Reservoir Water Quality Assessment for Loch Raven, Prettyboy and Liberty Reservoirs

Interim Report
September 25, 2000

Prettyboy Dam

CITY OF BALTIMORE
DEPARTMENT OF PUBLIC WORKS
BUREAU OF WATER AND WASTEWATER
ENVIRONMENTAL SERVICES DIVISION
WATER QUALITY MANAGEMENT SECTION

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September 25, 2000

Introduction

The Baltimore City Water Quality Management Section is submitting this interim report as a companion document to the 1999 Action Strategy for the Reservoir Watersheds. The report focuses on trends in reservoir and tributary water quality. The data are displayed in a way to depict obvious spatial and temporal variability. A more rigorous assessment will be completed in the final report expected later this year.

The findings indicate good and bad news. The good news is that algal levels in all three reservoirs have gradually improved over the past 15-18 years. This is most likely attributed to the cumulative actions implemented since the first Action Strategy was developed in 1984. Nitrate concentrations that have been steadily increasing over this period also appear to be leveling off. The City will be examining the causes of this phenomenon by relating watershed attributes (e.g., land use) to nitrate concentrations.

The bad news is that chloride concentrations continue to be increasing in the tributaries and reservoirs. Johns Hopkins University first noted this trend in a 1978 study. A rise of 260% was noted from 1930 to 1968 in water treatment plant data. Chloride levels have risen steadily ever since. Although current levels are far from EPA recommended guidelines (250 mg/l), the trend is none the less disconcerting. This report includes an investigation into the causes of the trend.

Algae and Chlorophyll a

A gradual decrease in total algae count and, although less apparent, chlorophyll a, an indicator of algae, is seen from the mid-1980’s to the present in Loch Raven, Prettyboy and Liberty Reservoirs. Typical trends are shown in Figures 1-6.

The Carlson Trophic State Index (TSI) is a widely used lake and reservoir water quality index for eutrophication and provides a benchmark from which to compare chlorophyll a and other data. The index is made up of three separate indices using chlorophyll a, phosphorus and secchi disk data. The indices can be used together or individually. A chlorophyll a value of 10 ug/l corresponds to the boundary between mesotrophic (moderately impaired) and eutrophic conditions and is used in this assessment.

Reservoir chlorophyll a data is displayed as a series of frequency histograms as this gives an indication of how often the threshold value delimiting the mesotrophic/eutrophic boundary is exceeded.

- Prettyboy Reservoir epilimnion (surface layer, from the surface to 30 feet below) samples equaled or exceeded the mesotrophic level (10 ug/l) 26.2 % of the time (see Figure 7).
- Loch Raven Reservoir epilimnion samples equaled or exceeded the mesotrophic level 19.8 % of the time (see Figure 8).
- Liberty Reservoir epilimnion samples equaled or exceeded the mesotrophic level 9.9% of the time (see Figure 9).

According to the chlorophyll a TSI, Prettyboy Reservoir is the most impaired of the three reservoirs. However, the other eutrophication indices described in this report do not corroborate this finding. Possible explanations are provided in the appropriate sections.

The chlorophyll a TSI indicates Loch Raven is moderately impaired as compared to the other two reservoirs. As with Prettyboy, the other indices described in this report indicate varying levels of impairment. This will also be discussed in the appropriate section.

Liberty Reservoir is by far the least impaired of the three reservoirs with respect to chlorophyll a or algae. This is most likely due to the relatively large volume of Liberty that is almost twice that of the other reservoirs. The large volume provides greater volume for dilution and settling. This is discussed in greater detail in the following sections of this report.

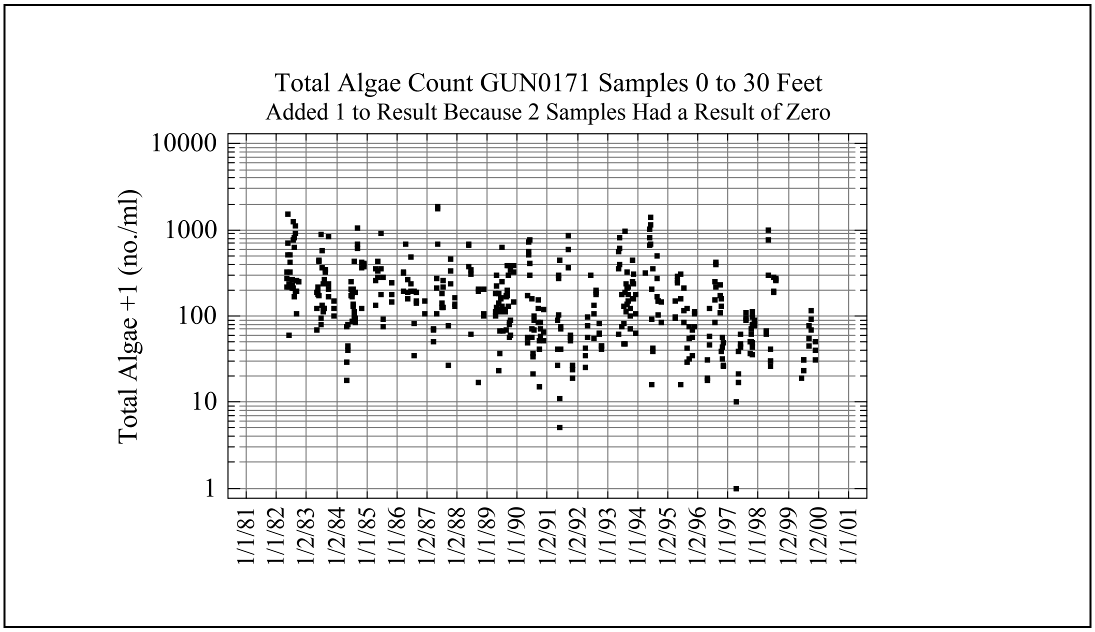


Figure 1

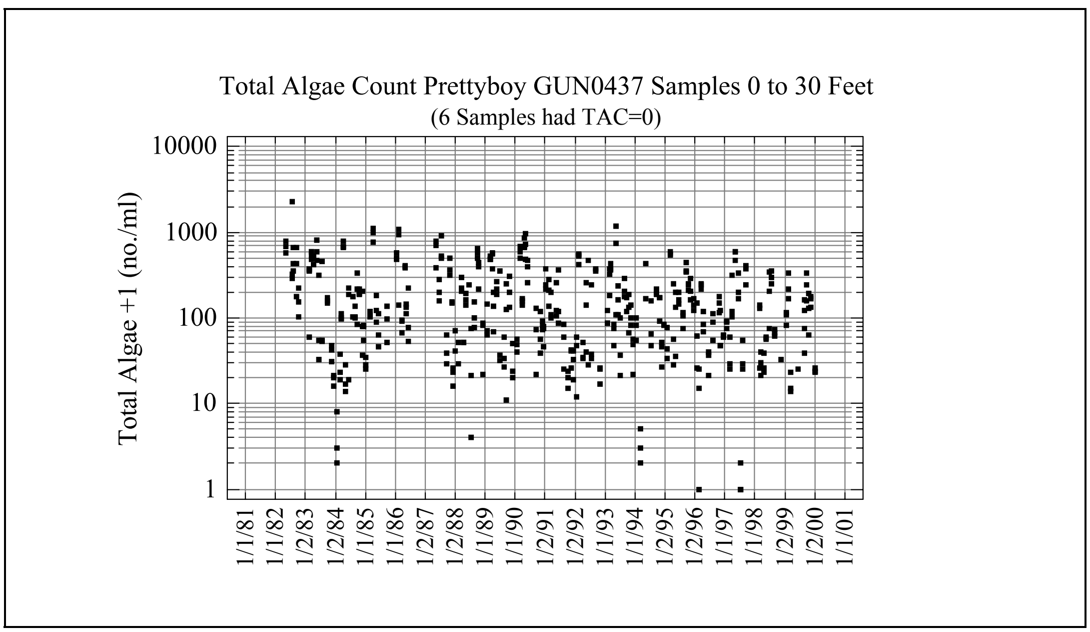


Figure 2

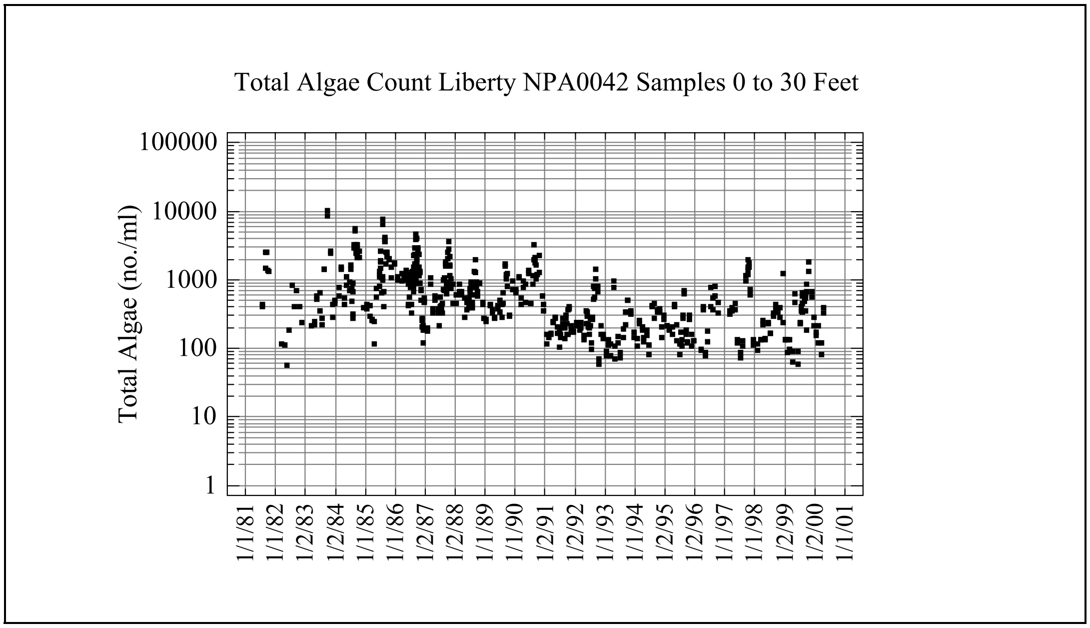


Figure 3

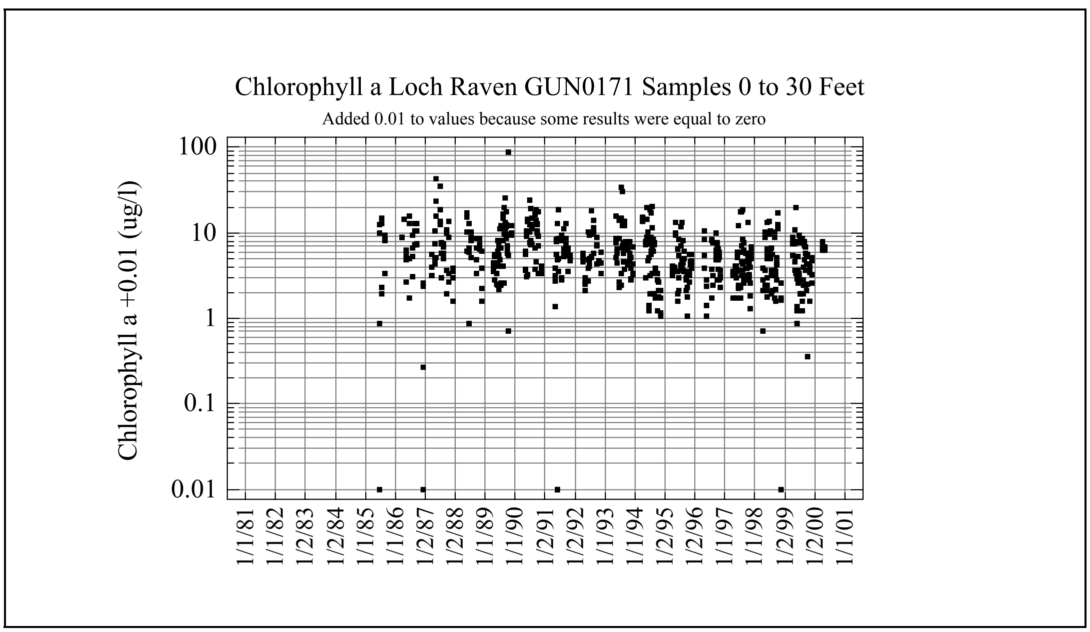


Figure 4

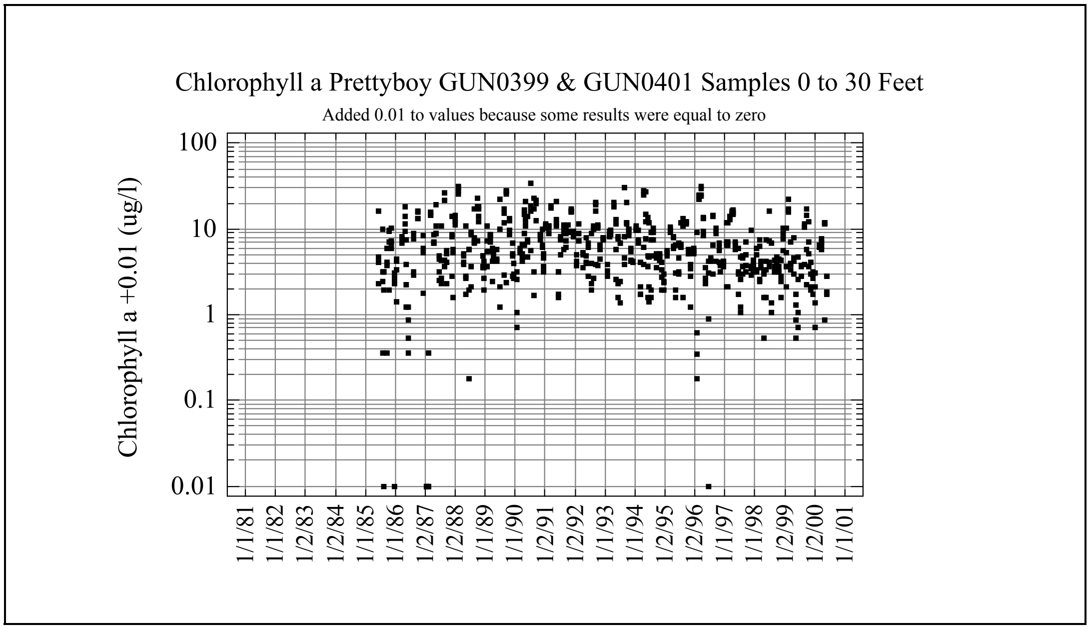


Figure 5

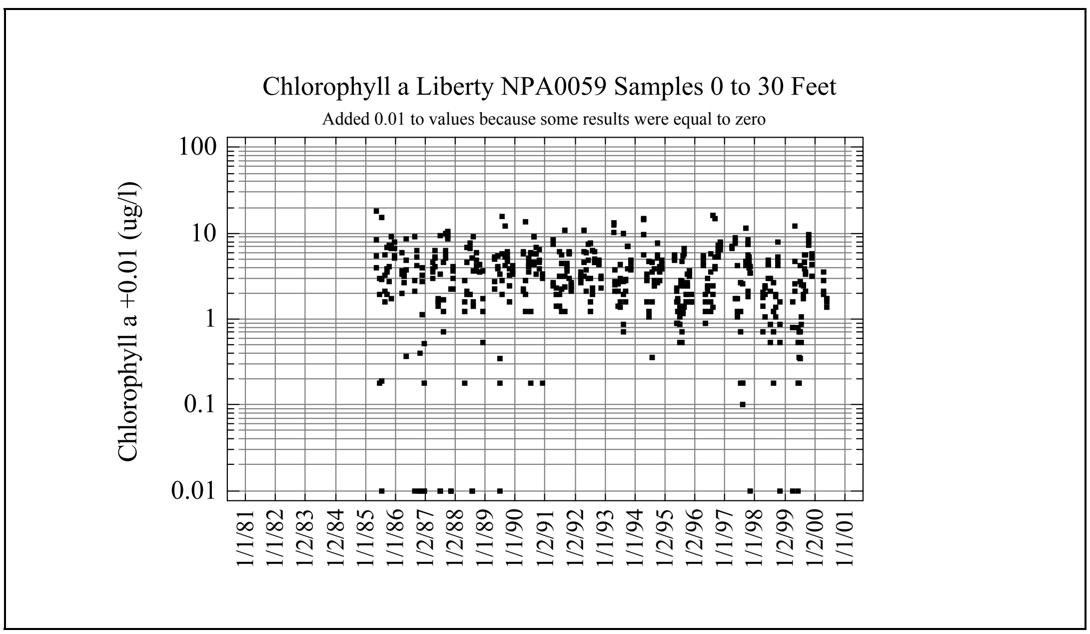


Figure 6

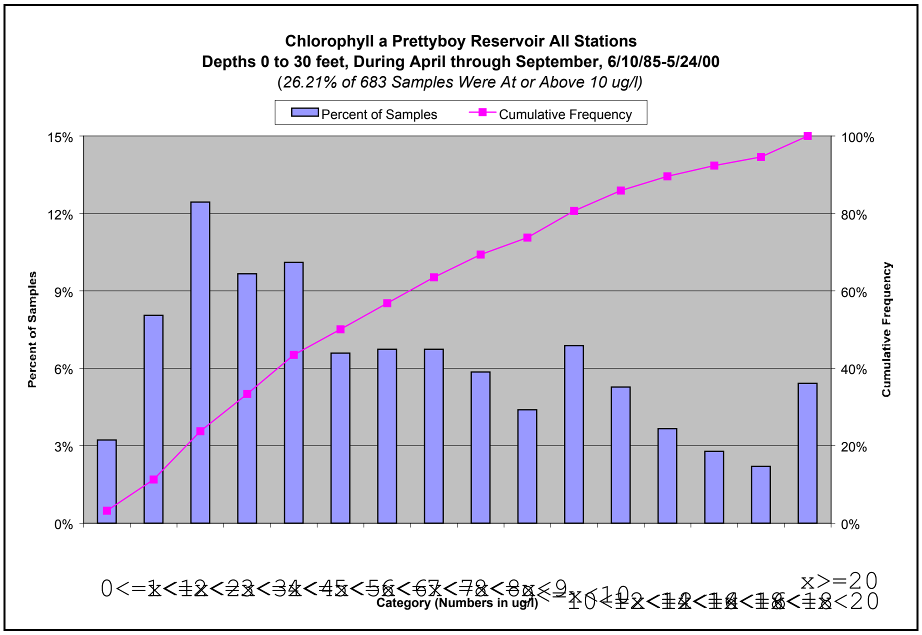


Figure 7

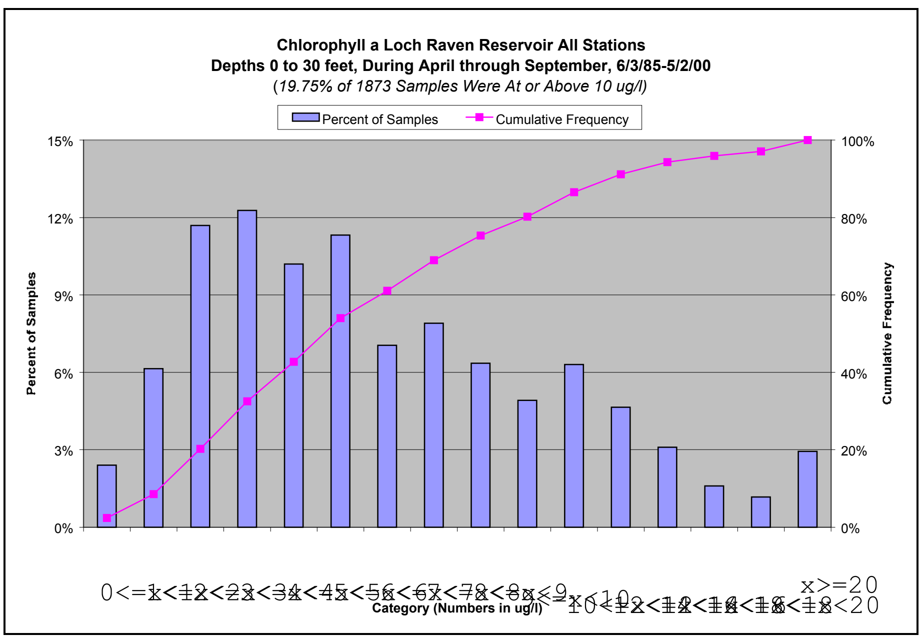


Figure 8

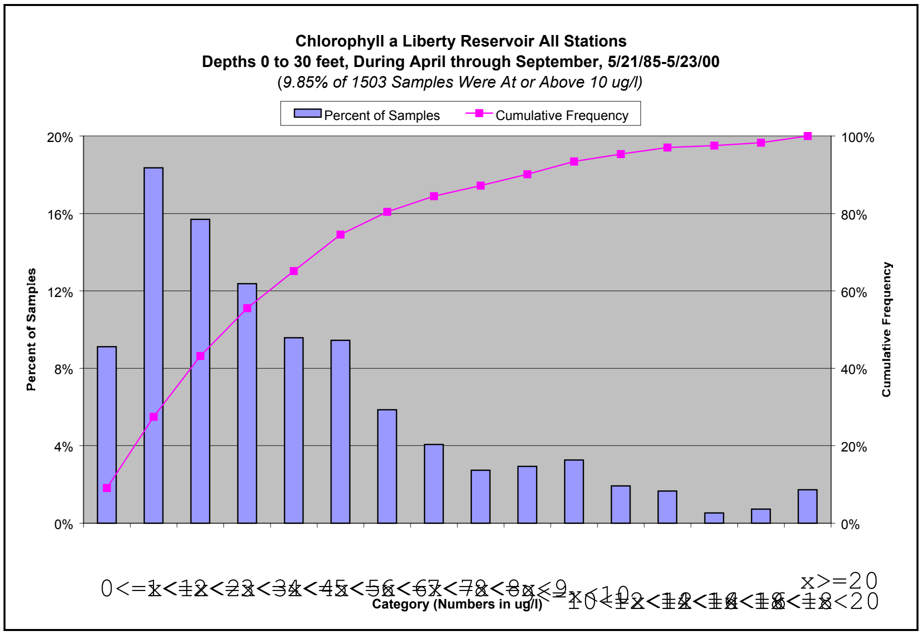

Chlorophyll a Liberty Reservoir All Stations
Depths 0 to 30 feet, During April through September, 5/21/85-5/23/00
(9.85% of 1503 Samples Were At or Above 10 ug/l)
Percent of Samples
Cumulative Frequency
20%
16%
12%
8%
4%
0%
100%
80%
60%
40%
20%
0%
Percent of Samples
Cumulative Frequency
x>=20
Category (Numbers in ug/l)

Figure 9

Dissolved Oxygen

The following analysis compares epilimnial (surface layer) reservoir dissolved oxygen data to the state ambient standard cited in the State Code of Maryland Regulations. Hypolimnetic dissolved oxygen data are compared to mesotrophic levels suggested by the literature, which indicates a range between 0.5 mg/l and 1.0 mg/l.

The data are presented as frequency histograms for easy comparison against the state standard and eutrophication index.

- Prettyboy Reservoir epilimnion samples were less than the surface waters standard (5.0 mg/l) 8.2 % of the time (see Figure 10). The hypolimnion (bottom layer, greater than 30 feet below the surface) was less than the upper mesotrophic range (1.0.mg/l) 24% of the time (see Figure 11).

- Loch Raven epilimnion samples were less than the surface water standard 15.7 % of the time (see Figure 12) while hypolimnion samples were less than the upper mesotrophic range 48% of the time (see Figure 13).

- Liberty epilimnion samples were less than the dissolved oxygen standard 10.9 % of the time (see Figure 14) while hypolimnion samples were less than the upper mesotrophic range 12 % of the time (see Figure 15).

There should be some degree of conformity among the different lake eutrophication indices; however in some cases indices can suggest varying degrees of impairment. For instance, in most water bodies, chlorophyll a and dissolved oxygen generally have a strong correlation, however, there may be certain situations where the correlation is weak or not at all. Factors besides algae such as reservoir morphology and hydrodynamics can play an important role in oxygen dynamics.

Liberty Reservoir appears to be the only reservoir where both dissolved oxygen and chlorophyll a indices suggest the same degree of impairment. Prettyboy Reservoir is the least impaired of the three reservoirs with respect to surface dissolved oxygen despite the fact that it is the most impaired using the chlorophyll a TSI index. Loch Raven is by far the most impaired using the dissolved oxygen indices but not using the chlorophyll a indices.

Hopefully the reservoir water quality model being developed under the Gunpowder Study will shed light on the relationship between reservoir chlorophyll a levels, dissolved oxygen and phosphorus.

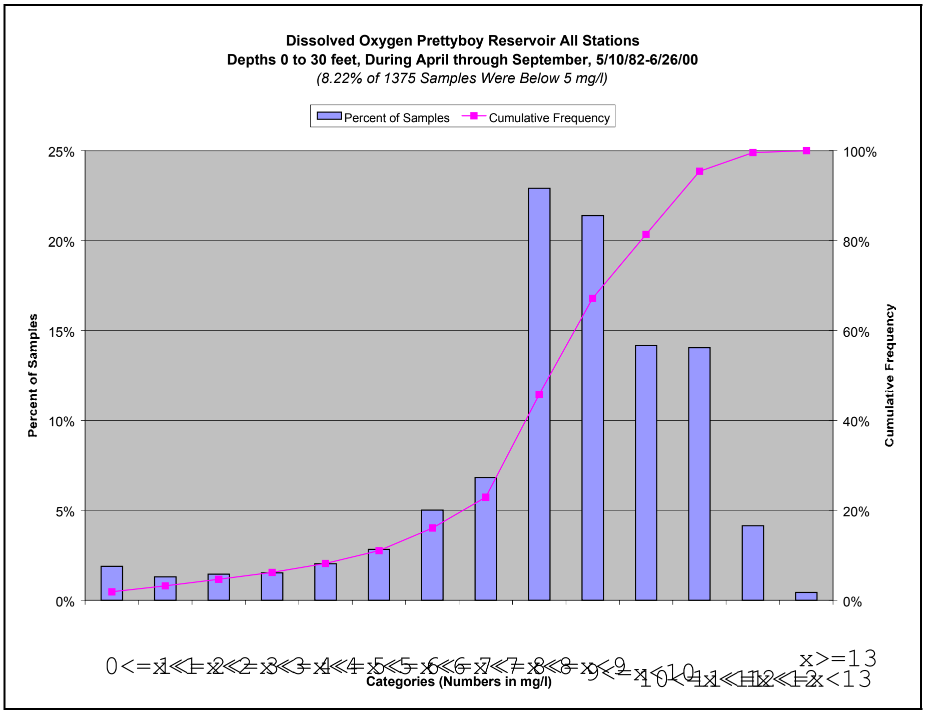


Figure 10

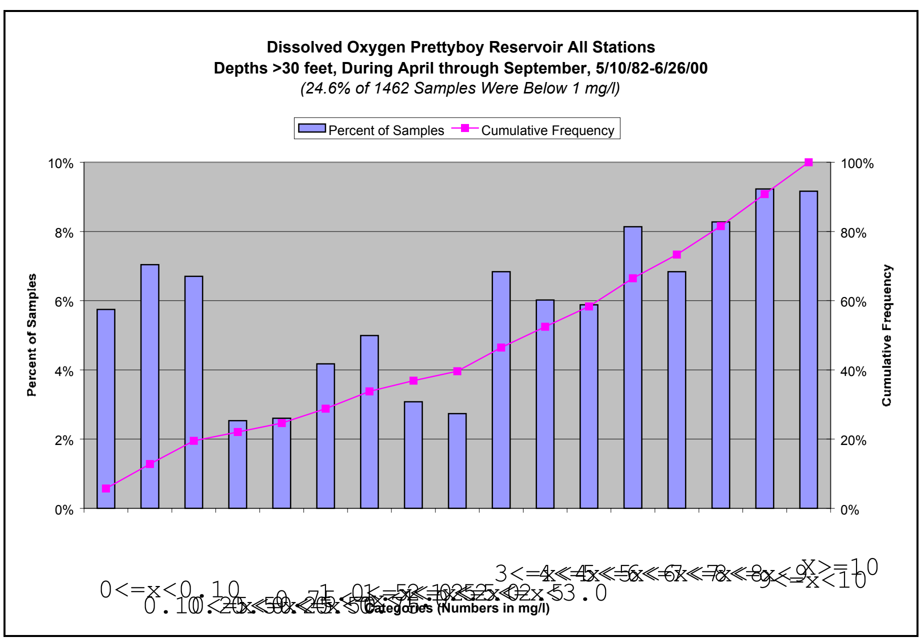


Figure 11

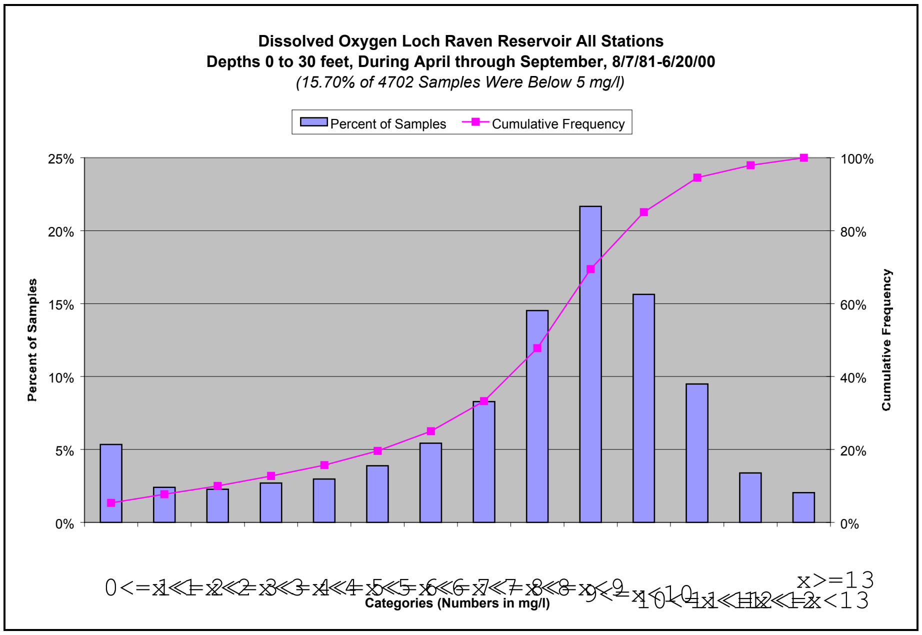


Figure 12

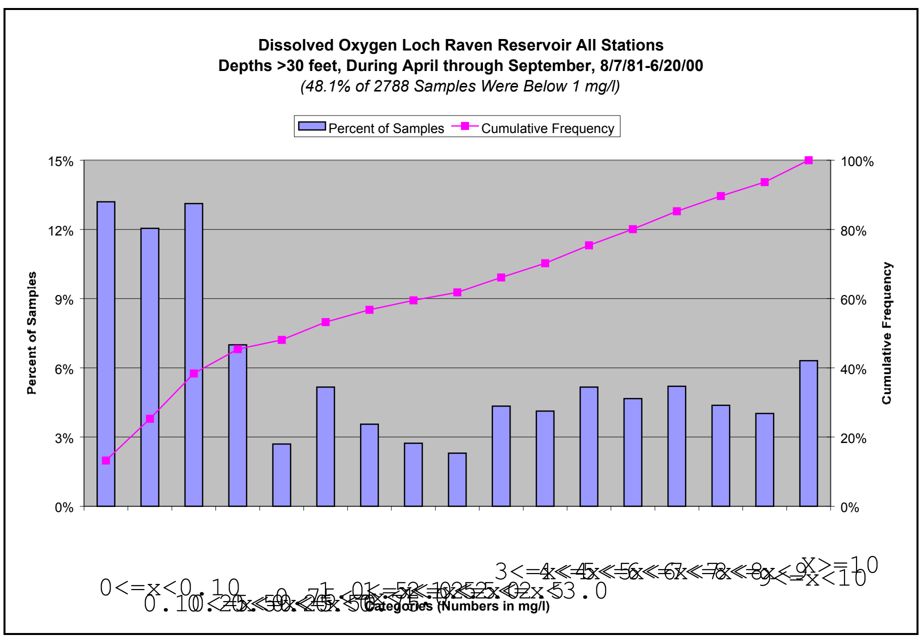


Figure 13

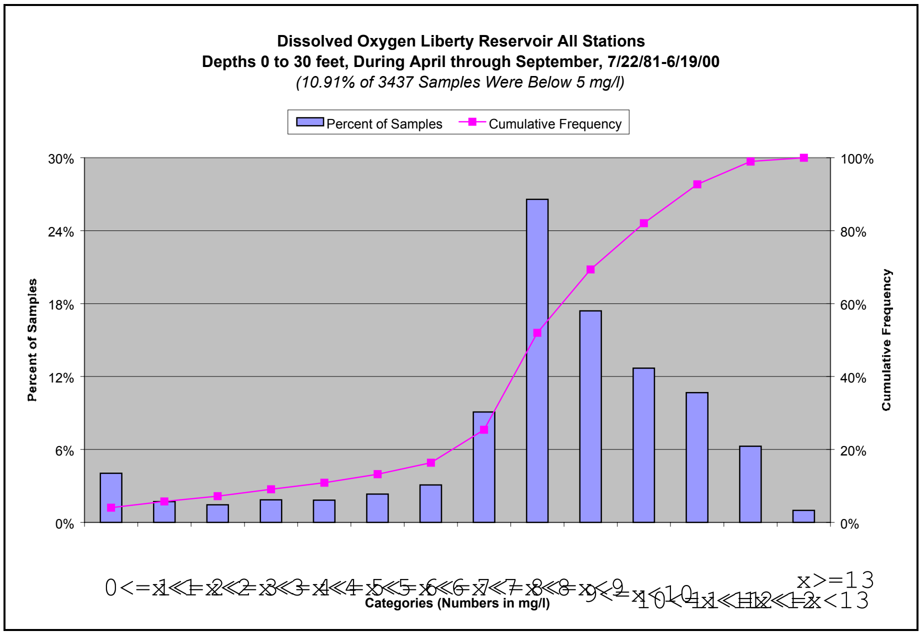


Figure 14

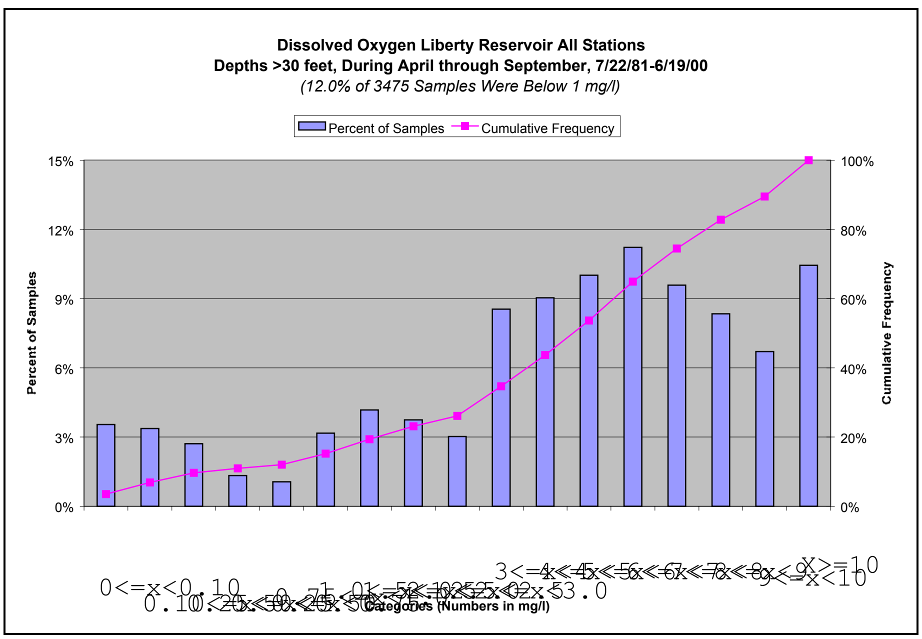


Figure 15

Phosphorus

Phosphorus data are presented as scatter-plots to detect temporal changes in in-lake phosphorus concentration. Since phosphorus is the limiting nutrient for algal populations in freshwater lakes and reservoirs, it is not surprising that decreases in total phosphorus concentrations in Liberty Reservoir (see Figure 16) corresponded to decreases in chlorophyll a. A similar trend is not apparent for Loch Raven and Prettyboy Reservoirs, which is confusing given the reductions in algal levels in these reservoirs. Dry and wet weather phosphorus loads each affect reservoir concentrations to varying degrees and must be considered together when interpreting their effect on algal trends. Unfortunately, wet weather monitoring data has been sparse since 1993 making it difficult to relate tributary loads to in-lake reservoir data.

Tributary concentration data are presented to determine if any temporal trends in dry weather phosphorus are occurring in the watershed. Ideally phosphorus loading (flow times concentration) would be used for this analysis; however, flow information is not available for all of the stations. Dry weather loads are important because unlike storm loads, a large percentage of the phosphorus is in the dissolved form, which is readily assimilated by algae.

The data suggest that some trends are apparent. Dry weather total phosphorus data for eight tributary stations show a decreasing trend. Examples are shown in Figures 17-19. In contrast, the three tributary stations along the Gunpowder Falls between Prettyboy and Loch Raven Reservoirs and Middle Run, a tributary to Liberty Reservoir, show an increasing trend (see Figures 20-23).

The Reservoir Watershed Management Program has used the Carlson Trophic State Index (TSI) for phosphorus to set water quality goals since the development of the initial Action Strategy for the Reservoir Watersheds in 1984. Phosphorus was chosen instead of chlorophyll a and secchi disk indices because it was believed to be more conservative and a better indicator of potential problems. A threshold of 26 ug/l, which corresponds to a TSI between the mesotrophic and eutrophic boundaries, was selected as the critical reservoir concentration (or criterion).

Phosphorus data are presented as a series of frequency histograms to determine the frequency of exceeding the TSI.

- Prettyboy Reservoir's epilimnion total phosphorus samples equaled or exceeded the critical value of 26 ug/l 55.5 % of the time (see Figure 24).

- Loch Raven's epilimnion total phosphorus samples equaled or exceeded this level 57.2 % of the time (see Figure 25).

- Liberty Reservoir equaled or exceeded this level 15.6 % of the time (see Figure 26).

While not all of the eutrophication indices reflect the same degree of impairment, the phosphorus index and dissolved oxygen index indicate Loch Raven to be the most impaired of the three reservoirs. However, depending on which index you use, Prettyboy Reservoir may be as impaired as Loch Raven. Liberty Reservoir is the least impaired of the reservoirs based on the phosphorus and chlorophyll a indices.

The difference in impairment among the reservoirs is more likely a function of reservoir assimilation capacity than pollution loading. Reservoir tributary loads are actually greater per acre in the Liberty watershed than the Loch Raven watershed (no loading data exists for Prettyboy).

Liberty Reservoir's greater ability to "self-cleanse" may be related to its longer residence time as Liberty Reservoir has twice the volume and almost half the drainage area of Loch Raven. The longer residence time may result in greater sedimentation of particulate forms of phosphorus from the water column.

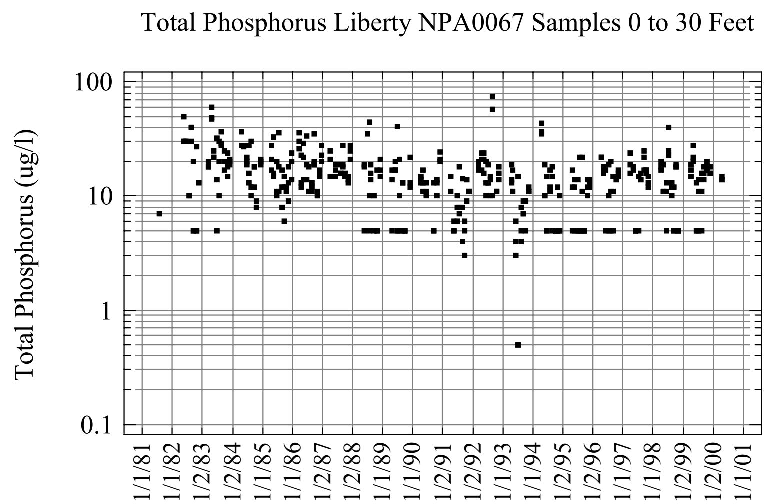


Figure 16

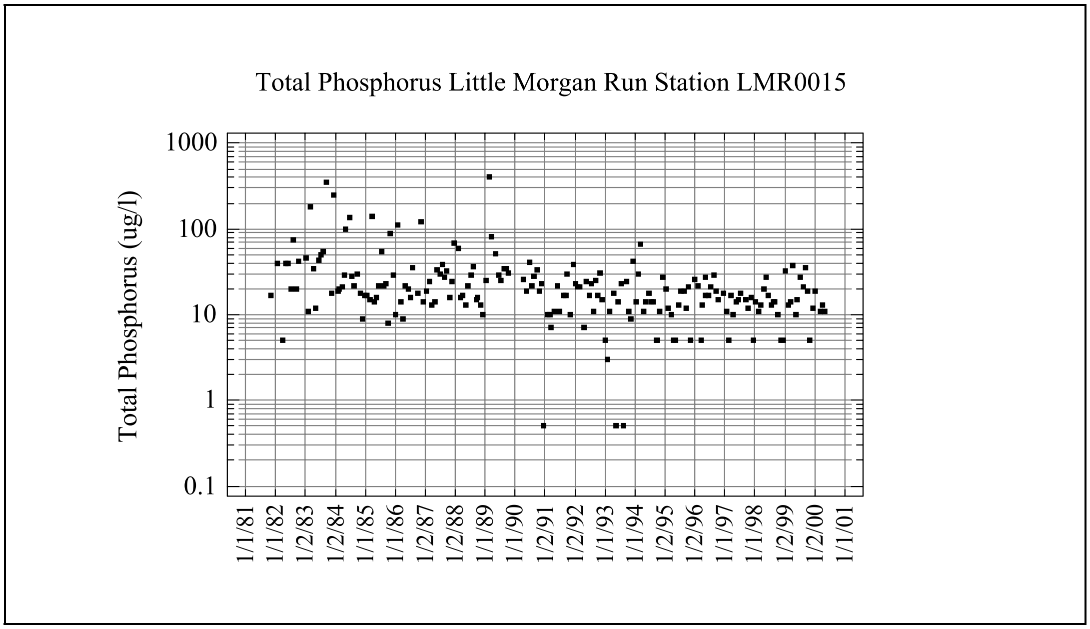


Figure 17

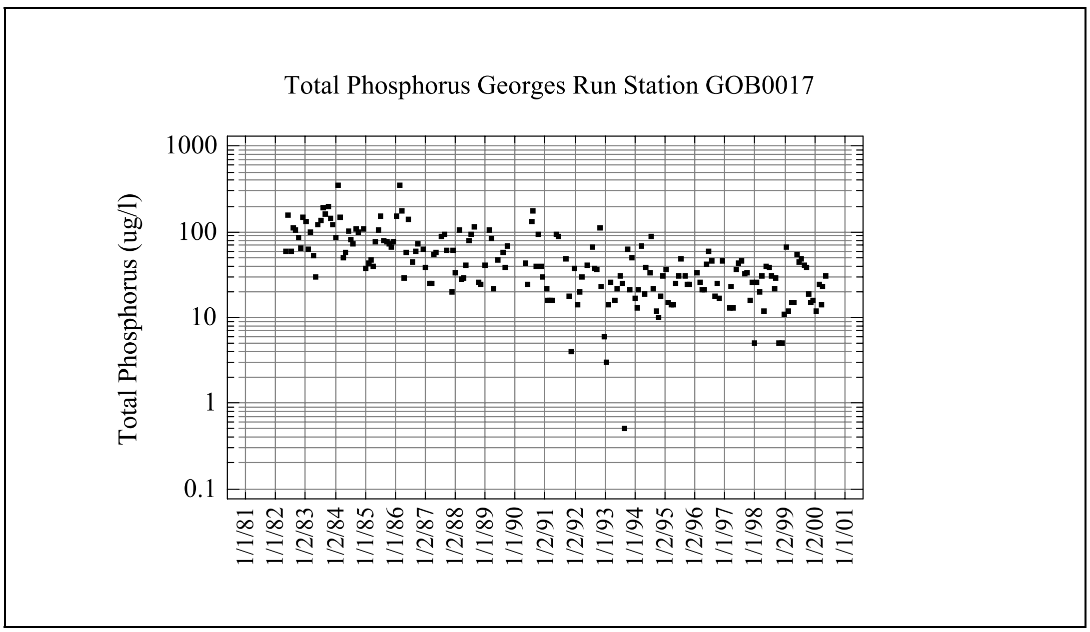


Figure 18

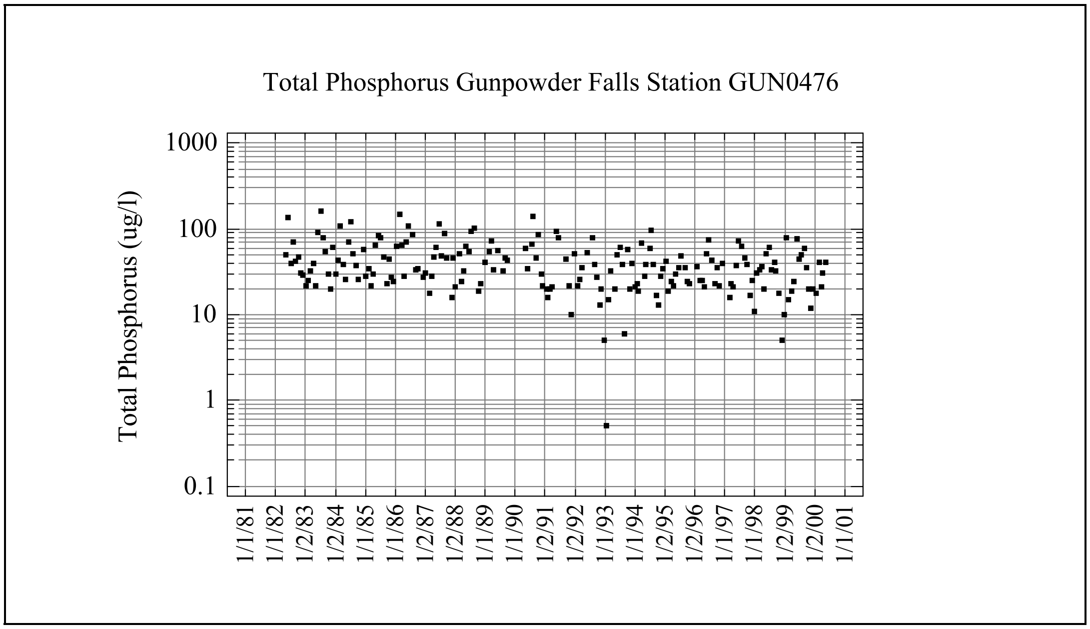
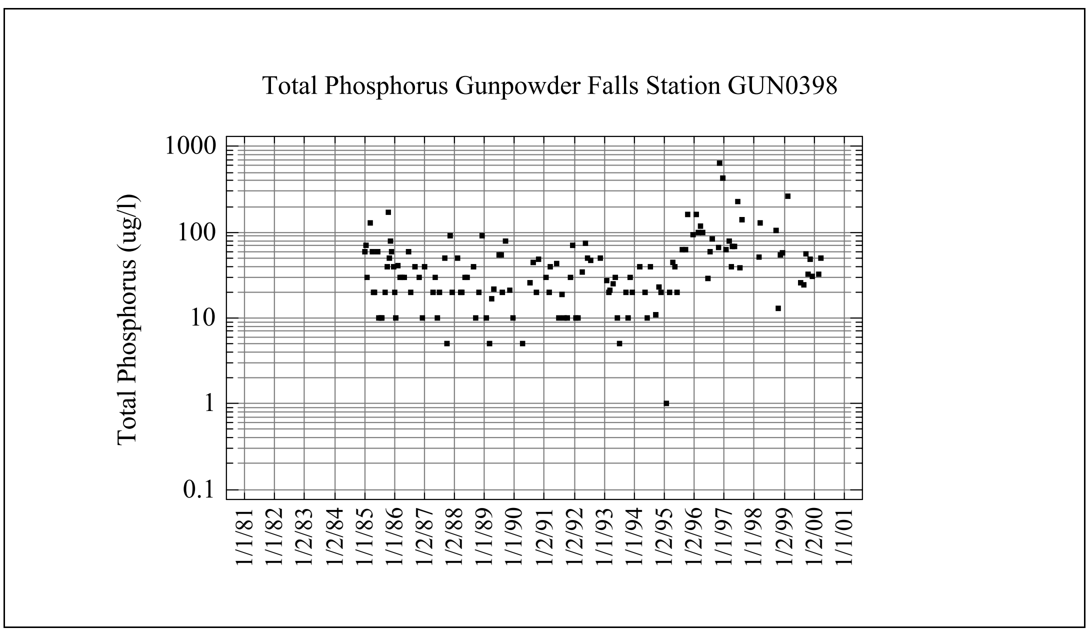


Figure 19



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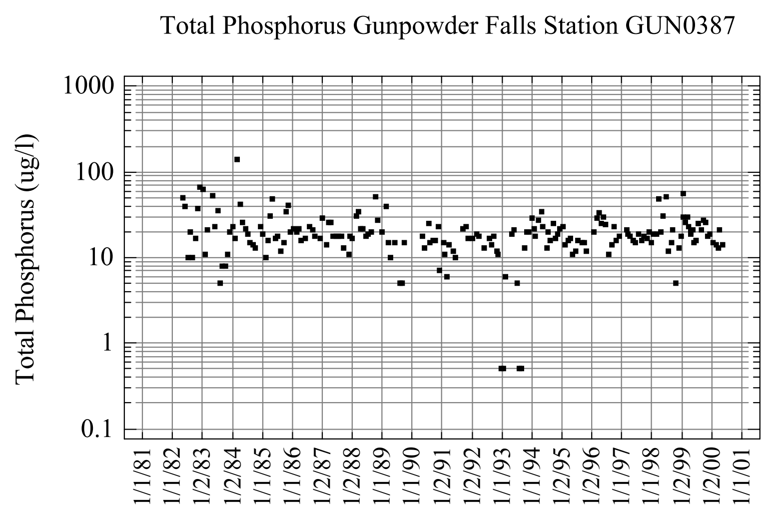

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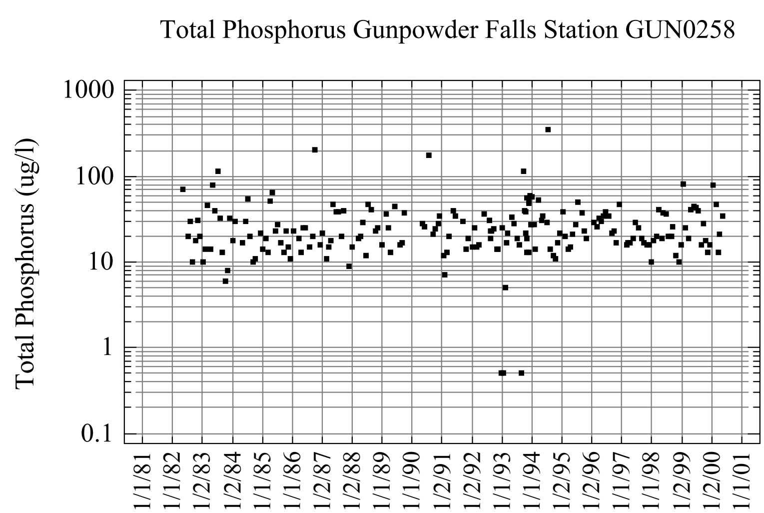

Figure 22

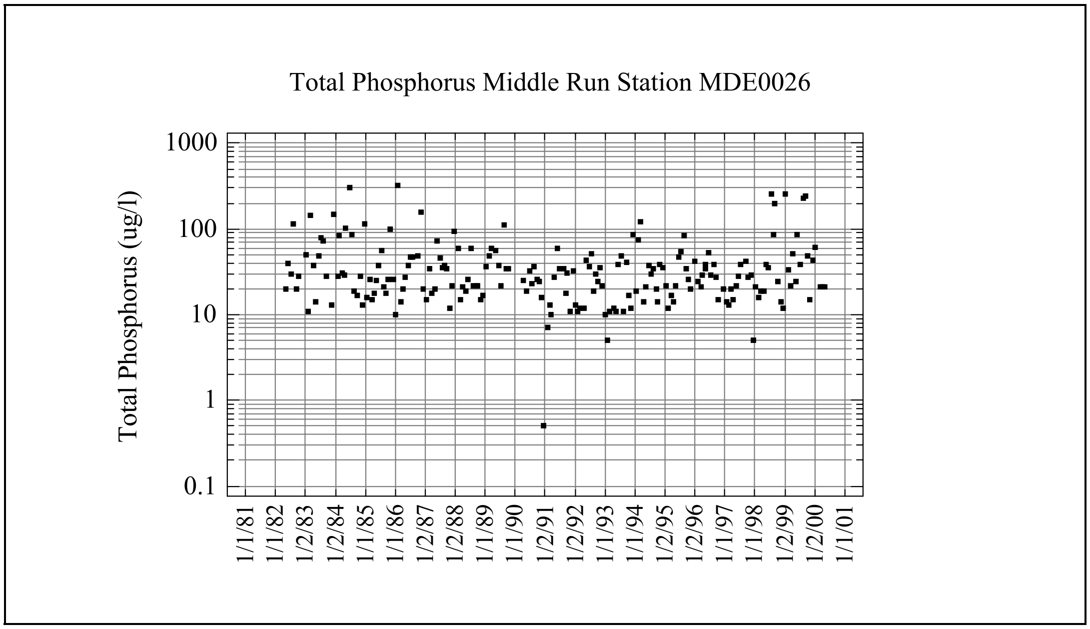

Figure 23

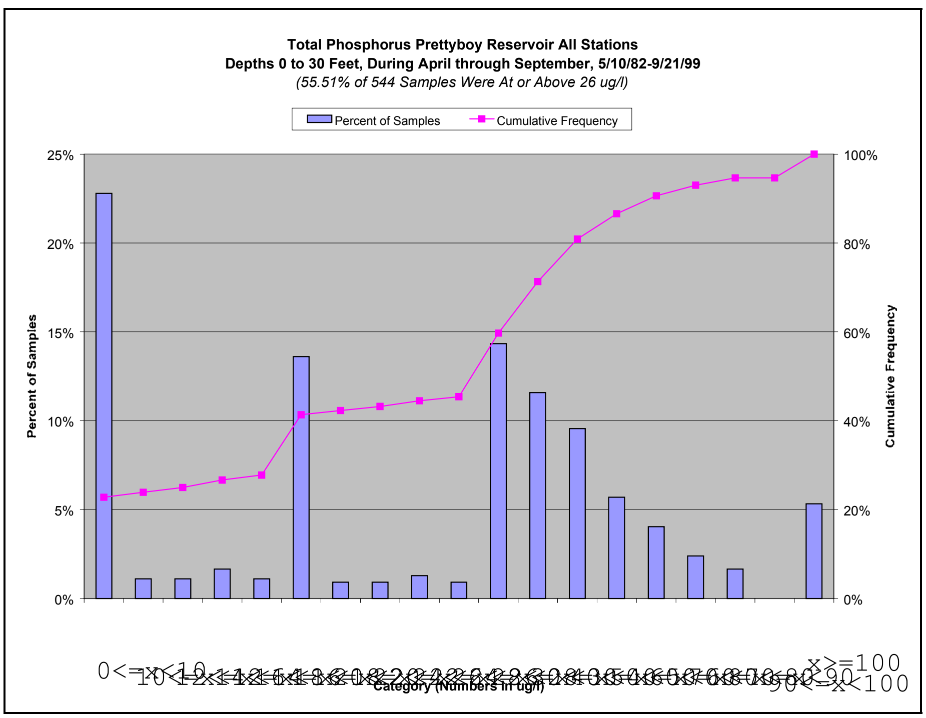

Figure 24

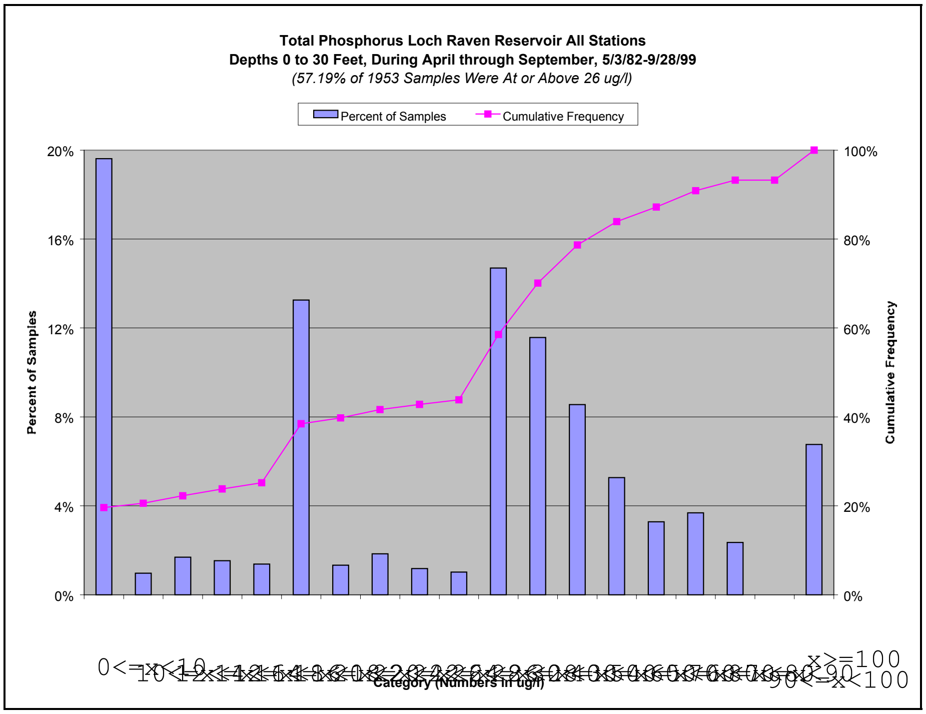

Figure 25

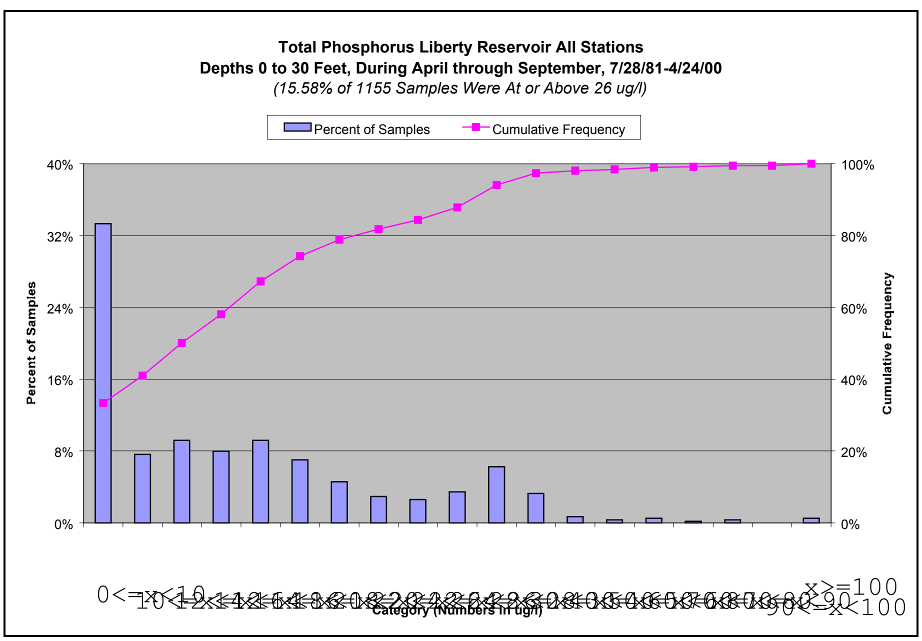

Figure 26

Secchi Disk Depth

Although secchi disk measurements indicate a relatively low level of impairment (as discussed below), measurements in Prettyboy Reservoir suggest a decreasing trend over time indicating greater turbidity levels (see Figure 27). Typical sources of lake and reservoir turbidity are sediments from the tributary watersheds or in-lake algae. As mentioned previously, algae levels seem to be decreasing, which may suggest that sediment is responsible for the increases observed in turbidity. However, the lack of storm water monitoring data for tributaries to Prettyboy Reservoir makes it difficult to assess this hypothesis.

There are no apparent long-term trends for secchi disk depth in the other two reservoirs (see Figures 29 and 31).

Frequency histograms are presented and compared against the Trophic State Index based on secchi disk measurements. The secchi disk threshold value indicating the boundary between the mesotrophic and eutrophic state is 1.86 m.

- Prettyboy Reservoir secchi disk measurements were less than the criterion (1.86 m) 7.3 % of the time (see Figure 28).

- Loch Raven secchi disk measurements were less than the criterion 7.9 % of the time (see Figure 30.

- Liberty secchi disk measurements were less than the criterion 5.8 % of the time (see Figure 32).

As was noted in previous reservoir reports, the secchi disk TSI indicates a lower level of impairment than either the phosphorus or chlorophyll a TSI's. It is remarkable that Loch Raven and Prettyboy show such low turbidity given the levels of algae. It will be interesting to see if the lake water quality model being developed under the Gunpowder Study can account for this phenomenon.

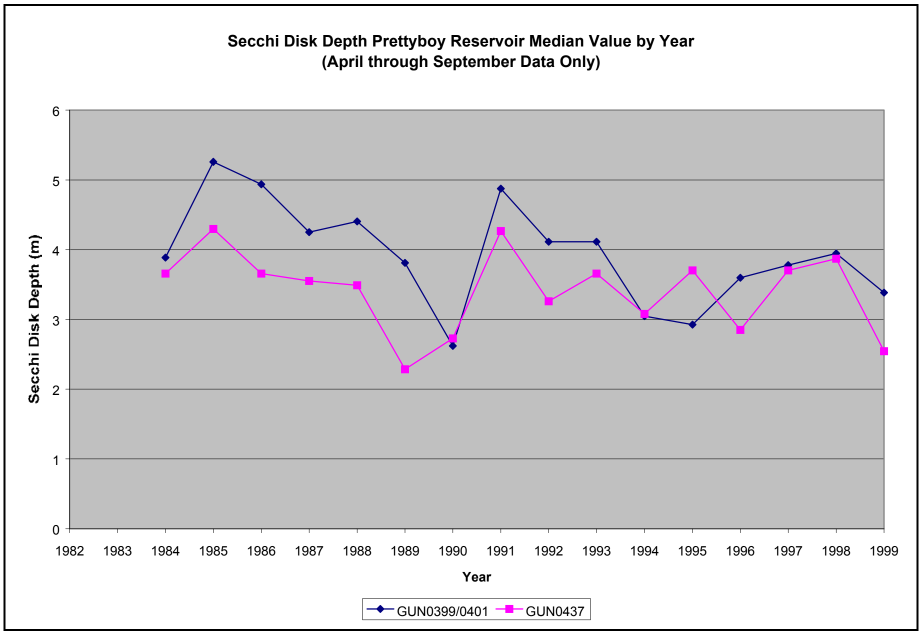

Figure 27

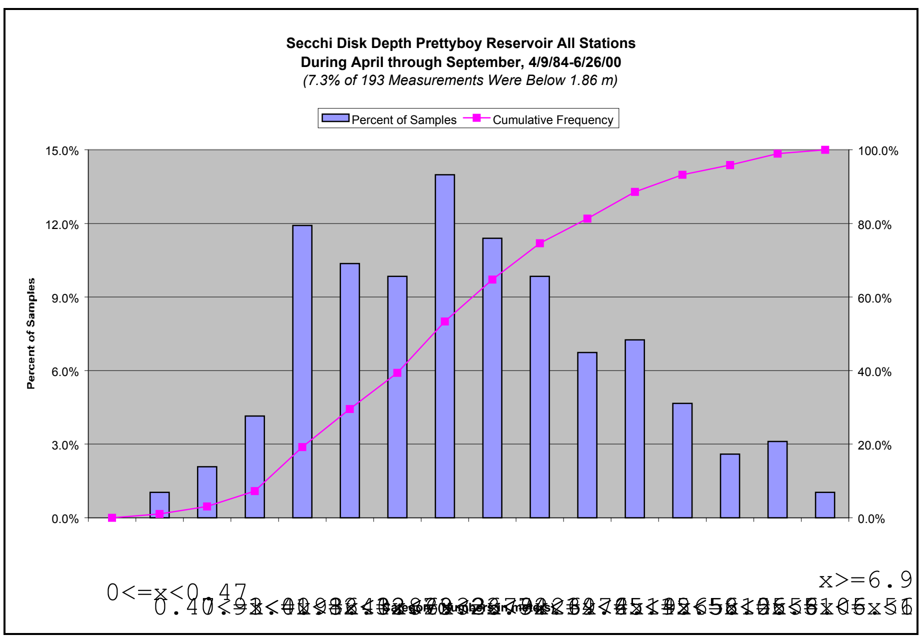

Figure 28

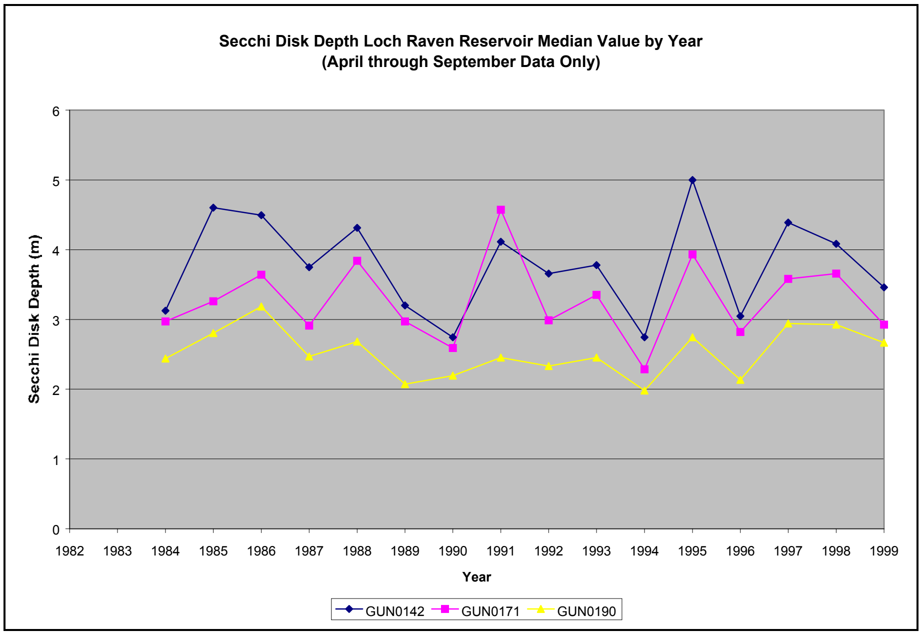

Figure 29

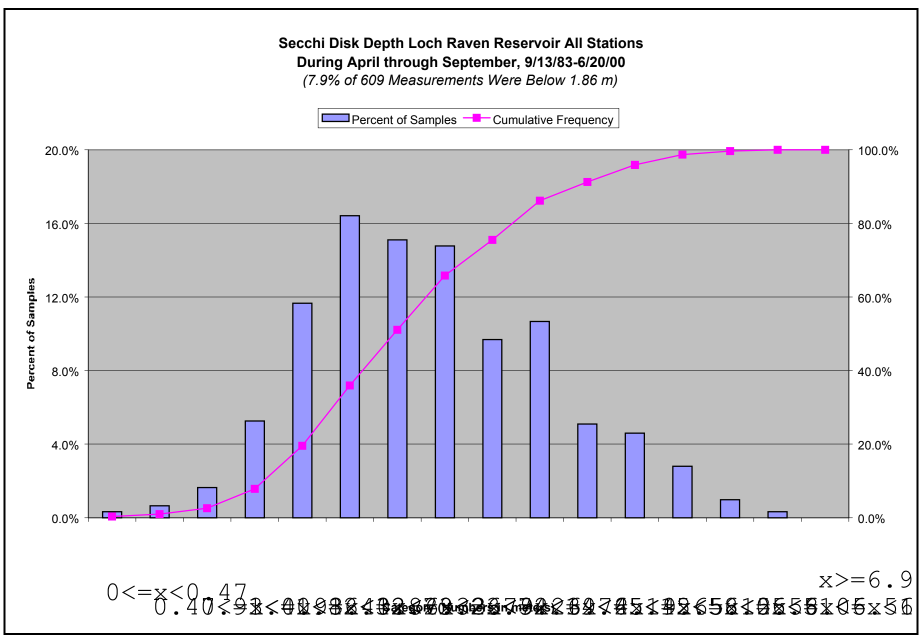

Figure 30

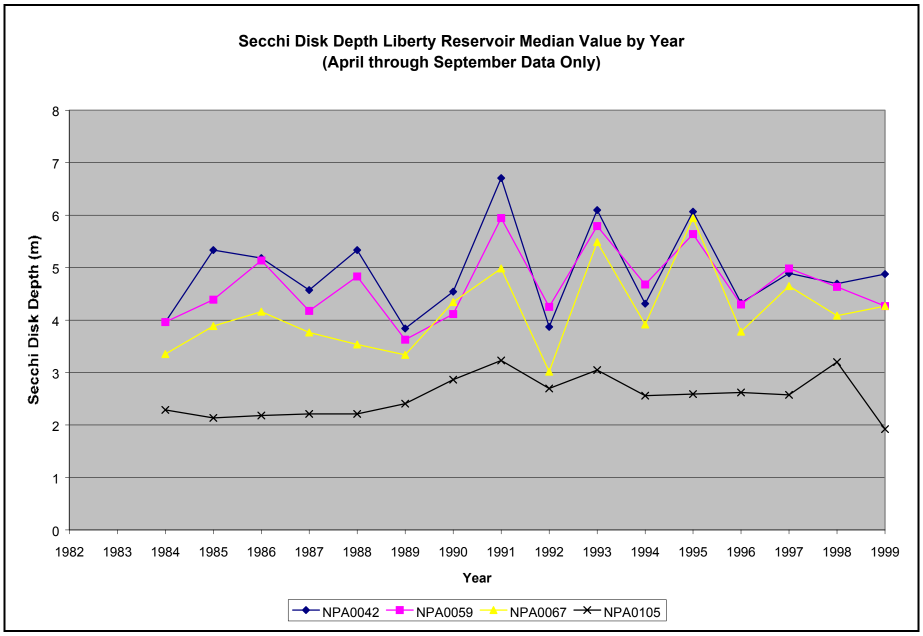

Figure 31

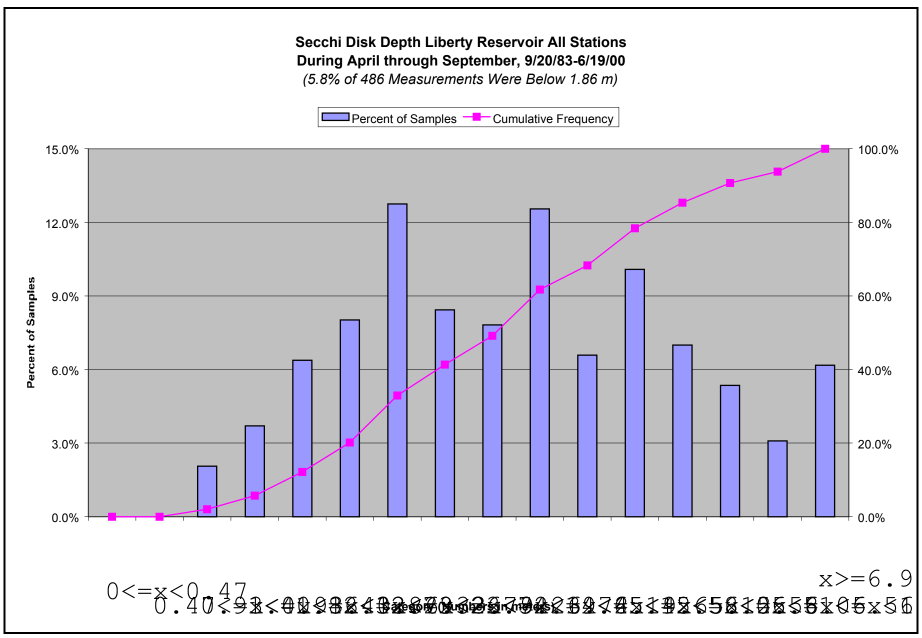

Figure 32

Nitrate Concentrations

Scatter-plots of dry-weather nitrate concentrations are presented to indicate temporal trends. Nitrate concentrations in the Liberty Reservoir appear to be steadily increasing from the early 1980's to the mid-1990's while nitrate data for Loch Raven and Prettyboy Reservoirs show no discernable trends. Nitrate concentrations in Liberty Reservoir appear to have leveled off since the mid-1990's. Figure 33 shows an example of this trend.

As with the other parameters, loading data is a more meaningful indicator of tributary trends, however, flow data is limited to a few stations. Despite the absence of loading data, dry weather nitrate concentrations in most of the tributaries monitored for each of the three reservoirs appear to have increased from the early 1980's to the mid-1990's and like the reservoir data, have since leveled off. See Figures 34-36 for examples of this trend.

A study by the Baltimore Metropolitan Council and the City of Baltimore found no significant relationship between land use patterns and nitrates in a pilot study of two watersheds (Beaver Run and Beaver Dam Run) conducted in 1992. A more comprehensive evaluation will be completed for the final report.

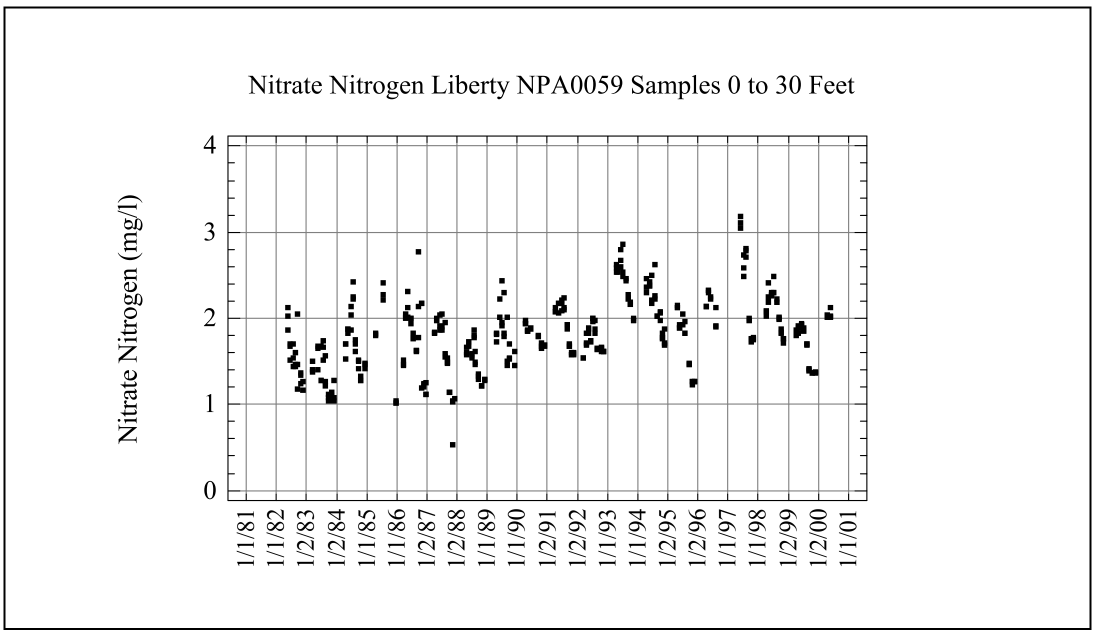

Figure 33

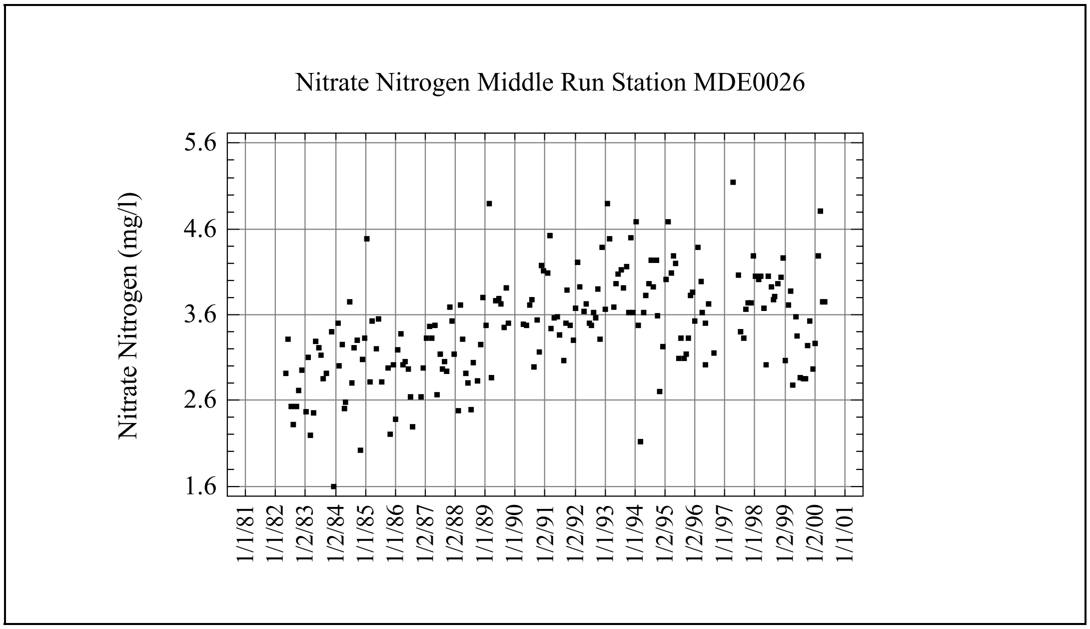

Figure 34

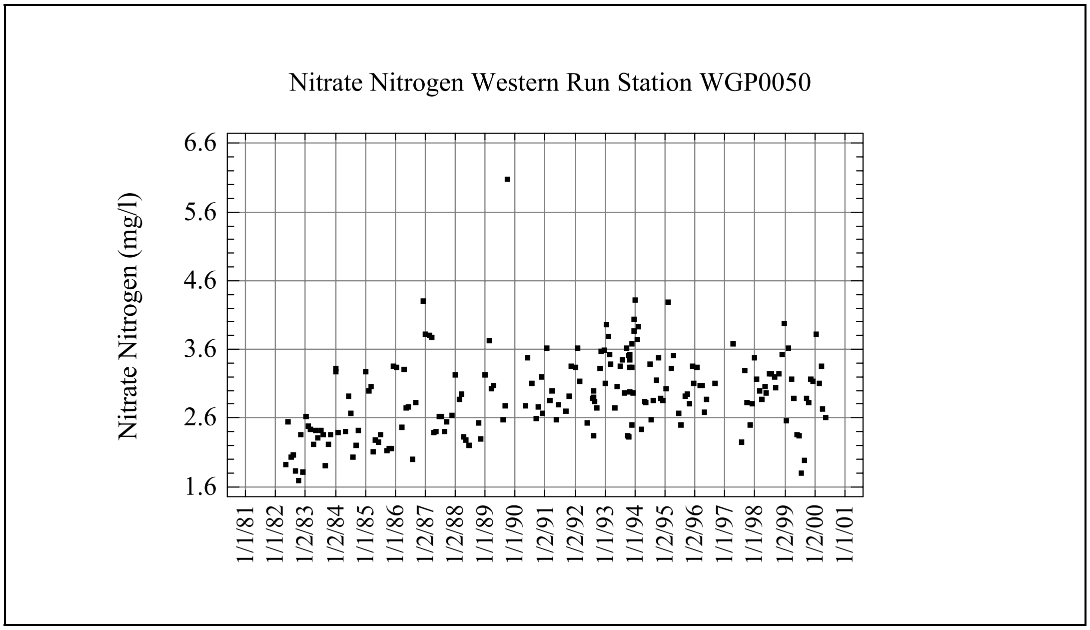

Figure 35

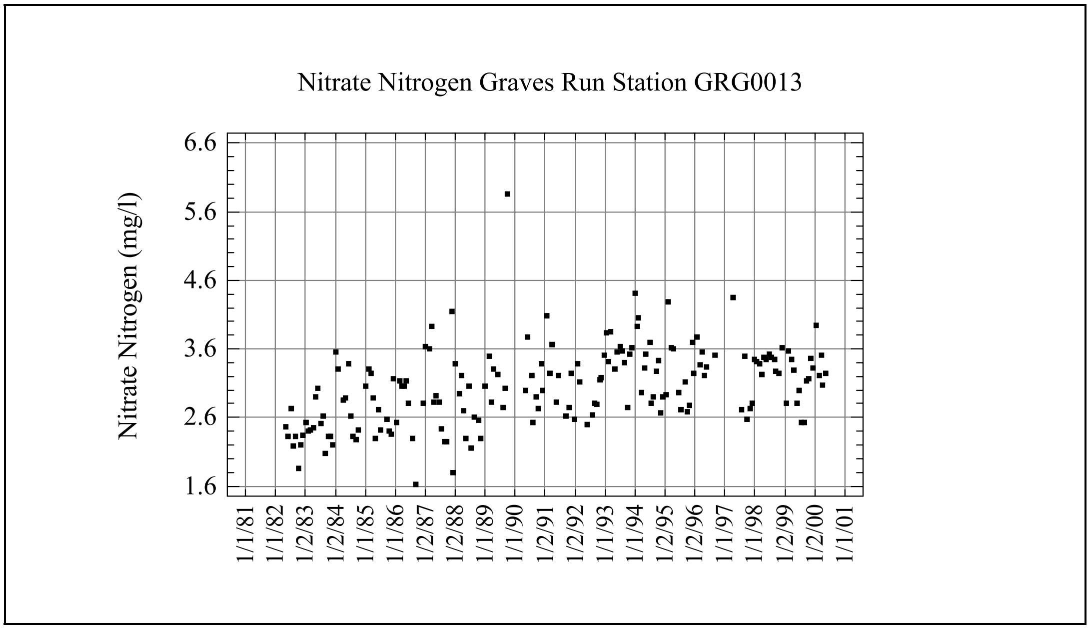
Nitrate Nitrogen Graves Run Station GRG0013
Nitrate Nitrogen (mg/l)
6.6
5.6
4.6
3.6
2.6
1.6
1/1/81
1/1/82
1/2/83
1/2/84
1/1/85
1/1/86
1/2/87
1/2/88
1/1/89
1/1/90
1/2/91
1/2/92
1/1/93
1/1/94
1/2/95
1/2/96
1/1/97
1/1/98
1/2/99
1/2/00
1/1/01

Figure 36

Chlorides

Scatter-plots are used to indicate chloride trends in the reservoirs and tributaries. The data shows that chlorides concentrations have increased dramatically in Liberty Reservoir from 1992 to present (see Figure 37). The data for chlorides previous to 1992 is not yet available.

Chlorides are not routinely measured in the other reservoirs; however, conductivity measurements are routinely taken and provide an excellent indication of chloride level. All three reservoirs show conductivity has increased from the early 1980's to present. Examples of this trend can be seen in Figures 38-40.

Dry weather tributary chlorides, conductivity and dissolved solids follow the reservoir trend for all stations from the early 1980's to present. Examples of this trend for chlorides are presented in Figures 41-43. An investigation into the causes of these trends is described in the following section.

Chlorides vs. Land Use Attributes

A study investigated the alarming trend of increasing chlorides concentration in baseline (dry weather) samples across all reservoir tributary monitoring stations. The Baltimore Metropolitan Council delineated watersheds for each of the tributary monitoring stations and gathered together data for each watershed on land use, road length and an estimate of the number of septic tanks. The hypothesis was that the increase in chlorides concentration was coming from the de-icing agent applied to roads, and/or waste from humans using septic tanks and farm animals. A preliminary analysis was run with this watershed characterization data and the median chlorides concentration for each of 13 tributary monitoring stations. Table 1 presents a list of the Spearman Rank correlations among selected variables.

- One of the strongest correlations (r_s=0.8033, p=0.0054) occurs between tributary chlorides 1999 median concentration and commercial and industrial land use percentage. See Figure 44 for a plot of these two variables. Among land use categories, commercial and industrial areas generally have the greatest amount of parking surfaces, which require the application of de-icing agent. This correlation suggests that de-icing agent contributes to chlorides concentration.

- There is a strong, positive correlation (r_s=0.6888, p=0.0170) between tributary chlorides median concentration for samples from January through March from 1996 through 1999 and road density for 1999. See Figure 45 for a plot of these two variables. This correlation also suggests that de-icing agent contributes to chlorides concentration.

- There is a strong negative correlation (r_s=-0.7345, p=0.0109) between the increase in tributary chlorides median concentration from 1990 to 1999 and agricultural (all types) land use percentage. See Figure 46 for a plot of these two variables.

So far the analysis has uncovered correlations between chlorides concentration and certain watershed characteristics such as land use and road density. This helps to explain differences in chlorides concentration among the sampling stations. However, the analysis so far has not uncovered relationships that explain the trend of increasing chlorides concentration at all sampling stations.

Comparing Tributary Chlorides Level with Watershed Characteristics: Spearman Rank Correlations					
The top number in each pair is the correlation that ranges between -1 and +1: the farther from zero, the stronger is the relation between the two variables. The bottom number is the p-value: the closer to zero, the more significant is the correlation (p-values <0.05 are considered significant; these have been shaded).					
	Chlorides Median 1999	Chlorides Median 1996-1999, Jan-Mar Only	Difference of Chlorides Median 1990 from 1999	Difference of Chlorides Median 1990 from 1999 Divided by Chlorides Median 1990	Chlorides Median 1990
Commercial & Industrial Land Use %	0.8033	0.7912	0.3714	-0.1978	0.7235
	0.0054	0.0061	0.1983	0.4932	0.0122
1999 Road Length per Unit Area	0.6135	0.6888	0.4814	0.0110	0.5475
	0.0336	0.0170	0.0954	0.9696	0.0579
1990 Road Length per Unit Area	0.6217	0.6833	0.4704	0.0769	0.5172
	0.0313	0.0179	0.1032	0.7899	0.0732
Agricultural (All Types) Land Use %	-0.4402	-0.4066	-0.7345	-0.4121	-0.1871
	0.1273	0.1589	0.0109	0.1534	0.5170
Institutional Land Use %	0.7400	0.7746	0.3576	-0.4560	0.8501
	0.0104	0.0073	0.2154	0.1142	0.0032
Residential (All Types) Land Use %	0.2751	0.3181	0.3301	0.2143	0.2173
	0.3406	0.2705	0.2528	0.4579	0.4515
Total Units Without Sewer Hook-up through 1999 per Unit Area	0.2173	0.2379	0.1953	0.1154	0.1871
	0.4515	0.4099	0.4986	0.6894	0.5170
Forest (All Types) Land Use %	-0.1403	-0.2158	0.1100	0.2473	-0.2476
	0.6269	0.4548	0.7031	0.3917	0.3911
New Units Without Sewer Hook-up 1991-1999 Divided by Units Without Sewer Hook-up 1990	0.5007	0.5118	0.3274	0.0165	0.4402
	0.0828	0.0763	0.2568	0.9545	0.1273
Total New Units Without Sewer Hook-up 1991-1999 per Unit Area	0.3906	0.4232	0.2173	-0.0659	0.4099
	0.1760	0.1426	0.4515	0.8193	0.1556
1999 Road Length per Unit Area - 1990 Road Length per Unit Area	0.4842	0.5394	0.4539	-0.2582	0.5860
	0.0935	0.0617	0.1159	0.3710	0.0424
Units Without Sewer Hook-up 1990 per Unit Area	0.1568	0.1881	0.1403	0.0495	0.1210
	0.5870	0.5146	0.6269	0.8640	0.6750

Table 1

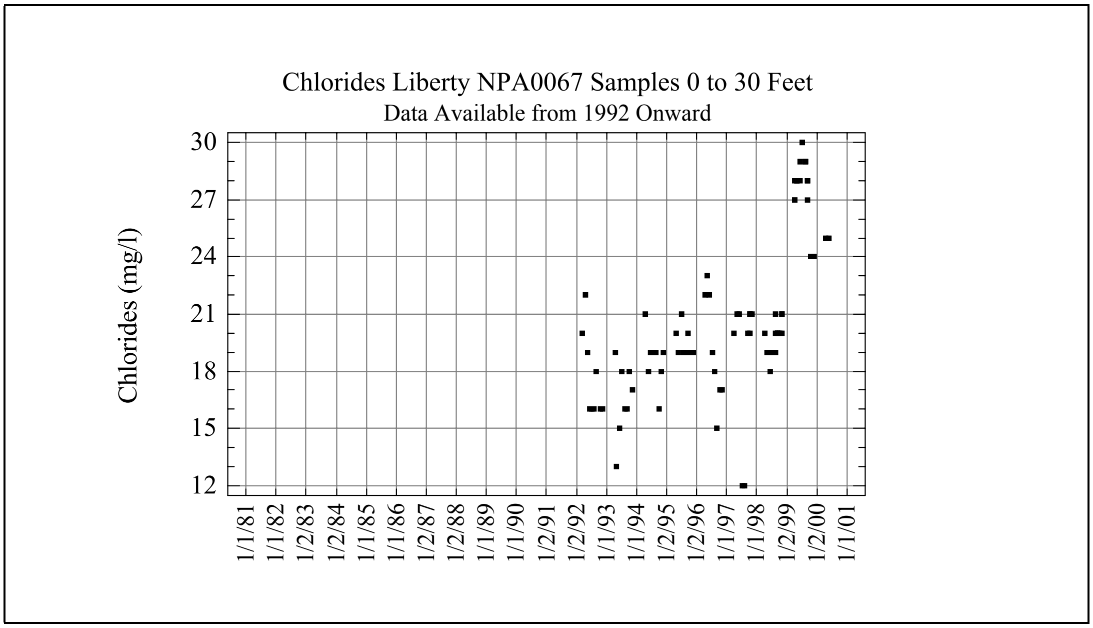

Figure 37

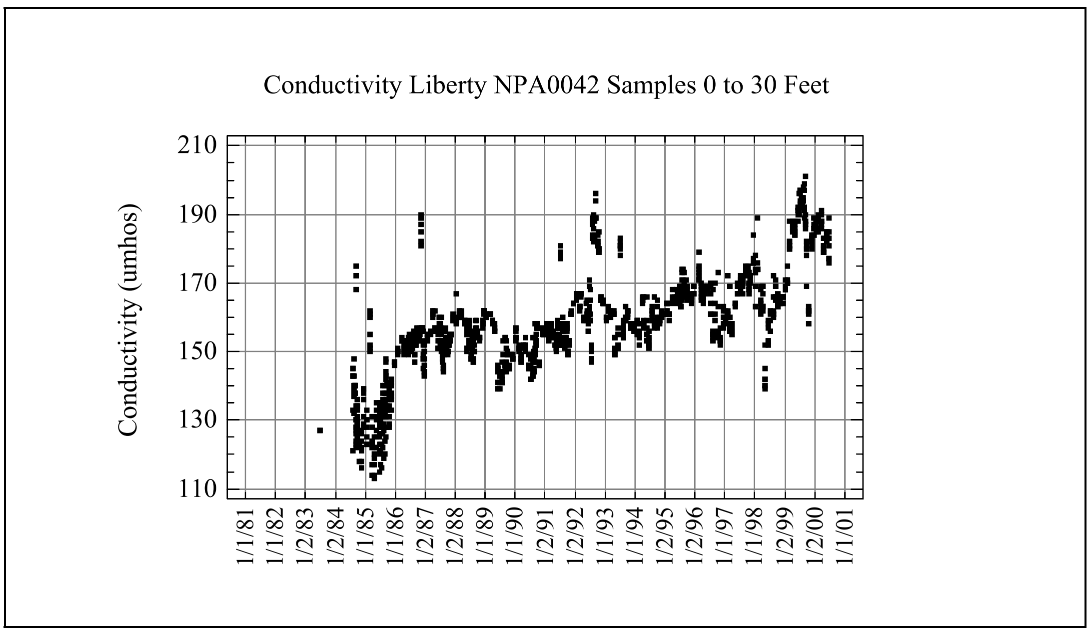

Figure 38

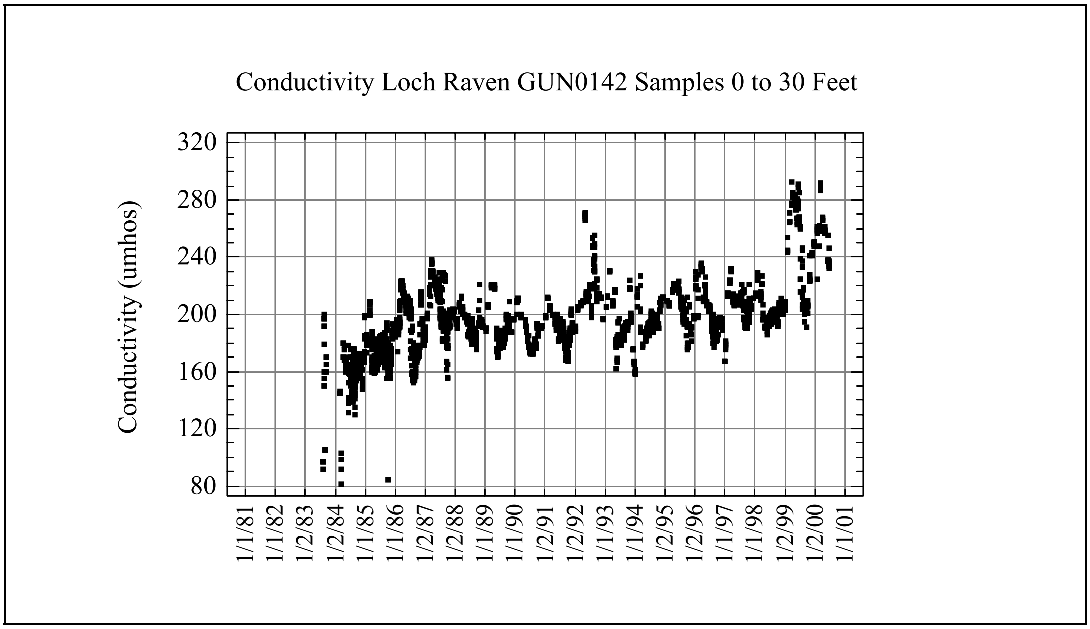

Figure 39

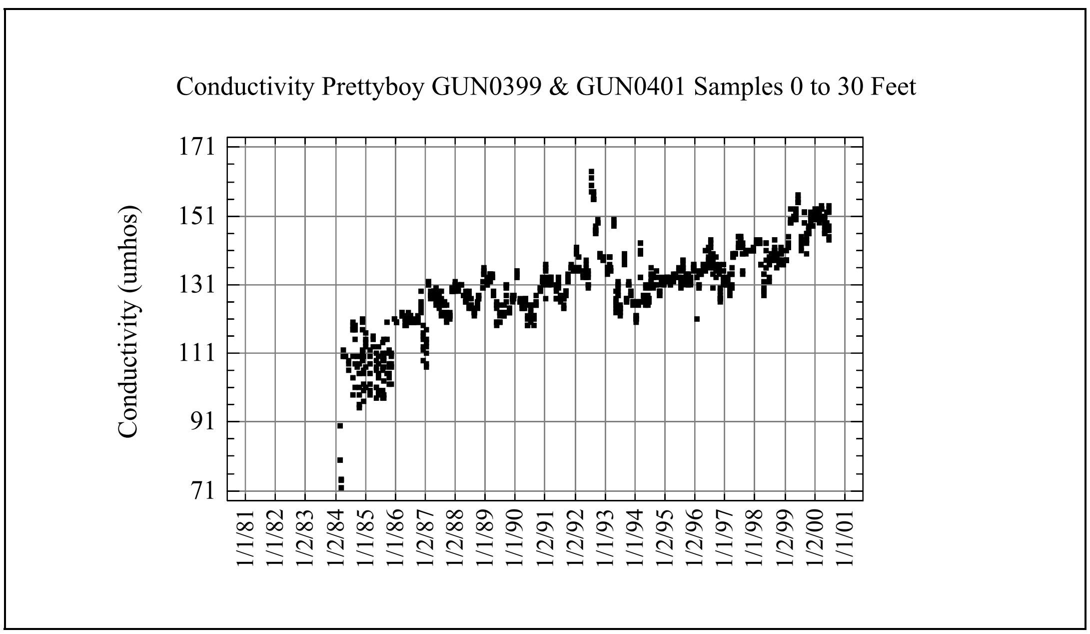

Figure 40

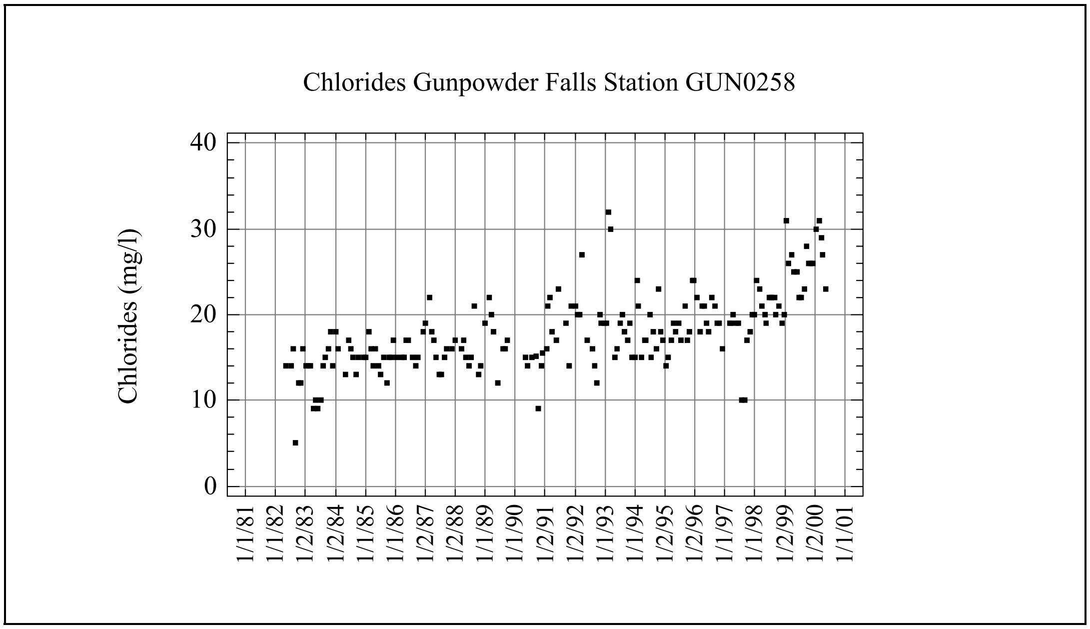

Figure 41

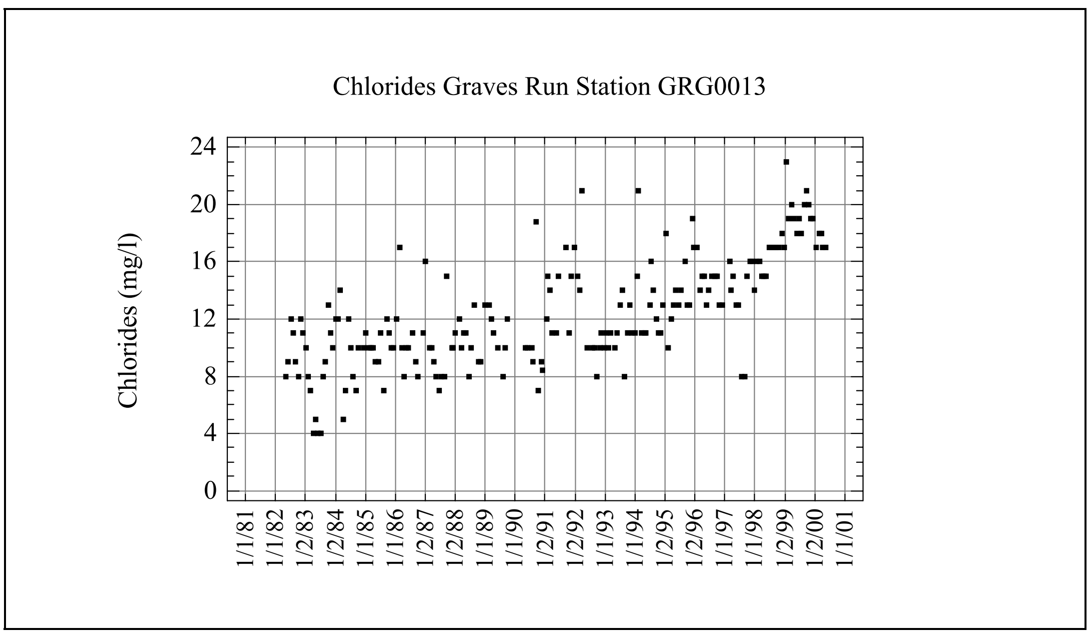

Figure 42

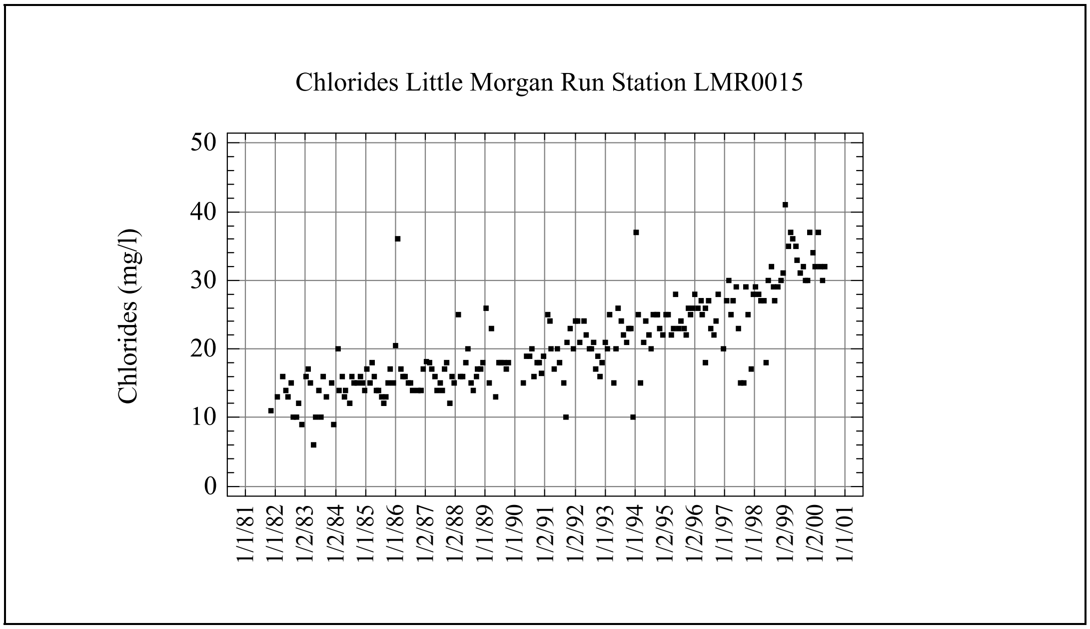

Figure 43

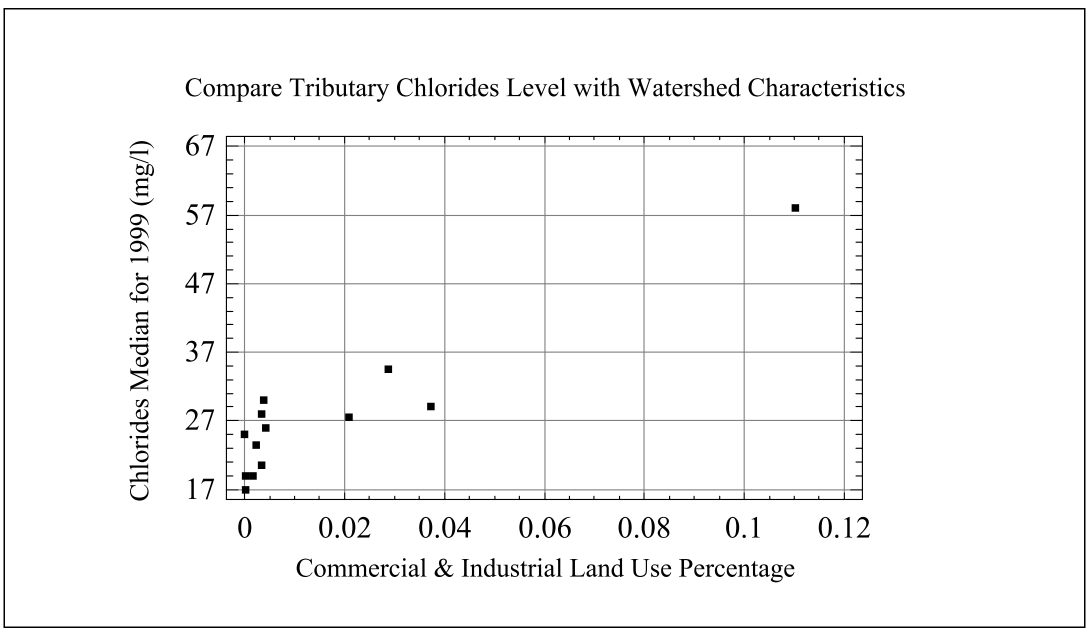

Figure 44

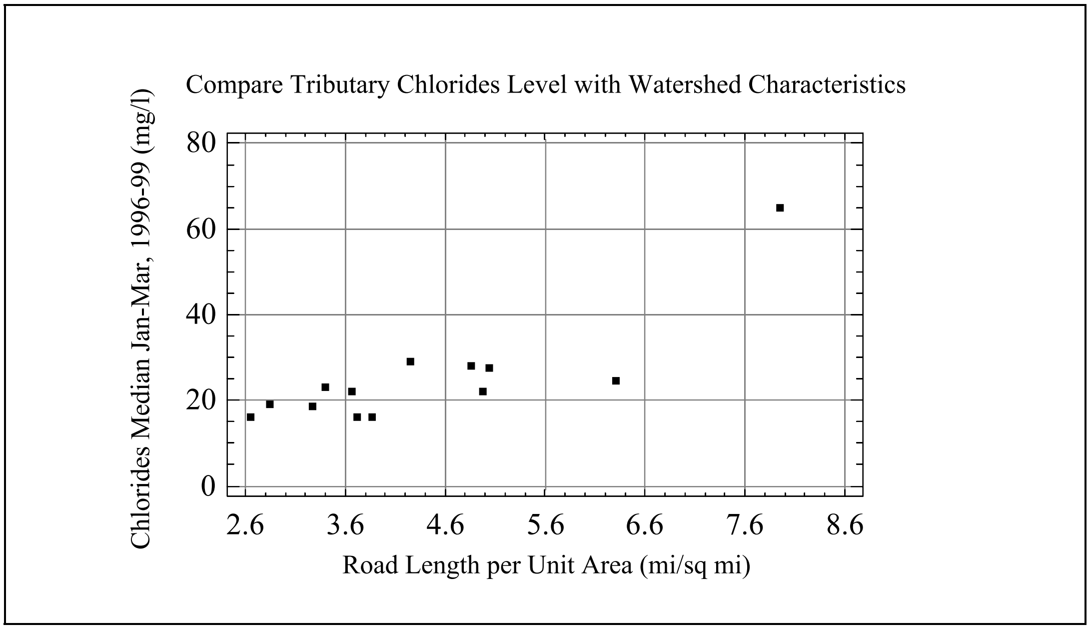

Figure 45

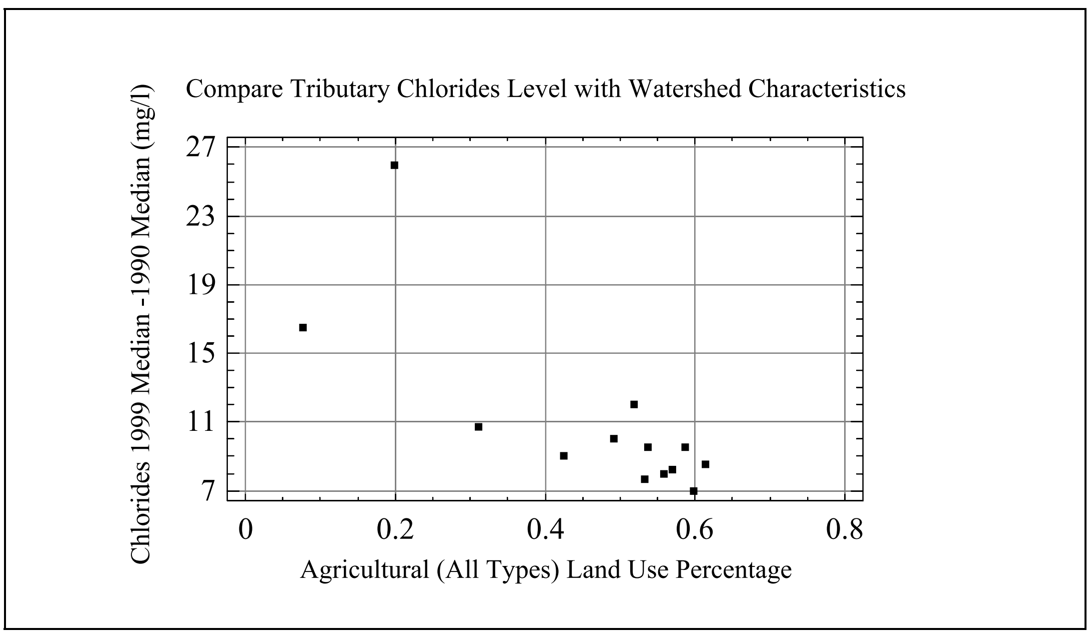

Figure 46