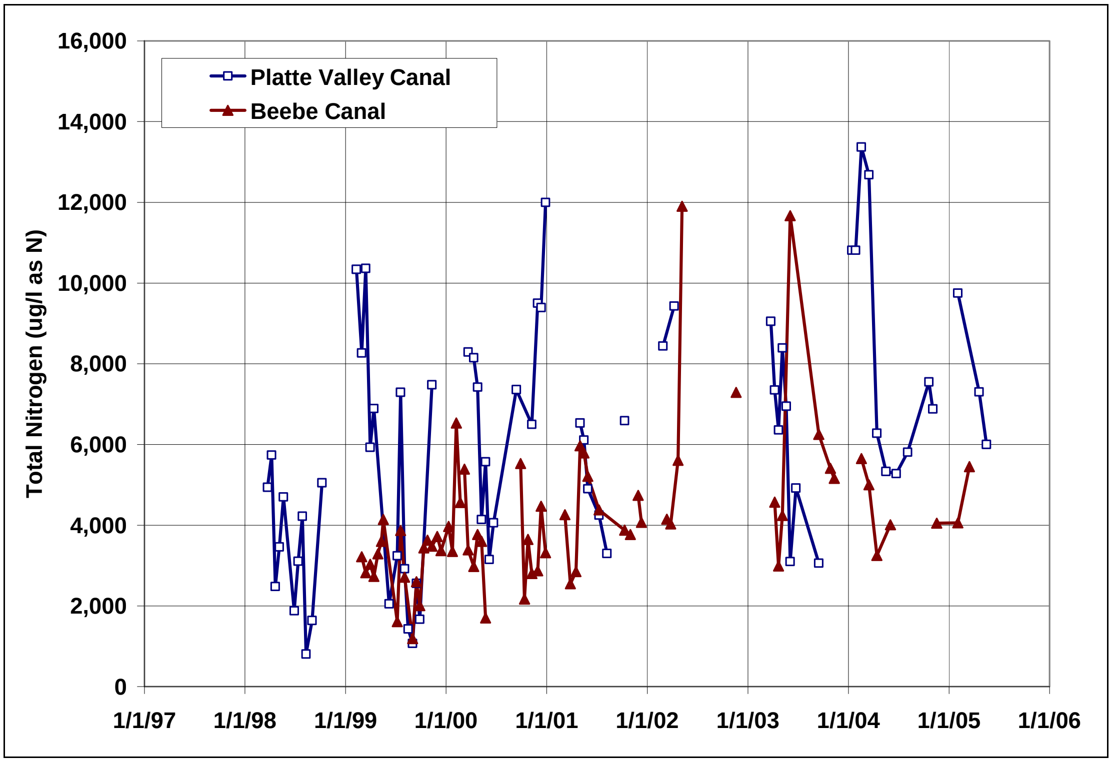

Figure 25. Total Nitrogen Concentrations in the Inflows to Milton Reservoir

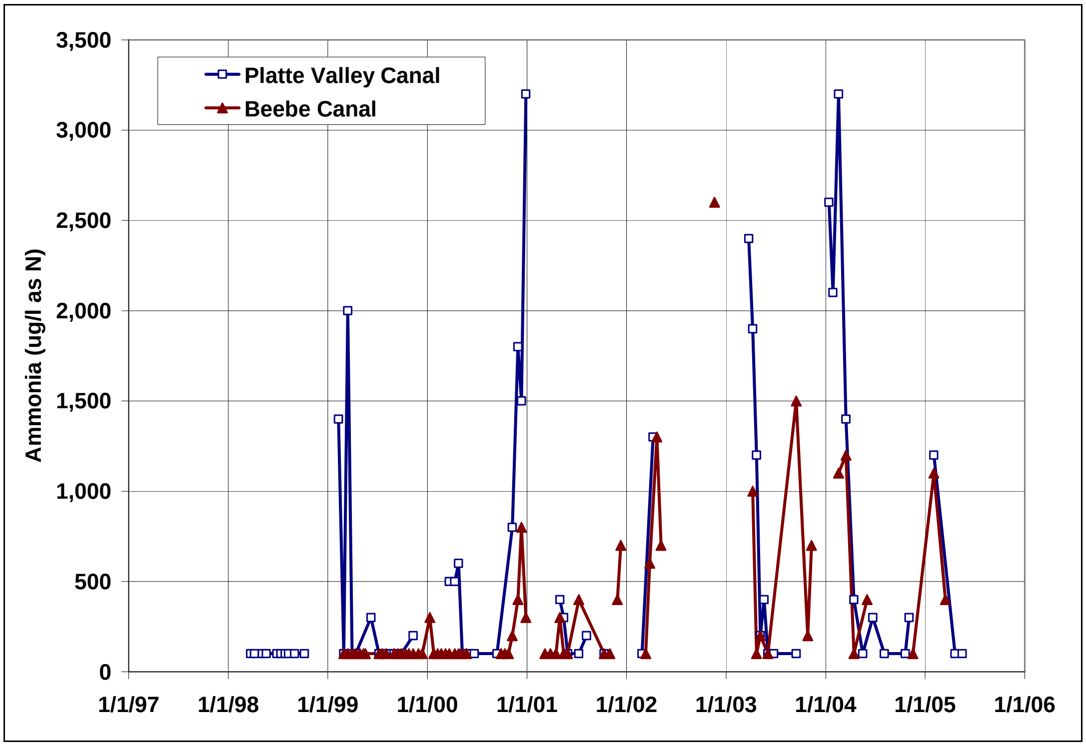

Figure 26. Ammonia Concentrations in the Inflows to Milton Reservoir

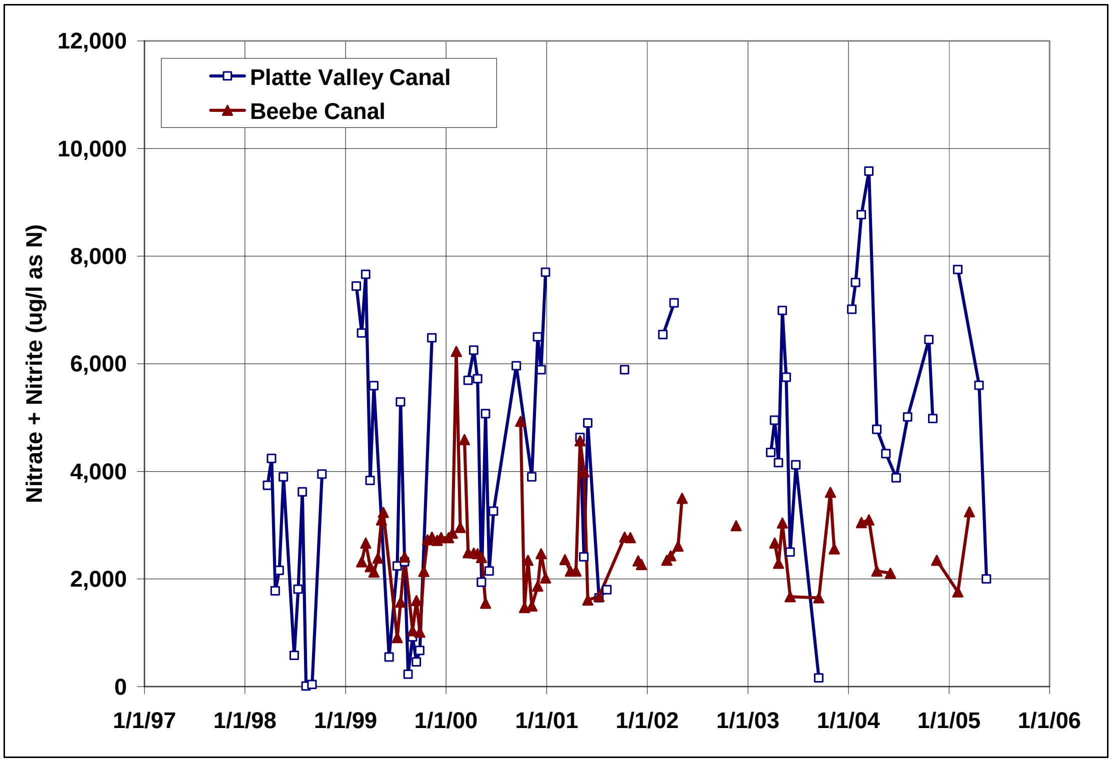

Figure 27. Nitrate Plus Nitrite Concentrations in the Inflows to Milton Reservoir

For both the Platte Valley Canal and the Beebe Canal, total ammonia and Total Kjeldahl Nitrogen have been statistically increasing since 1998. Nitrate + nitrite have been increasing in the Platte Valley Canal but there is no statistical trend in nitrate + nitrite concentrations in the Beebe Canal.

Outflow concentrations are shown in Figure 28. Observed total nitrogen concentrations were higher for the past three years versus the previous years. Inflow and outflow concentrations are shown in Figure 29 for total nitrogen for comparison purposes.

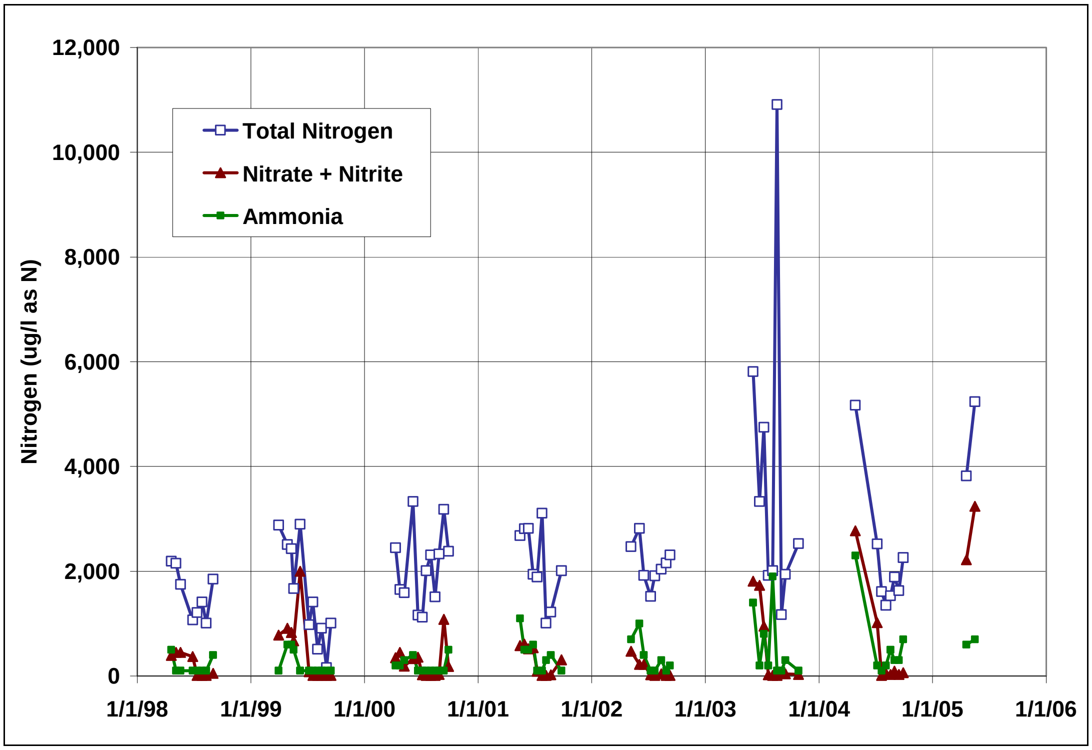

Figure 28. Nitrogen Concentrations in the Outflow from Milton Reservoir

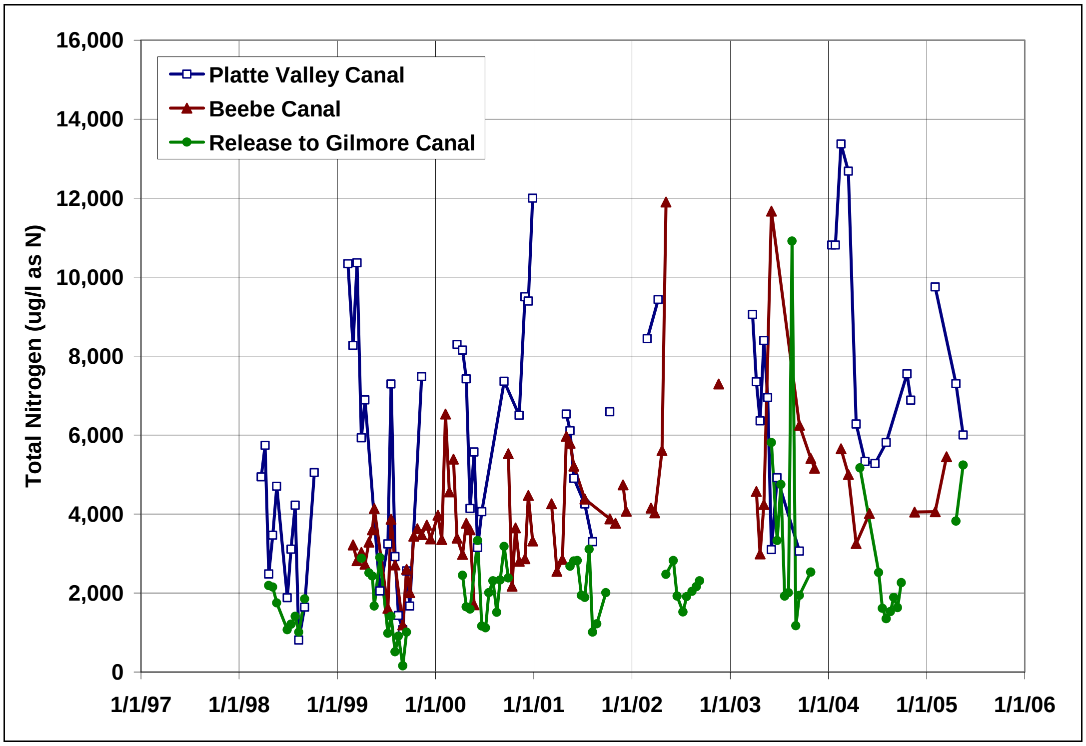

Figure 29. Total Nitrogen Concentrations in the Inflow to Milton Reservoir (via the Platte Valley Canal and the Beebe Canal) and the Release to the Gilmore Canal

Inflow / Outflow Data Analysis Summary

The concentrations of nutrients in the inflows and outflows of Milton Reservoir are high and have increased over the period 1998 to 2005. Nutrient concentrations in the Platte Valley Canal are higher, in general, than in the Beebe Canal. Mean concentrations and results of the trend analyses for the inflow from the Platte Valley Canal are shown in Table 7 while findings for the inflow from the Beebe Canal are shown in Table 8. Concentrations of total phosphorus, orthophosphate, nitrate + nitrite, and ammonia are at least 50% higher in the Platte Valley Canal over the Beebe Canal.

Table 7. Milton Reservoir Inflow Summary (1998-2005) – Platte Valley Canal

Constituent	Mean	Trend
Total Phosphorus (µg /l)	918	Increasing
Orthophosphate (µg /l)	736	Increasing
Total Nitrogen (µg /l)	6,086	Increasing
Total Kjeldahl Nitrogen (µg /l)	1,845	Increasing
Nitrate + Nitrite (µg /l)	4,268	Increasing
Ammonia (µg /l)	559	Increasing
pH (SU)	8.2*	No Trend
Dissolved Oxygen (mg/l)	8.5	No Trend
Temperature (°C)	13.4	No Trend
Specific Conductance (µS/cm)	906	Increasing

* Although we recognize that calculating the mean of observed pHs introduces a bias as compared to –log (mean [H+]), the mean of the observed pHs is presented as a useful value to the reader.

Table 8. Milton Reservoir Inflow Summary (1998-2005) – Beebe Canal

Constituent	Mean	Trend
Total Phosphorus (µg /l)	415	Increasing
Orthophosphate (µg /l)	197	Increasing
Total Nitrogen (µg /l)	4,165	Increasing
Total Kjeldahl Nitrogen (µg /l)	1,627	Increasing
Nitrate + Nitrite (µg /l)	2,538	No Trend
Ammonia (µg /l)	323	Increasing
pH (SU)	8.1*	No Trend
Dissolved Oxygen (mg/l)	10.2	No Trend
Temperature (°C)	9.8	No Trend
Specific Conductance (µS/cm)	1,328	No Trend

* Although we recognize that calculating the mean of observed pHs introduces a bias as compared to –log (mean [H+]), the mean of the observed pHs is presented as a useful value to the reader.

RESERVOIR WATER BALANCE

A reservoir water balance was computed for Milton Reservoir using the relationship:

$$\text{Change in Storage} = \text{Total Inflow} - \text{Total Outflow} \qquad (1)$$

The change in storage was computed as:

$$\text{Change in Storage} = \text{Contents at the End of the Period} - \text{Contents at the Beginning of the Period} \qquad (2)$$

Reservoir contents were developed on a daily basis by D. Helton Consulting (Rink, 2007a). The computed changes in storage by irrigation year are summarized in Table 9.

Table 9. Change in Storage by Irrigation Year (AF)

	IY00	IY01	IY02	IY03	IY04	Average (IY00-IY04)
Change in Storage (AF)	-8,259	10,005	-15,719	2,697	5,193	-1,217

Water enters Milton Reservoir via 1) the Platte Valley Canal, 2) the Beebe Canal, 3) subsurface inflow, 4) precipitation, and 5) runoff from the direct watershed. It is assumed that the fifth inflow is relatively small given the small watershed area directly surrounding the reservoir.

A time series of monthly inflows into Milton Reservoir from the Platte Valley Canal were developed by D. Helton Consulting (Rink, 2008a). The inflows were based on diversions from the South Platte River into the Platte Valley Canal for delivery to Milton Reservoir which were calculated by the Department of Water Resources to account for water withdrawn on the Platte Valley Canal by the Evans #2 ditch (Rink, 2008b). In addition, ditch losses of 20% were assumed. Monthly inflows from the Beebe Canal and subsurface inflow were developed from the Beebe groundwater model and provided as a combined daily value (Rink, 2008d). Precipitation estimates were made by AMEC Earth & Environmental using monthly reservoir surface area and precipitation records from Denver International Airport. In conducting the water balance, there were unaccounted for gains during some months. These gains were distributed to the Platte Valley Canal inflow and the combined Beebe Canal / subsurface inflow terms by volume.

Inflows by source and by year are summarized in Table 10. A pie chart representing the average of the five years is shown in Figure 30. The Platte Valley Canal supplies 54% of the inflow into Milton Reservoir while the Beebe Canal / subsurface inflow contributes 37%.

Table 10. Sources of Water into Milton Reservoir by Irrigation Year (AF)

	IY00	IY01	IY02	IY03	IY04	Average (IY00-IY04)
Platte Valley Canal	4,733	24,760	5,707	21,144	26,420	16,553
Beebe Canal / Subsurface Inflow	18,789	12,890	7,398	9,215	7,114	11,081
Precipitation	2,896	3,337	1,630	2,843	2,904	2,722
TOTAL INFLOW	26,418	40,987	14,735	33,203	36,437	30,356

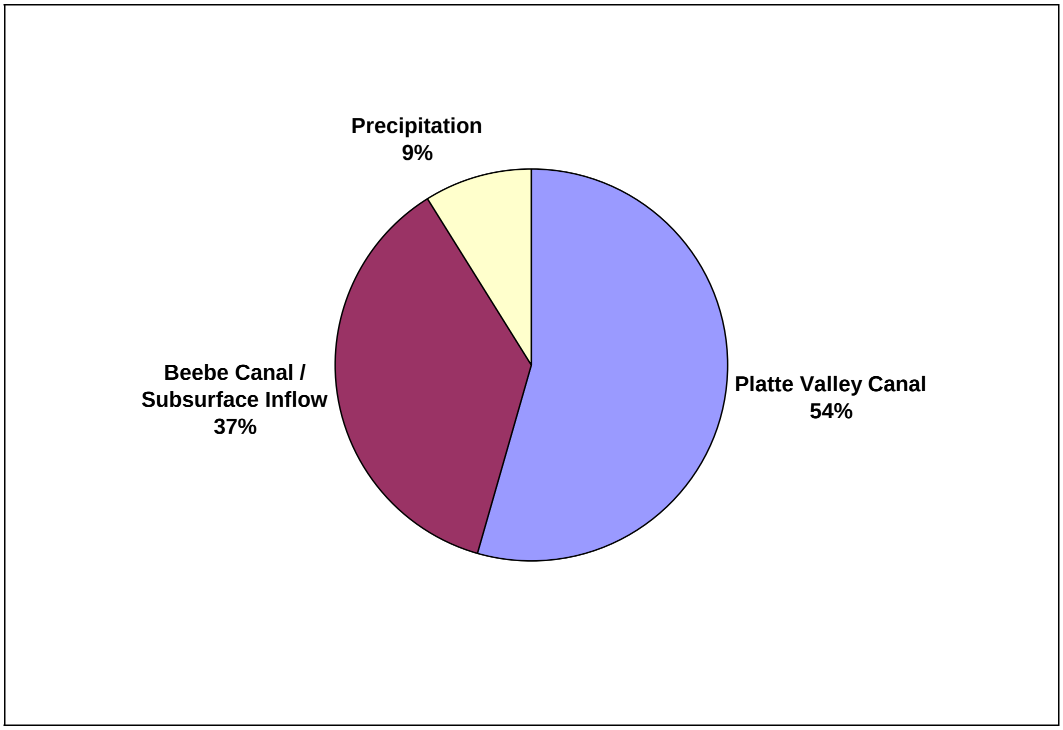

Figure 30. Distribution of Total Inflows into Milton Reservoir (Based on Average of IY00-IY04)

Water leaves the reservoir via 1) reservoir releases to the Gilmore Canal, 2) reservoir seepage, and 3) evaporation. A time series of monthly releases from Milton Reservoir to the Gilmore Canal were developed by D. Helton Consulting (Rink, 2008a). Monthly estimates of reservoir seepage were also developed by D. Helton Consulting based on the results from the Beebe groundwater model (Rink, 2008b). Evaporation was estimated by AMEC Earth & Environmental using monthly reservoir surface areas and pan evaporation estimates. In conducting the water balance, there were unaccounted for losses during some months. These losses were distributed to the seepage term since more uncertainty was associated with this term.

The outflows by source and by year are summarized in Table 11 and described graphically for an average year in Figure 31.

Table 11. Outflows from Milton Reservoir by Irrigation Year (AF/Year)

	IY00	IY01	IY02	IY03	IY04	Average (IY00-IY04)
Releases to Gilmore Canal	21,439	17,128	17,230	17,349	17,907	18,211
Outflow Seepage	6,821	7,282	7,330	7,741	7,818	7,398
Evaporation	6,417	6,573	5,894	5,416	5,520	5,964
TOTAL OUTFLOW	34,677	30,982	30,454	30,506	31,244	31,573

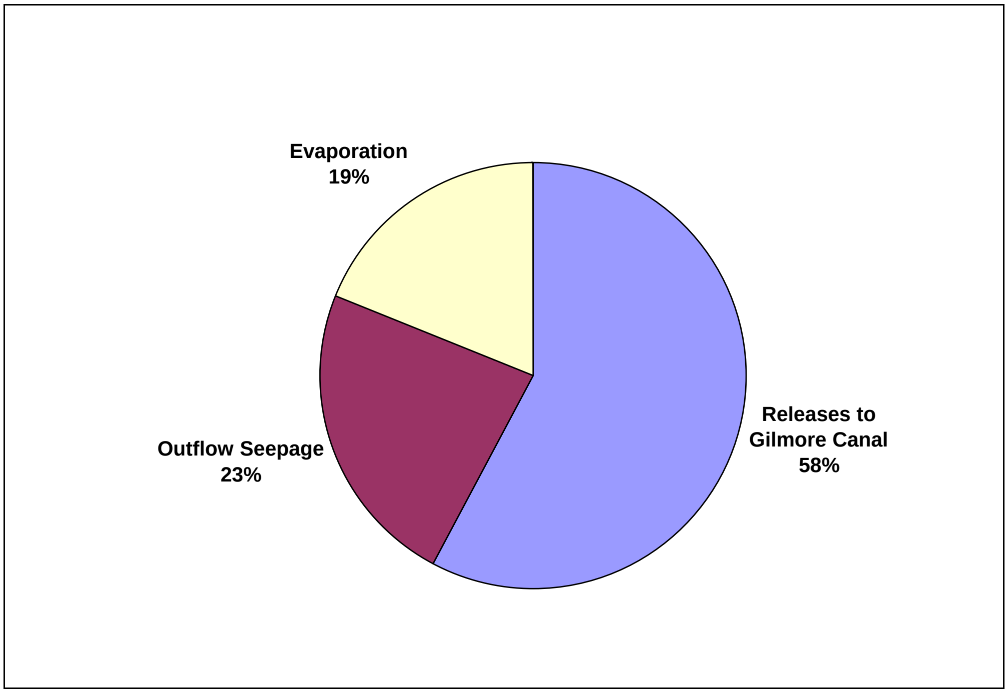

Figure 31. Distribution of Total Outflows from Milton Reservoir
(Based on Average of IY00-IY04)

The overall water balance by year is shown in Table 12. There is variability between the individual years. The highest inflow occurred in IY01 and the lowest occurred in IY02. The outflows vary less, year to year. The largest drop in contents occurred in IY02 while the largest gain occurred in IY01.

Table 12. Milton Reservoir Water Balance (AF)

	IY00	IY01	IY02	IY03	IY04	Average (IY00-IY04)
Change in Storage	-8,259	10,005	-15,719	2,697	5,193	-1,217
Total Inflow	26,418	40,987	14,735	33,203	36,437	30,356
Total Outflow	34,677	30,982	30,454	30,506	31,244	31,573
Unaccounted For	0	0	0	0	0	0

RESERVOIR NUTRIENT BALANCE

A nutrient balance was conducted for Milton Reservoir over a two-year period (IY03-IY04). Adequate in-reservoir nutrient data were not available prior to June 2002 and flow data were not provided past IY04. Phosphorus and nitrogen enter the reservoir via the Platte Valley Canal, the Beebe Canal, subsurface seepage, precipitation, internal loading from the bottom sediments, and runoff from the direct watershed. Nitrogen can also be introduced to the reservoir via fixation by cyanobacteria (blue-green algae). Nutrients leave the reservoir via the releases to the Gilmore Canal and seepage. Nitrogen can also be lost due to denitrification. Estimates were made for each of these sources and sinks for both total phosphorus and total nitrogen, with the exception of nitrogen fixation and denitrification. Loading as a result of nitrogen fixation is assumed to be small compared to the other nitrogen loading sources. In addition, losses due to denitrification were assumed to be relatively insignificant.

Total phosphorus and total nitrogen loads were estimated using flow and nutrient concentrations. For the inflows, water-quality samples were provided for the Platte Valley Canal and the Beebe Canal as they enter Milton Reservoir (Dorsch, 2004; Lundt, 2006b). Inflowing subsurface seepage was assumed to have the same water quality as the Beebe Canal. Contributions from precipitation were estimated based on precipitation data and from precipitation chemistry data taken near Cherry Creek Reservoir (2001-2005). Internal loading from the bottom sediments is described below.

For the outflows, the mass of nutrients leaving the reservoir was also estimated using flow and nutrient concentrations, along with the time-interval method (Scheider, et al., 1979). Water-quality samples were provided for releases to the Gilmore Canal (Dorsch, 2004; Lundt, 2006b). Concentrations of outflow seepage were assumed to be approximated by the release concentrations. Nutrient water balances are described after the next section on internal loading.

Internal Loading

Orthophosphate and ammonia (dissolved forms of nutrients which are bioavailable) can be released from the bottom sediments during periods of anoxia (low dissolved oxygen) at the sediment-water interface. Low dissolved oxygen concentrations near the bottom are accompanied by a reduction in redox potential, which govern the release of phosphorus from the sediments (Bostrom, et al., 1988). Ammonia has not been studied to the degree that phosphorus has and less is understood about the driving forces behind its release. However, Beutel (2003) has shown that the amount of ammonia released by the sediments is controlled by the presence or lack of oxygen in the overlying waters. Although releases of phosphorus and ammonia under oxic conditions have been reported, it is widely accepted that oxic releases are much lower than anoxic releases. Note also that feeding activities of benthic fish can disturb the sediments and increase diffusion of nutrients into the water column (Keen and Gagliardi, 1981). When external loadings to a lake or reservoir are small, these activities can be important (Wetzel, 2001). For Milton Reservoir, there are insufficient data to quantify the impacts of fish on nutrient loading. Due to the amount of external loading (see below), the impacts of fish on overall loading to Milton Reservoir are assumed to be relatively small. An additional internal source of phosphorus could be due to resuspension of bottom sediments during reservoir filling or drawdown. Again, this source is assumed to be relatively small compared to other nutrient sources.

For some lakes and reservoirs, internal loading can be a significant source of nutrients relative to the external loads. If this is the case, decreasing the external loading to the lake will not result in the same in-reservoir improvements one might see for a lake that is dominated by external loads.

For this effort, phosphorus and ammonia release rates were estimated based on three methods. The first method involves using published release rates from similar lakes and reservoirs. Phosphorus release rates measured in lakes and reservoirs have been compiled by Nurnberg (1988). For hyper-eutrophic lakes listed in her compilation (n = 20), phosphorus release rates range from 6 mg P/m^2/day to 42.5 mg P/m^2/day. The median value is 20 mg P/m^2/day.

If one considers the hyper-eutrophic lakes listed with sediment phosphorus concentrations similar to Milton Reservoir (approximately 1.5 mg/gm dry weight), the release rates range from 6 to 31 mg P/m^2/day with a median of 12 mg P/m^2/day. A value of 12 mg P/m^2/day is assumed using this method for Milton Reservoir.

There is much less literature published on the release of ammonia than the release of phosphorus. Published rates are displayed in Table 13.

Table 13. Published Ammonia Release Rates (Beutel, 2001)

Ammonia Release Rate	Notes	Source
12-50 mg N/m^2/day	- 4 Wisconsin Lakes - Anoxic conditions - Incubation Results	Graetz et al., 1973
80 mg N/m^2/day	- A Danish Lake - Anoxic Conditions - Incubation Results	Rysgaard, et al., 1994
6-13 mg N/m^2/day	- A Swiss Lake - Hypolimnetic Accumulation before Oxygenation	Hohener and Gachter, 1994
18.1 - 20.6 mg N/m^2/day	- Walker Lake, CA - Anoxic Conditions - Incubation Results	Beutel, 2001
16.5 mg N/m^2/day	- Walker Lake, CA - Anoxic Conditions - Hypolimnetic Accumulation	Beutel, 2001

A value of 19 mg N/m^2/day is assumed for Milton Reservoir. This is the median of the mid-point results and is in line with the recent work conducted by Beutel (2001) on a western reservoir.

The second method involves the use of an empirical relationship between sediment total phosphorus concentrations and phosphorus release rates, which was formulated by Nurnberg (1988). The regression is based on lakes world wide (n = 63) and has an R^2 of 0.21. Using a sediment total phosphorus concentration of 1.5 mg/g dry weight, the predicted total phosphorus release rate is 8.6 mg P/m^2/day. Note that empirical relationships for ammonia were not located in the literature.

The third method involves making an estimate based on changes in hypolimnetic concentrations. This approach is often considered to provide the best estimate of internal phosphorus loadings and has been found to be in agreement with results from laboratory experiments (Nurnberg, 1987). It is complicated, however, by failing to isolate sediment releases from other sinks and sources from and to the hypolimnion (e.g., diffusion to epilimnion, settling decaying phosphorus from epilimnion, etc.) (Effler, et al., 1996).

The application of this method to Milton Reservoir is less straight forward than it is for a typical dimictic lake (a lake that completely mixes twice per year) due to periodic mixing during the summer months. In 2003, however, there is a period between June 25, 2003 and July 8, 2003 where the reservoir is somewhat stratified and dissolved oxygen concentrations at the bottom are low (Figure 8). During this period, there is an increase in orthophosphate at the bottom of the reservoir. Orthophosphate concentrations at the bottom rose from 492 µg/l as P to 825 µg/l as P. Using profile data and elevation - volume relationships to determine the size of the hypolimnion, the phosphorus release is computed to be approximately 27 mg P/m^2/day. Ammonia at the bottom of the reservoir continually decreased over the period June 25 - July 8, 2003 period so a similar computation could not be made for nitrogen.

Since this method is considered to be better than the other two methods and the result is within the range found using the first method, a release rate of 27 mg P/m^2/day was assumed for the nutrient mass balance. The best estimate of nitrogen release is 19 mg N/m^2/day based on published rates and is used in the nutrient mass balance described below.

In order to translate the release rates to pounds of nutrients released into the reservoir, one needs to estimate the active sediment area, and the average period of anoxia. In addition, since Milton Reservoir is warmer than other reservoirs whose rates were published, a temperature correction factor is used for the nitrogen loading calculation.

The active sediment area was estimated at 202 acres based on the average thermocline depth. The average period of anoxia was estimated to be 22 days / year based on the average period of anoxia for 2003-2005. The temperature correction factor using the Arrhenius equation (Chapra, 1997) was estimated to be 1.1 based on a summertime bottom reservoir temperature of 23 °C (Figure 7) and a θ of 1.02 (Chapra, 2005). These values were used in an initial estimate to compute the mass of nutrients released per year. In addition, release rates, active sediment area, and the period of anoxia were varied up and down by 50%, 20% and 20% respectively to estimate a range of possible releases. Note that in the case of nitrogen, the release rate was varied between 6 and 80 mg N/m^2/day, the range of published rates. The results are listed in Table 14.

Table 14. Computed Internal Nutrient Loading (lbs / Year)

	Phosphorus	Nitrogen
Initial Estimate	1,070	829
Minimum	535	262
Maximum	1,606	3,289

Based on these results, the values of 1,000 pounds / year of phosphorus and 800 pounds / year of nitrogen were used in the nutrient balance described below.

Phosphorus Balance

A phosphorus balance was computed using the same methodology used in the water balance computation.

Change in Mass in Storage = Total Mass In – Total Mass Out (3)

The change in storage is based on the reservoir contents and phosphorus concentrations at the beginning and end of the irrigation year. The results are shown in Table 15.

Results for loads from inflows are shown in Table 16 and displayed graphically in Figure 32. The total annual loading of phosphorus is about 89,300 pounds / year, which translates to about 7.7 g P/m^2-yr. Note that for lakes with a mean depth similar to that of Milton Reservoir, a permissible loading rate of 0.07 g P/m^2-yr is suggested while a rate of 0.13 g P/m^2-yr and above is referred to as excessive (Vollenweider, 1968).

Table 15. Estimated Change in Mass in Storage of Total Phosphorus (lbs)

	IY03	IY04	Average (IY03-IY04)
Change in Mass in Storage (based on initial contents/ concentration and final contents / concentration)	5,603	10,805	8,204

Table 16. Estimated Mass of Total Phosphorus Entering Milton Reservoir (lbs)

	IY03	IY04	Average (IY03-IY04)
Platte Valley Canal	48,322	76,913	62,617
Beebe Canal / Subsurface Seepage	43,083	7,588	25,336
Precipitation	408	226	317
Internal Loading	1,000	1,000	1,000
TOTAL INFLOW	92,813	85,727	89,270

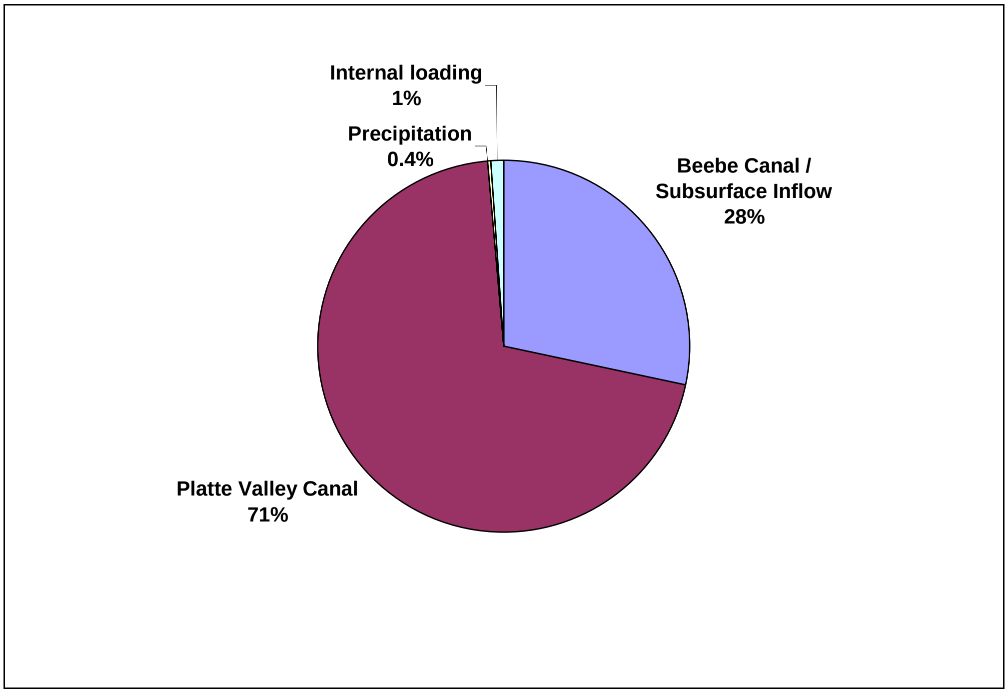

Figure 32. Distribution of Total Phosphorus Entering Milton Reservoir (Based on the Average of IY03-IY04)

For the incoming phosphorus, 71% was from the Platte Valley Canal, <1 % was from precipitation, 28% from the Beebe Canal and subsurface inflow, and the remaining 1% was from internal loading. Note that using the maximum internal loading numbers computed in the previous section would not significantly change the overall distribution.

The mass of phosphorus leaving the reservoir are summarized in Table 17 and shown graphically in Figure 33.

Table 17. Estimated Mass of Total Phosphorus Leaving Milton Reservoir (lbs)

	IY03	IY04	Average (IY03-IY04)
Releases to Gilmore Canal	22,701	31,661	27,181
Outflow Seepage	10,837	14,022	12,599
TOTAL OUTFLOW	33,539	46,022	39,780

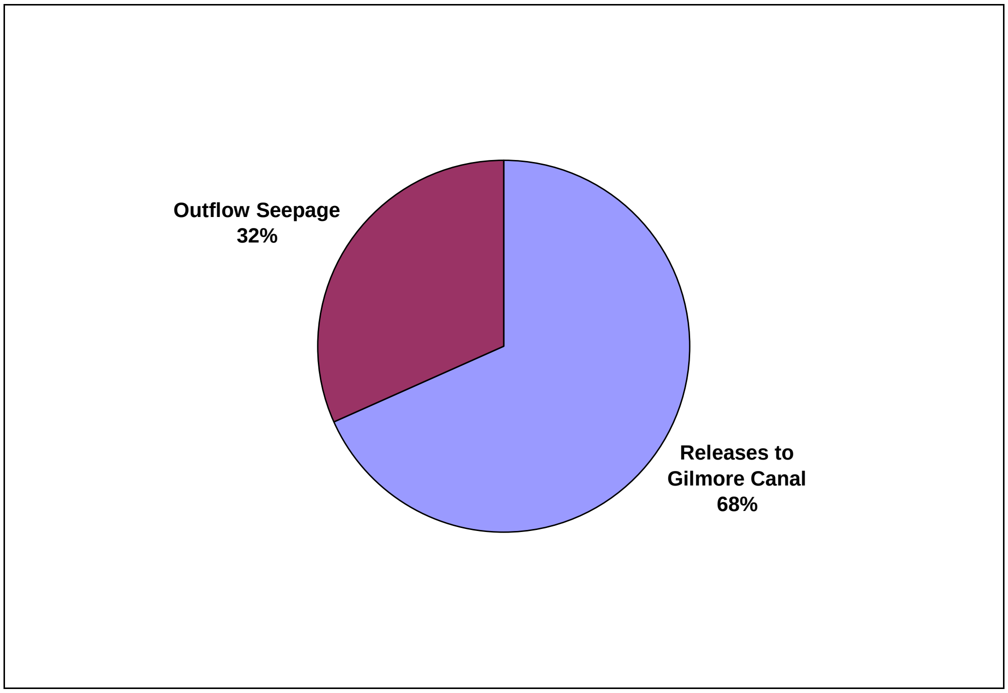

Figure 33. Distribution of Total Phosphorus Leaving Milton Reservoir (Based on the Average of IY03-IY04)

The overall phosphorus balance in shown in Table 18 by irrigation year. Reservoir retention is the unaccounted mass divided by the sum of the initial mass stored in the reservoir and the total inflow. The reservoir retained an average of 44% of the inflowing phosphorus plus that initially stored, which is in the range of values (5% to 86%) found on other plains reservoirs (Sprague, 2002a). It is also close to the values found using data from 149 lakes and reservoirs around the world (Kronvang, et al., 2004). Kronvang, et al. (2004) found nutrient retention to vary by hydraulic residence times and reported that lakes and reservoirs with hydraulic residence times of 0.1 to 1 year (Table 5) had a median phosphorus retention of 45%. Reservoirs tended to have higher retention rates than lakes.

Phosphorus retention occurs in reservoirs due to several factors including 1) sedimentation of phosphorus imported from the inflow, 2) adsorption of phosphorus with inorganic compounds, and 3) sedimentation of phosphorus with algae and other organic matter (Wetzel, 2001). The latter two mechanisms are most likely important for Milton Reservoir.

Table 18. Milton Reservoir Phosphorus Balance (lbs)

	IY03	IY04	Average (IY03-IY04)
Change in Storage	5,603	10,805	8,204
Total Inflow	92,813	85,727	89,270
Total Outflow	33,539	46,022	39,780
Unaccounted For	-53,671	-28,900	-41,286
% Retained*	57%	31%	44%

* Mass unaccounted for as a percent of total inflow and initial mass in storage

Nitrogen Balance

The nitrogen balance was computed similarly to the phosphorus balance. The changes in mass stored in the reservoir are shown in Table 19.

Results for loads from inflows are shown in Table 20 and displayed graphically in Figure 34. The total annual loading of nitrogen is about 532,000 pounds / year, which translates to about 36 g N/m^2-yr. Note that for lakes with a mean depth similar to that of Milton Reservoir, a permissible loading rate of 1.0 g N/m^2-yr is suggested while a rate of 2.0 g N/m^2-yr and above is referred to as excessive (Vollenweider, 1968).

Table 19. Estimated Change in Mass in Storage of Total Nitrogen (lbs)

	IY03	IY04	Average (IY03-IY04)
Change in Mass in Storage	11,369	85,732	48,551

Table 20. Estimated Mass of Total Nitrogen Entering Milton Reservoir (lbs)

	IY03	IY04	Average (IY03-IY04)
Platte Valley Canal	308,025	496,024	402,025
Beebe Canal / Subsurface Seepage	158,399	80,495	119,447
Precipitation	7,534	12,567	10,051
Internal Loading	800	800	800
TOTAL INFLOW	474,758	589,886	532,323

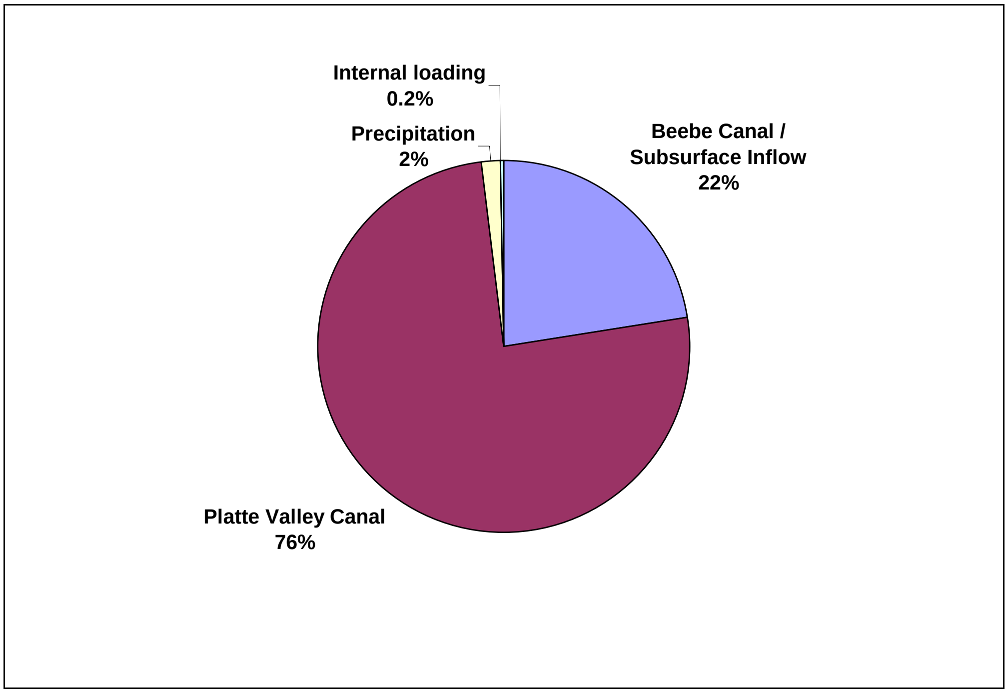

Figure 34. Distribution of Total Nitrogen Entering Milton Reservoir (Based on the Average of IY03-IY04)

For the incoming nitrogen, 76% was from the Platte Valley Canal, 22% was from the Beebe Canal and subsurface inflow, 2% from precipitation, and <1% was from internal loading. Note that using the maximum internal loading numbers computed in the previous section would not significantly change the overall distribution.

The mass of nitrogen leaving the reservoir is summarized in Table 21 and shown graphically in Figure 35.

Table 21. Estimated Mass of Total Nitrogen Leaving Milton Reservoir (lbs)

	IY03	IY04	Average (IY03-IY04)
Releases to Gilmore Canal	107,815	120,439	114,127
Outflow Seepage	81,922	67,463	74,693
TOTAL OUTFLOW	189,737	187,902	188,820

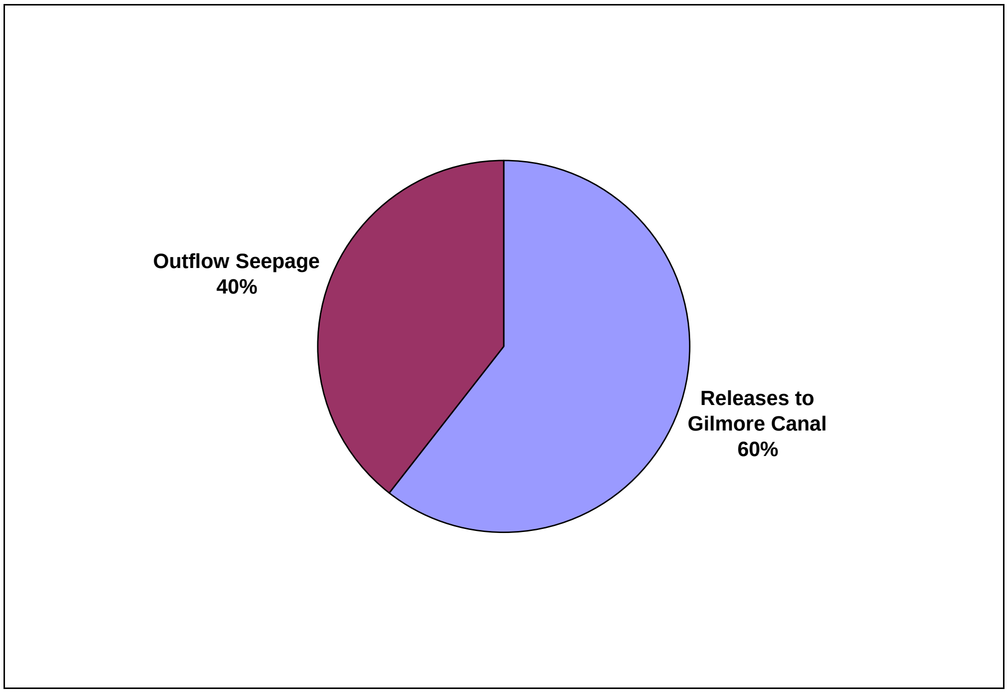

Figure 35. Distribution of Total Nitrogen Leaving Milton Reservoir (Based on the Average of IY03-IY04)

The overall nitrogen balance is shown in Table 22. Reservoir retention is the unaccounted for mass divided by the sum of the initial mass stored in the reservoir and the total inflow. The reservoir retained an average of 53% of the inflowing nitrogen plus that initially stored, which is in the range of values (49% to 88%) found on other plains reservoirs (Sprague, 2002a). It is also close to the values found using data from 149 lakes and reservoirs around the world (Kronvang, et al., 2004). Kronvang, et al. (2004) found nutrient retention to vary by hydraulic residence times and reported that lakes and reservoirs with hydraulic residence times of 0.1 to 1 year (Table 5) had a median nitrogen retention of 50%. Reservoirs tended to have higher retention rates than lakes. Nitrogen retention occurs in reservoirs due to biological uptake and deposition of particulate organic nitrogen (Sprague, 2002a).

Table 22. Milton Reservoir Nitrogen Balance (lbs)

	IY03	IY04	Average (IY03-IY04)
Change in Storage	11,369	85,732	48,551
Total Inflow	474,758	589,886	532,323
Total Outflow	189,737	187,902	188,820
Unaccounted For	-273,652	-316,252	-294,952
% Retained*	55%	51%	53%

* Mass unaccounted for as a percent of total inflow and initial mass in storage

COMPARISON WITH SIMILAR RESERVOIRS

A comparison with similar reservoirs located in the Colorado plains was made. Several off-channel irrigation reservoirs are located along the Lower South Platte River and some data were available. The US Geologic Survey conducted a study on five reservoirs in 1995 -- Riverside Reservoir, Jackson Reservoir, Prewitt Reservoir, North Sterling Reservoir, and Julesburg Reservoir (Figure 36). Samples were collected throughout the irrigation season (March - September) at several sites for each reservoir. Final results are reported in Sprague, 2002a. Although there is no in-reservoir data for Milton Reservoir in 1995, some insights can be drawn by comparing the available data (Table 23).

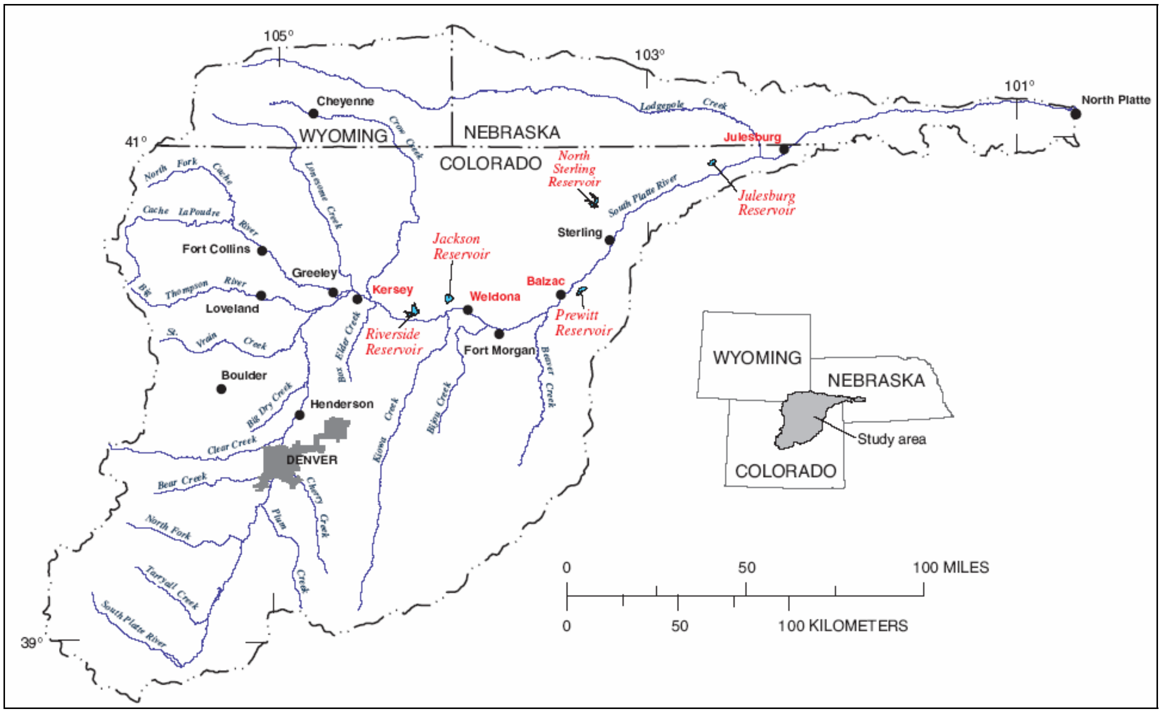

Figure 36. Off-Channel Reservoirs Investigated in 1995 (Figure from Sprague, 2002b)

Table 23. Comparison Between Milton Reservoir and Five Off-Channel Reservoirs Near the Lower South Platte River (Epilimnion)*

Reservoir	Total Phosphorus (µg/l)	Total Nitrogen (µg/l)	Chlorophyll *a* (µg/l)	Secchi-Disk Depth (m)
Milton Reservoir	567	3,380	20	2.2
Riverside Reservoir	540	3,500	13	1.5
Jackson Reservoir	180	2,900	63	0.3
Prewitt Reservoir	77	2,000	20	1.2
N. Sterling Reservoir	110	3,100	34	0.8
Julesburg Reservoir	52	1,700	52	1.1

* Data for Milton Reservoir represent means for March - September, 2003-2005. Values for the other reservoirs are means for 1995 (March - September).

Milton Reservoir is similar to these reservoirs in that all are eutrophic - hypereutrophic with the exception of Riverside Reservoir, which is eutrophic and Jackson Reservoir which is hypereutrophic. Nutrients in Milton Reservoir are higher than in several of the other reservoirs, yet the chlorophyll *a* concentrations are lower. Milton Reservoir is also clearer than the other reservoirs. Differences in residence time, lake morphometry, and reservoir operations can cause variations among these systems.

A more useful comparison can be made between Milton Reservoir and the other three nearby reservoirs that are sampled by MWRD. Barr Lake, Horse Creek Reservoir, and Prospect Reservoir are often sampled on the same day, providing a means for a direct comparison between the reservoirs. Mean water-quality concentrations were computed for each reservoir, only using data on 25 days when all four reservoirs were sampled. Data were generally available on a monthly basis. The results are displayed in Table 24.

Table 24. Comparison Between the Surface Layers of Milton Reservoir, Barr Lake, Horse Creek Reservoir, and Prospect Reservoir (2003-2005)

Reservoir	Total Phosphorus (µg/l)	Total Nitrogen (µg/l)	Chlorophyll *a* (µg/l)	Secchi-Disk Depth (m)
Milton Reservoir	625	3,945	27	2.4
Barr Lake	590	4,954	37	1.8
Prospect Reservoir	371	5,888	68	1.2
Horse Creek Reservoir	568	5,168	90	0.7

Nitrogen concentrations and chlorophyll *a* concentrations are higher in Barr Lake, Prospect Reservoir and Horse Creek Reservoir than in Milton Reservoir. Water clarity is also diminished in these three reservoirs. Milton Reservoir has the lowest nitrogen concentrations, the lowest chlorophyll *a* concentrations, and the highest Secchi-disk depth, even though its phosphorus concentrations are the highest.

OBSERVATIONS AND DISCUSSION

Milton Reservoir is on the State of Colorado's 303(d) list for exceeding the upper pH standard. Although it is unusual for the pH of a lake to exceed 9.0 (Hem, 1992) it is not unknown. Lakes and reservoirs can have high pH levels for a number of reasons, including geology, certain types of industry, and excessive algal populations.

Lakes can have naturally elevated pH levels due to the surrounding geology, especially in volcanic areas. Runoff from certain types of industries in the watershed such as soda ash processing plants or cement kilns has been known to cause elevated pH levels in lakes. When algae photosynthesize, they remove carbon dioxide from the water column which tends to result in increases in pH. In very productive lakes, large changes in pH can occur. In an extreme case, maximum pH values have exceeded 12.0 in a poorly buffered, highly productive lake (Livingstone, 1963).

For Milton Reservoir, the evidence points to excessive algal populations as the cause for high pH levels. The lake is highly productive, as evidenced by the hyper-eutrophic trophic status. There is also a relationship between chlorophyll *a* concentrations and pH in the lake (Figure 37). There is no evidence of the high levels of pH being caused by geologic or industrial impacts.

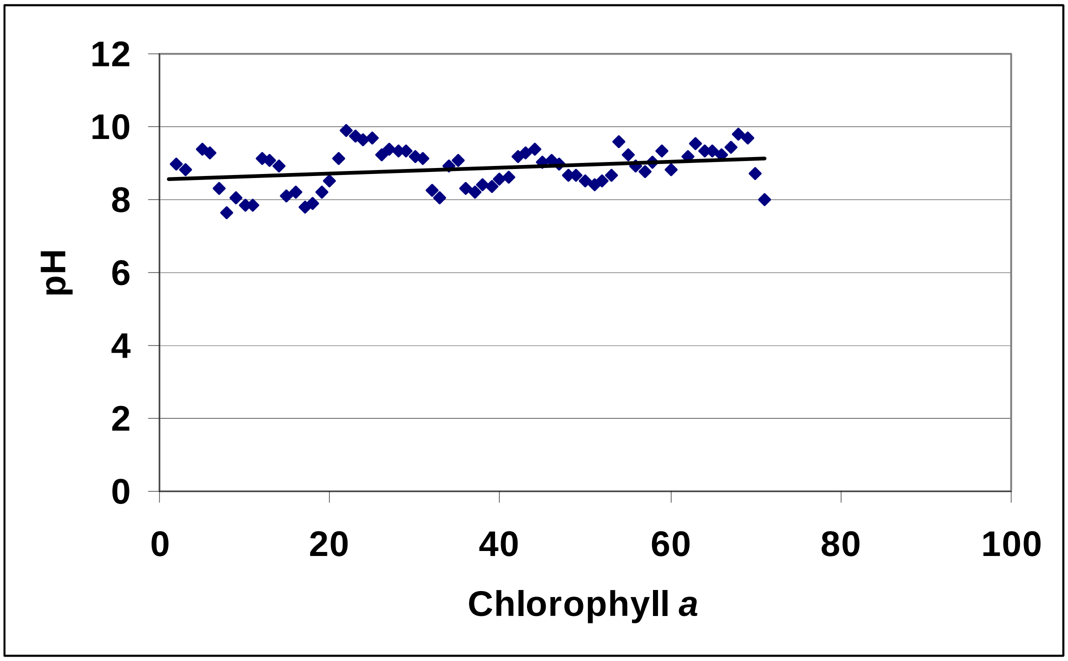

Figure 37. Surface pH versus Chlorophyll *a* Concentrations

With respect to overall water-quality dynamics within Milton Reservoir, there is an observable response to loadings from the Platte Valley Canal. Phosphorus concentrations in the reservoir are shown in Figure 38. Note the increases in concentration in March 2003, January 2004, and July 2004. These months correspond to periods when the Platte Valley Canal is flowing into the reservoir (Figure 39). Platte Valley Canal flow data for 2005 were not available. The sharp increases in in-reservoir phosphorus in 2005 might also be explained by Platte Valley Canal flows during that period.

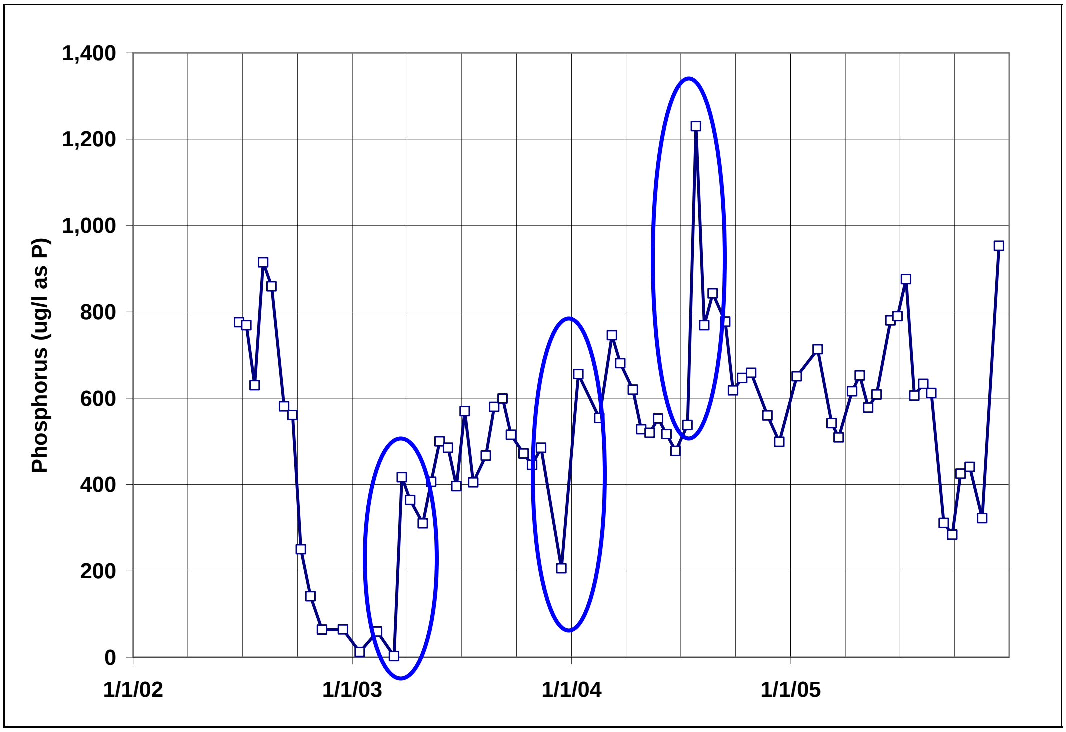

Figure 38. Phosphorus Concentration Increases in Milton Reservoir (Station M3 – Surface)

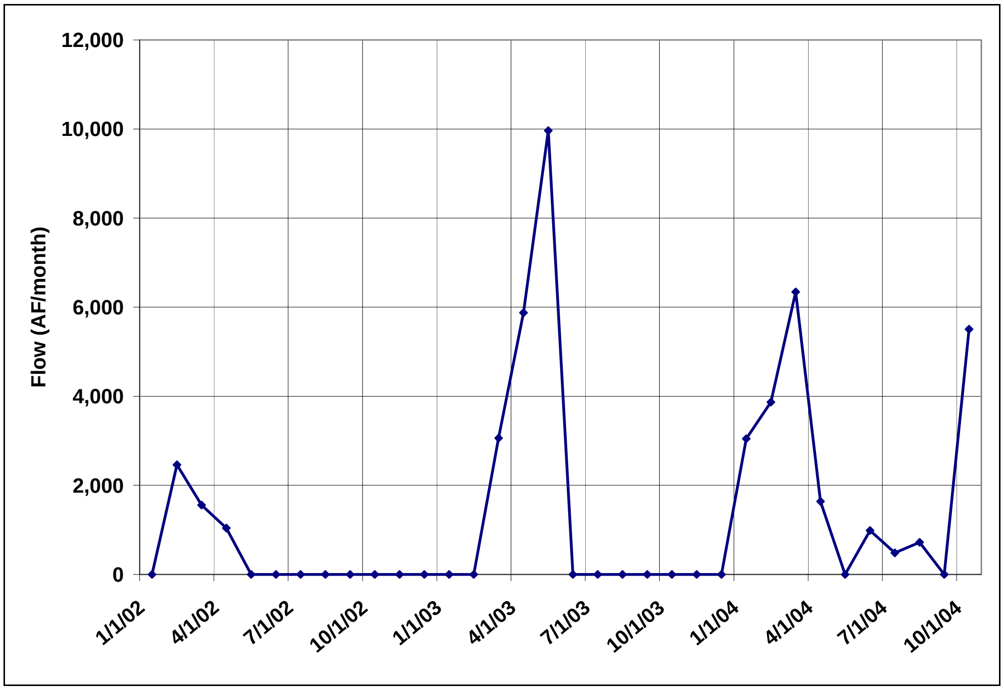

Figure 39. Flow from the Platte Valley Canal into Milton Reservoir

Total nitrogen concentrations also respond in the reservoir to Platte Valley Canal flows (Figure 40). Note the sharp increases in March 2003, January 2004, and October 2004.

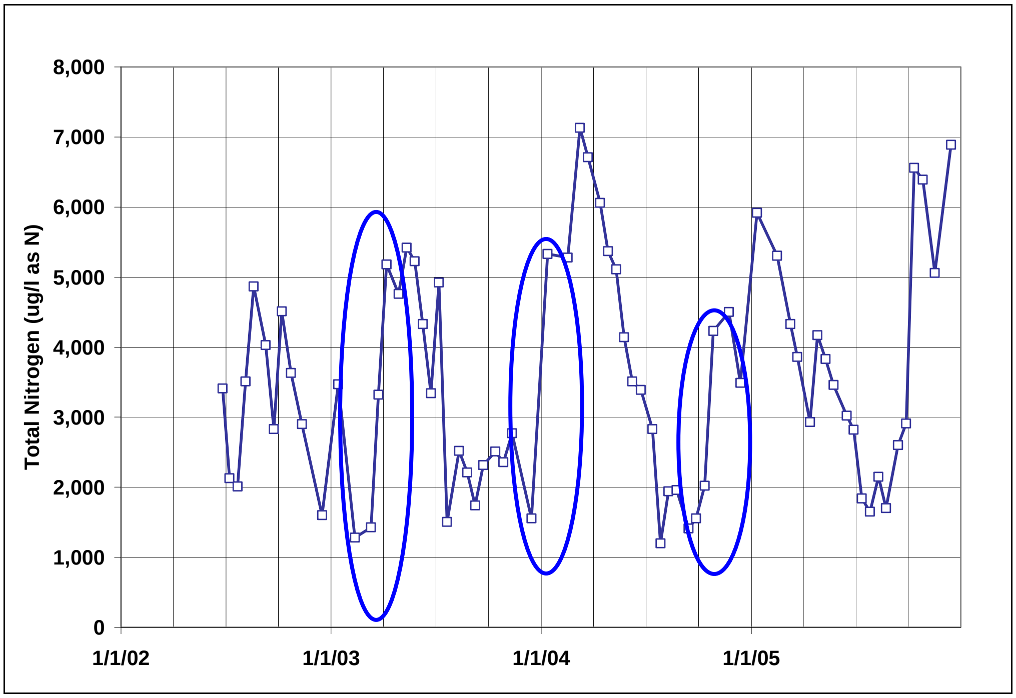

Figure 40. Nitrogen Concentration Increases in Milton Reservoir (Station M3 – Surface)

FUTURE MONITORING AND MODELING RECOMMENDATIONS

Based on this study, the following recommendations are made with respect to future monitoring and reservoir modeling:

1. A flow gage should be installed on the Platte Valley Canal and on the Beebe Canal immediately upstream of where they enter Milton Reservoir.

2. Practical improvements to the accuracy of flow measurements around the reservoir should be identified by working with D. Helton Consulting.

3. The number of data points per year and the frequency of water-quality data collection for the flows into and out of the reservoir and at the Burlington-O'Brian headgate varies considerable. The reason for this should also be determined.

4. A two-dimensional dynamic model is recommended for Milton Reservoir due to its fluctuating water surface, its mixing patterns, and the dynamic nature of the reservoir (Hydrosphere, 2005). The recommended reservoir model is CE-QUAL-W2. It has a proven track record and has been applied successfully for several Colorado reservoirs. It also has the capability to simulate pH, multiple algal groups. In addition, it allows one to model internal loading mechanistically.

5. Total organic carbon and dissolved organic carbon should be added to the monitoring program for the reservoir inflow. This will aid in reservoir modeling to differentiate between the autochthonous (originating within the reservoir) and the allochthonous (originating from the inflows) organic carbon.

6. A hydrodynamic model of the reservoir requires meteorological data. A weather station should be installed in the vicinity of Milton Reservoir.

7. Improvements in the quality of phytoplankton and zooplankton data analysis are suggested.

8. Sources of nutrients for the inflows into Milton Reservoir should be identified and quantified.

CONCLUSIONS

Milton Reservoir is a shallow eutrophic - hypereutrophic reservoir located in the high plains of Colorado. This highly-enriched reservoir has low clarity, low summertime hypolimnetic dissolved oxygen, high chlorophyll *a* concentrations, and high pH. Elevated pH values are a result of photosynthesizing algae. In general, the water quality in the reservoir has degraded between IY2003 through IY2005. Analysis of the data indicates specific patterns between Platte Valley inflows and in-reservoir nutrient concentrations.

The main source of water supply to the reservoir is the Platte Valley Canal, supplying 54% of its water. This inflow and the inflow from the Beebe Canal have elevated concentrations of nutrients. Overall, nutrient concentrations in both inflows have increased over the period 1998 to 2005. The nutrient loading analysis indicates that for the period IY2003-IY2004, phosphorus loads on average are approximately 89,300 pounds per year. The corresponding number for nitrogen is 532,000 pounds per year. Less than 5% of the phosphorus loading is from internal loading, and precipitation. The areal loading rates to the reservoir are high - 7.7 g /m^2-yr for phosphorus and 36 g /m^2-yr for nitrogen.

The water quality of Milton Reservoir is similar in some respects to several other local plains reservoirs. Chlorophyll *a* concentrations in Prospect Reservoir and Horse Creek Reservoir are significantly higher than in Milton Reservoir.

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