# Appendix L

# Nutrients in the Lower Cuyahoga River

A nutrient is a substance that promotes growth or development in living things, most often in reference to plants. In aquatic systems, nutrients are mainly responsible for determining the level of productivity in terms of algal or macrophyte biomass. Waters enriched in nutrients have increased productivity which can have a profound effect on stream ecology. This process is called eutrophication and has been defined as “The biological reaction of aquatic systems to nutrient enrichment, the eventual consequence of which is the development of primary production to nuisance proportions” (Marsden 1989). Although the individual constituents of nutrients themselves can have adverse effects on aquatic life in high concentrations, it is this eutrophication, or over fertilization, that is usually of most concern.

While essential to the functioning of healthy aquatic ecosystems, nutrients can exert negative effects by altering trophic dynamics, increasing algal and macrophyte production, increasing turbidity (via increased phytoplanktonic algal production), decreasing average dissolved oxygen concentrations, and increasing fluctuations in diurnal dissolved oxygen and pH (Sharpley et al. 1994). Such changes are caused by excessive nutrient concentrations that contribute to shifts in species composition away from functional assemblages of intolerant species, benthic insectivores and top carnivores (e.g.,darters, insectivorous minnows, redhorse, and esocids) typical of high quality warmwater streams towards less desirable assemblages of tolerant species, niche generalists, omnivores, and detritivores (e.g., creek chub, bluntnose minnow, white sucker, carp, green sunfish) typical of degraded warmwater streams (OEPA, 1999). As eutrophication proceeds, an increase in DELT anomolies and a reduction in fish biomass can occur and, in extreme conditions, the complete loss of the fishery. Other adverse effects of eutrophication on lakes and rivers include: increased biomass of phytoplankton; shifts in phytoplankton to bloom-forming species that may be toxic or inedible; increased biomass of benthic and epiphytic algae; changes in macrophyte species composition and biomass; decreases in water transparency; taste, odor, and water treatment problems; oxygen depletion; increased incidence of fish kills; loss of desirable fish species; reduction in harvestable fish and shellfish; reduction of aesthetic value of water body. (Smith, 1998). More specific effects depend on other factors such as physical properties of the water body and habitat. In addition, running water, simply because it is running, is an enriched environment compared to still waters because stream currents promote more efficient transfer of nutrients. Therefore, apparent low instream concentrations of nutrients can still exert a negative effect (Ruttner 1926). Eutrophication can result in visible algal blooms, algal mats and benthic algal and submerged macrophyte agglomerations. During respiration and upon decay, the algae contribute to dissolved oxygen depletion which can have negative consequences on the aquatic biota and is likely the major source of fish mortality and morbidity due to eutrophication.

Nutrients are subject to rapid increases due to human activities. Accelerated eutrophication is the main cause of water quality impairment in the United States (EPA, 1996). The process of accelerated enrichment and its impacts, arising from human activities, is termed cultural eutrophication and has been recognized internationally as a significant environmental problem/challenge for decades (Vollenweider and Kerekes, 1982). Eutrophication can be assessed through direct observations of algal mass, or indirectly through measurements such as nutrients and dissolved oxygen. Nutrients can include many types of ions and compounds, but are most often identified as compounds of nitrogen and phosphorus. For the lower Cuyahoga River TMDL, when the term nutrients is used, it will be used as in the common sense to mean nitrogen and phosphorus compounds.

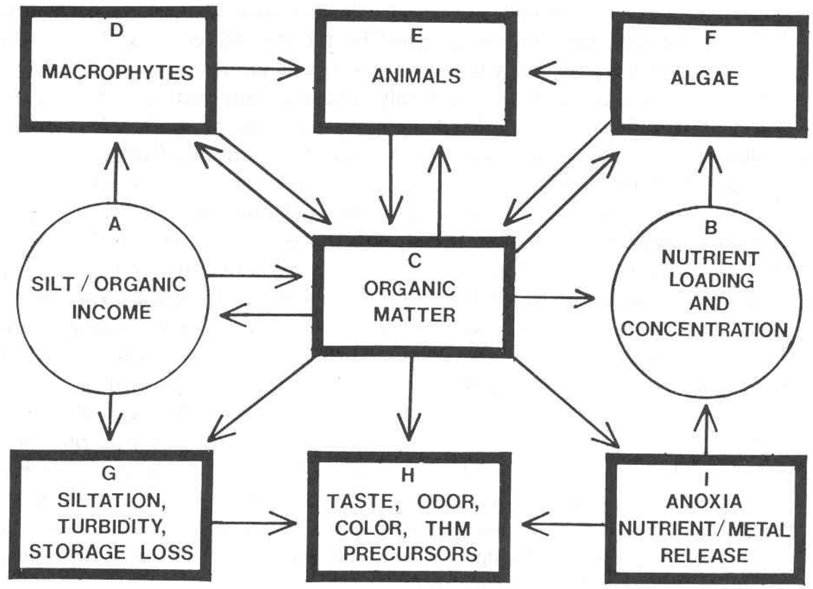


Figure 1 Primary interactions and effects of eutrophication process. THM-trihalomethane. From Cooke et.al. 1986

Sources of nutrients can be natural or from human activities. Deforestation results in losses of nutrients from the forest as they are carried into surface waters through adsorption to eroded soils or leached into surface and subsurface waters. Agriculture and construction activities can be large sources of nutrients to waterways. Atmospheric deposition, especially of nitrogen compounds, can also be significant. Treated domestic wastewater is one of the largest sources of nutrients to the lower Cuyahoga River. Of great significance, the nutrients in treated effluent from well operated or tertiary wastewater treatment plants are usually found in the dissolved form. Dissolved nutrients are much more readily available for uptake by organisms than when sorbed onto particles. In natural systems, very little phosphorus is contained in the dissolved form as nearly all phosphorus in unimpacted streams are sorbed to sediment particles associated with bank or soil erosion. Treated domestic wastewater may also be associated with organic enrichment and can compound the effects of nutrients on the environment. Symptoms and manifestations of eutrophication are similar in all types of waters from lakes to flowing waters to estuarian and marine habitats (Meybeck *et. al.*, 1990). A general diagram of interactions and effects of the eutrophication process in water supply reservoirs is shown in figure 1 (Cooke *et.al.*, 1986).

Ohio EPA currently does not have statewide numeric criteria for nutrients but potential targets have been identified in a technical report entitled "Association Between Nutrients, Habitat, and the Aquatic Biota in Ohio Rivers and Streams" (OEPA, 1999). This document provides the results of a study analyzing the effects of nutrients on the aquatic assemblages of Ohio streams and rivers. The study reaches a number of conclusions and stresses the importance of habitat and other factors, in addition to instream nutrient concentrations, as having an impact on the health of biologic communities. The study also includes suggested targets for nitrate+nitrite and total phosphorus concentrations based on observed values at reference sites. Reference sites are relatively unimpacted streams that are used to define the expected or potential biological community within an ecoregion. The Cuyahoga River has a drainage area of 809 $mi^2$ which places it in the small river category. Ohio EPA selected the median value associated with measured aquatic life performance at all warmwater habitat sites within the Erie Ontario Lake Plain (EOLP) ecoregion regardless of attainment status. The selection of the median value is an implicit margin of safety and is not an upper limit or threshold. The Phosphorus and habitat target values selected for the Lower Cuyahoga River watershed are shown in Table 1.

**Table 1.** Nutrient and Habitat TMDL Targets

| Watershed Size(D.A. = Drainage Area) | Ecoregion | Total P(mg/l) | Habitat(QHEI) |
|---|---|---|---|
| Headwaters (D.A. < 20 $mi^2$) | EOLP | 0.08 | 60 |
| (20 $mi^2$ < D.A. < 200 $mi^2$) | EOLP | 0.10 | 60 |
| Small Rivers (200 $mi^2$ < D.A. < 1000 $mi^2$) | EOLP | 0.12 | 60 |

The reader is referred to "Legal and Technical Basis for Nutrient Target Values Used in TMDL Projects", DSW Water Quality Standards Guidance #4, November 27, 2000, for a general discussion of the approach being used. The total phosphorus target concentrations used in this TMDL project are considered fully protective of the Warmwater Habitat biological criteria for the EOLP ecoregion. The pertinent facts supporting this statement are provided below.

**Nitrogen**

Nitrogen can be measured as total nitrogen (TN), total Kjeldahl nitrogen (TKN), ammonia-nitrogen, nitrate-nitrogen (NO3), nitrite-nitrogen (NO2) (the later two are usually measured as nitrate-nitrite-nitrogen (NO3+NO2). TN is used to represent the total amount of nitrogen in a sample while TKN represents the fraction of TN that is unavailable for growth or bound up in organic form. The TKN test includes NH4 so that subtracting $NH_4$ from TKN results in a determination of organic nitrogen. The remaining fractions (NO3+NO2 and $NH_4$) represent bioavailable forms of nitrogen, and, if summed can be compared to the soluble reactive fraction of phosphorus. The threshold for observed degradation of WWH communities is in the range of 3-4 mg/l NO3+NO2 (OEPA, 1999). The mesoeutrophic boundary value of 1.5 mg/l NO3+NO2 has been reported in the literature from a wide range of streams and would be consistent with probable WWH attainment (Dodd, 1998 reported in OEPA, 1999). The Cuyahoga River watershed, especially downstream from domestic wastewater treatment plants, exceeds these values. At first look, it seems appropriate to place limitations on the nitrogen loadings from these waster water treatment facilities. However, a reduction in nitrogenous compounds may not achieve desired results because of the concept of a limiting nutrient which is essential to understanding biological processes. A limiting nutrient is the nutrient in short supply relative to others that will be exhausted first and will thus limit cellular growth. Therefore, any reduction in a limiting nutrient causes a direct reduction in production (eutrophication). Reduction of other nutrients that are not limiting will not. Whenever the ratio of nitrogen to phosphorus, or the N/P ratio, in surface waters is greater than about 7-10:1, then phosphorus is considered the limiting factor in productivity. Because of the biochemical composition of algae, balanced algal growth requires a ratio of nitrogen to phosphorous to be in this 7:1 ratio. In the lower Cuyahoga River the N/P ratio of year 2000 sample averages was 19.5:1 which indicates the lower river productivity is unequivocably controlled by TP concentrations (Smith, 1982). Therefore, phosphorus is the limiting nutrient in the lower Cuyahoga River and has thus been selected for load reduction in this TMDL rather than nitrogen compounds. Nitrogen may need to be considered for load reductions if the phosphorus targets proposed in this TMDL are met and the river continues to be in non-attainment of its aquatic life uses or if nitrogenous compounds are found to have a direct negative effect on the aquatic biota. This phased approach to reducing stressors to the aquatic community from nutrient impacts is consistent with Ohio EPA guidance.

**Phosphorus**

Phosphorus can be measured as total phosphorus (TP), or soluble reactive phosphorus (SRP) (also sometimes called phosphate (PO4) or orthophosphate (ortho-P) or dissolved phosphorus. The last four represent different terms or tests used to describe the fraction of TP that is soluble or readily available to organisms for growth and is somewhat analogous to $NH_4$ plus the ions of NO3+NO2. Data from the Erie Ontario Lake Plain ecoregion was examined to determine the relative frequency of total phosphorus concentrations and WWH attainment. The target value of 0.12 mg/l for the mainstem and 0.07 mg/l for major tributaries are median values in the Erie Ontario Lakeplain ecoregion where there is a reasonable expectation of attainment of the WWH biocriteria. In other words, for those similar sized streams in the ecoregion that are attaining the WWH use designation, 50% of the values for total phosphorus are below this target and 50% are above it.

Research of the OECD (Organization for Economic Co-Operation and Development) prepared by the Soil & Water Conservation Society of Metro Halifax (Canada) have demonstrated that, in most cases, phosphorus is the factor which determines the development of eutrophication; even when another nutrient such as nitrogen is (occasionally or normally) the limiting factor, phosphorus may still be made to play the role of limiting factor through appropriate control. Control of point sources of pollution from municipalities and industries is usually given priority as it is generally the most cost-effective measure. After reduction of phosphorus from point sources, the relative role of phosphorus from diffuse sources will increase. This means that measures against diffuse sources may become necessary if improvement of water quality cannot be achieved by further elimination of phosphorus point sources. Diffuse source control is more difficult to achieve. Yet, in many cases, effective prevention of eutrophication, or restoration of eutrophied waters cannot be achieved without such control. Therefore, the improvement of all aspects of land use practices which contribute nutrients to water bodies should be encouraged (Soil and Water, 2002). Further, because phosphorus is often sorbed onto sediment, non point control of phosphorus often requires reduction of soil and bank erosion which will improve instream habitat.

**Evidence for Nutrient Impacts in the Lower Cuyahoga River**

Total Phosphorus concentrations in the lower Cuyahoga River mainstem had a median total phosphorus concentration of 0.17 mg/l from all samples collected in 2000 (N= 83). The maximum value was 0.69 mg/l and the minimum was less than 0.05 mg/l. National Park Service samples collected during 2000 from the mainstem at Station Road and Ira Road had an average concentration of 0.22 mg/l (n=11). These values exceed the target value of 0.12 mg/l which is derived from all EOLP ecoregion warmwater habitat sampling locations and also exceeds the USEPA recommended phosphorus criterion of 0.1 mg/l. In comparison, a USGS NAWQA study reported the results of samples collected at 213sites (8420 samples) from 1991 to 1996 at locations biased towards agriculture impacted streams and storm events. The mean value reported in the USGS study was 0.24 mg/l, the median was 0.08 mg/l. The median total phosphorus concentration in the Cuyahoga River downstream from NEORSD Southerly WWTP was 0.25 mg/l from five samples collected in 2000. The maximum value was 0.52 mg/l and the minimum was 0.21 mg/l. As shown in Figure 2, both the Akron and NEORSD Southerly discharges increases the instream total phosphorus concentration in the Cuyahoga River compared to upstream concentrations. NEORSD and Akron self monitoring reports indicate the instream phosphorus concentrations corroborates Ohio EPA 2000 survey data.

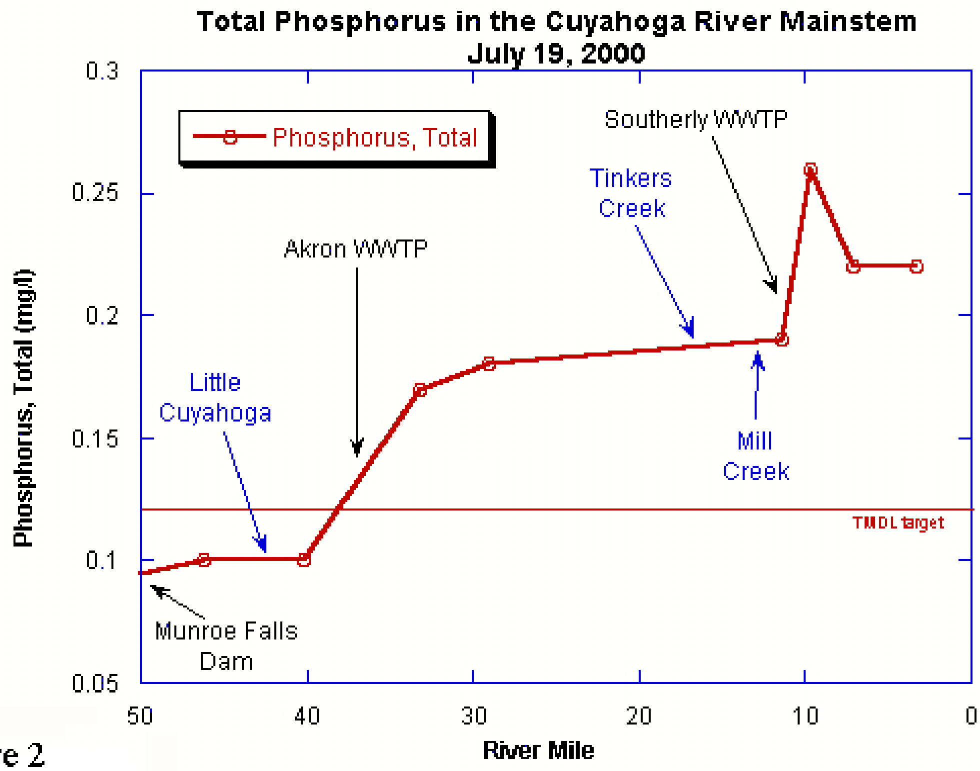


**Figure 2**

Plant production and total respiration are major factors in dissolved oxygen concentrations in streams (Simonsen and Harremoes, 1978). Supersaturated dissolved oxygen concentrations, indicative of nuisance conditions caused by nutrient enrichment, have been documented in the lower Cuyahoga River. Supersaturated dissolved oxygen is a physical condition of a stream where the oxygen dissolved within the water exceeds the concentration that is in equilibrium with the atmosphere at a particular water temperature. The oxygen in the water that exceeds the equilibrium concentration is derived from algal photosynthesis. Photosynthetic oxygen is produced in sufficient quantities to supersaturate a stream only when the algal communities are in enriched conditions. Upon respiration (nighttime) and decay, oxygen is used and concentrations drop to well below atmospheric equilibrium. Percent saturation in non enriched streams, or in streams segements that may be enriched, but are aerated by riffles or other means (see gorge area at RM 49.8) is around 95% and diel ranges are low. Excessive growths of attached algae have been noted and documented by Ohio EPA investigators at several locations in the Cuyahoga River mainstem including at the gorge, Peninsula, and Boston Mills. Supersaturated conditions have been found by Ohio EPA in continuous monitors, monthly NAWQMN sampling, and in 2000 survey samples. These data are shown in Figures 3-9 USGS water quality data collected in 2000 (Appendix 1) also reveal supersaturated conditions. The large swings in dissolved oxygen concentrations can be illustrated through a series of grab samples collected at Independence, lower Harvard Avenue and West Third Street (Figure 10). Dissolved oxygen concentrations at Independence on April 24 were at 101.84 % saturation, June 7 at 56.48 % and June 14 at 101.29%. At lower Harvard Avenue, dissolved oxygen concentrations on April 24 were at 94.36 %, June 7 at 55.57% and June 14 at 109.79%. And dissolved oxygen concentrations on April 24 were at 89.60 %, June 7 at 96.53 % and June 14 at

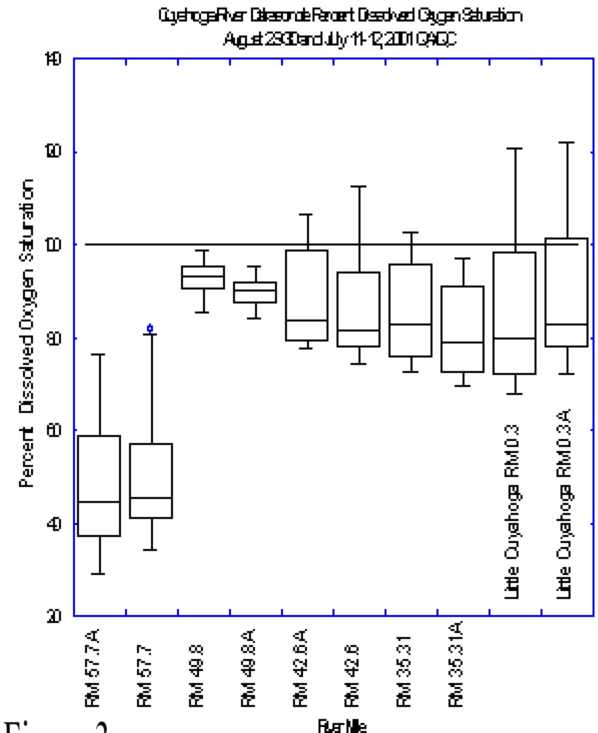


Figure 3

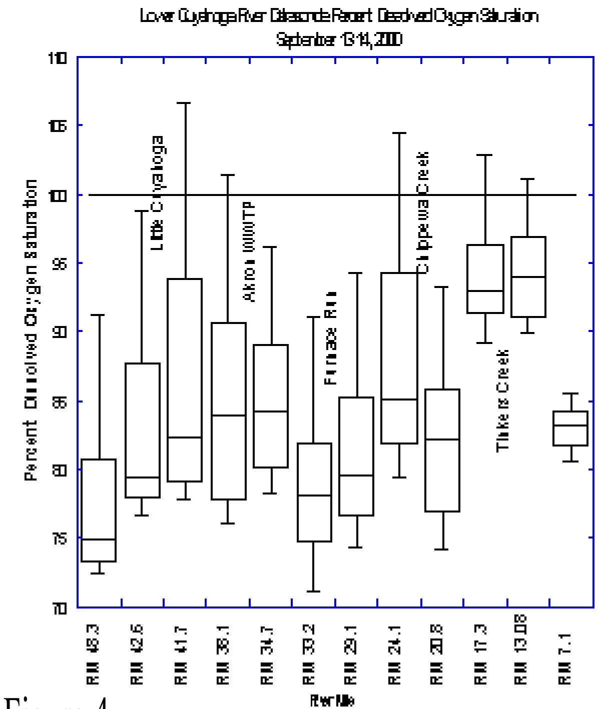


Figure 4

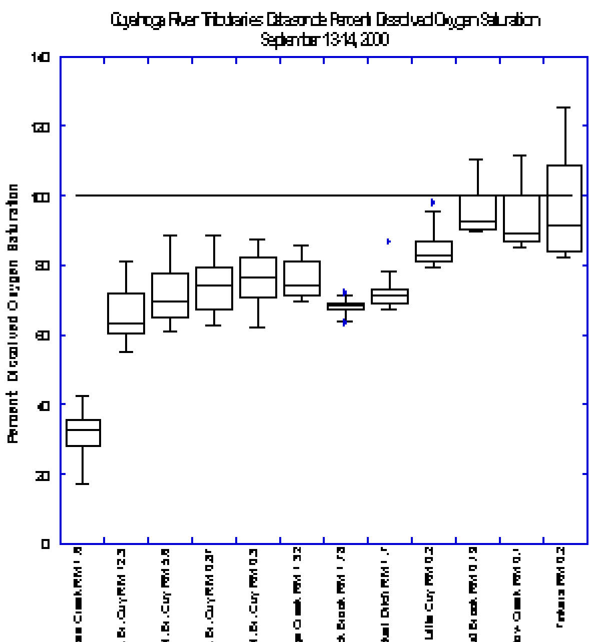


Figure 5

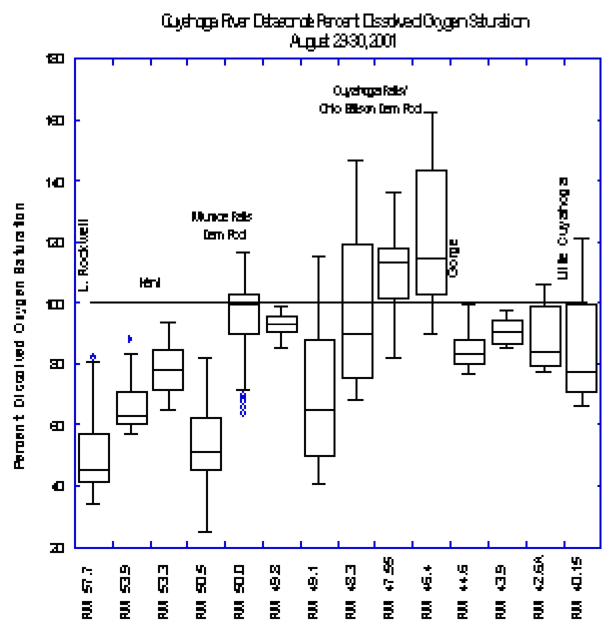


Figure 6

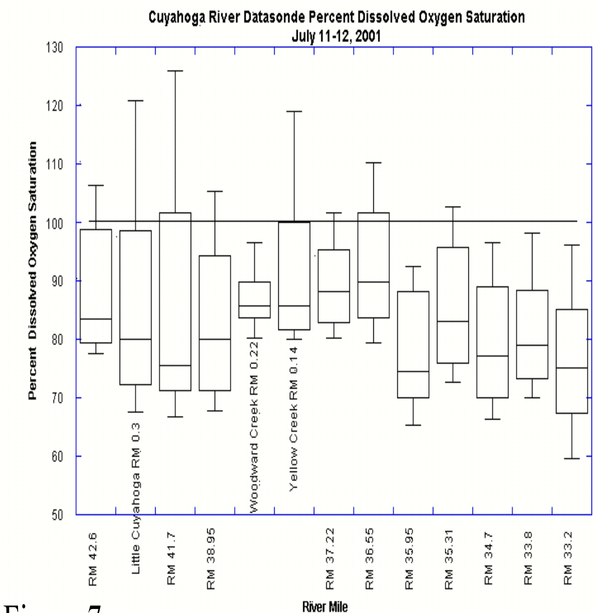


Figure 7

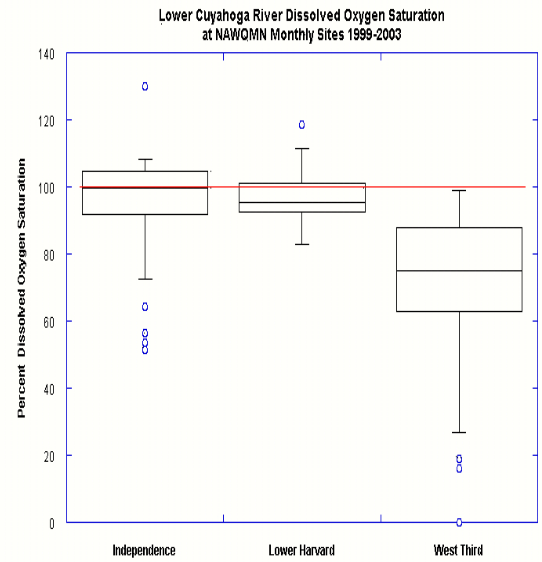


Figure 8

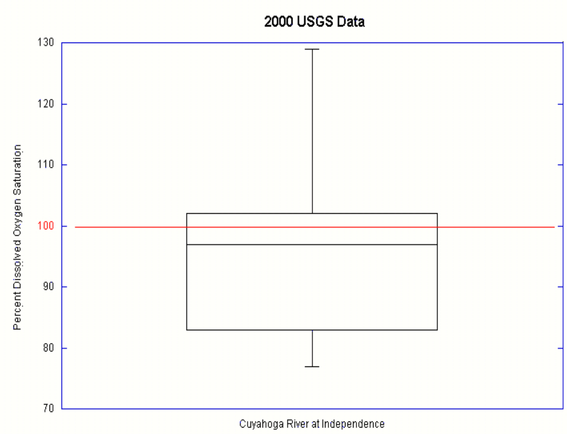


Figure 9

94.88% at West 3rd Street. Although measurements from continuous dissolved oxygen monitors were not available to determine diel changes, the large variation in dissolved oxygen saturations may be a response similar to daylight/nighttime conditions. The lowest dissolved oxygen saturation occurred on June 7 following a brief storm event that increased suspendedsolids up to 109 mg/l which likely would reduce available light below that which is needed for photosynthesis and would thus mimic night time or other low light conditions. At the West third site, suspended solids concentration was 36 mg/l on June 7.

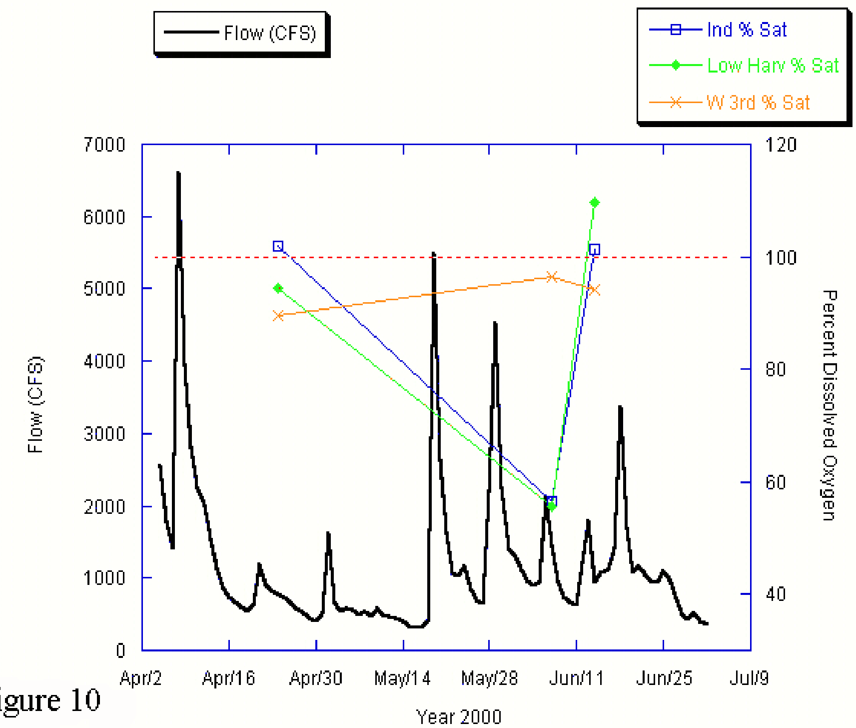


Figure 10

Total phosphorus concentrations are more correlated with lower IBI scores than with lower ICI scores (Ohio EPA, 1999). This pattern is observed in the Lower Cuyahoga River. Non-Attainment in the Lower Cuyahoga is due, in part, to a shift in the fish community away from functional assemblages of intolerant fish species, benthic insectivores and top carnivores (e.g.,darters, insectivorous minnows, redhorse, and esocids towards assemblages of tolerant species, niche generalists, omnivores, and detritivores (e.g., creek chub, bluntnose minnow, white sucker, carp, green sunfish). A summary of the 2000 lower Cuyahoga River biosurvey is shown in Appendix 2. This pattern of the aquatic community is consistant with nutrient enrichment (OEPA, 1999; Lyons, 1992 reported in Simon, 2002). Low fish biomass and high incidences of DELT anolomolies were found at some locations in the Lower Cuyahoga River which are also correlated with elevated total phosphorus concentrations. While there are some indications of instream toxicity based on discharger bioassays, toxic effects on the fish community are generally revealed across the entire community and are not targeted to specific assemblages. Thus toxic effects have a significant effect on a stream's fish biomass (MIwb), but not necessarily on their community structure (IBI). If toxicity were the only agent acting on the fish community, it would be expressed in the MIwb scores, not the IBI scores. The Cuyahoga River MIwb scores are closer to the ecoregion criteria than are the IBI scores.

The Cuyahoga River ship channel (lacustuary) has been defined as highly eutrophic based upon fish ominvore composition (Thoma, 2002). The Lake Erie nearshore fish communities of Lorain and Cuyahoga Counties indicate mesotrophic conditions. The near shore and lacustuary conditions in the Grand and Ashtabula Rivers in adjoining eastern counties are not considered eutrophic. Since the Cuyahoga River is, among others, a significant discharger to near shore Lake Erie in Cuyahoga County, it is assumed that the river is a significant contributor to the nearshore enriched conditions. Highest relative loading from WWTPs occur during lower flows and, therefore, contaminants not normally associated with suspended sediment are negatively correlated with flow. This is illustrated in Figure 11 using nitrate-nitrite. These compounds are normally associated with advanced treatment of domestic wastes. Direct runoff components

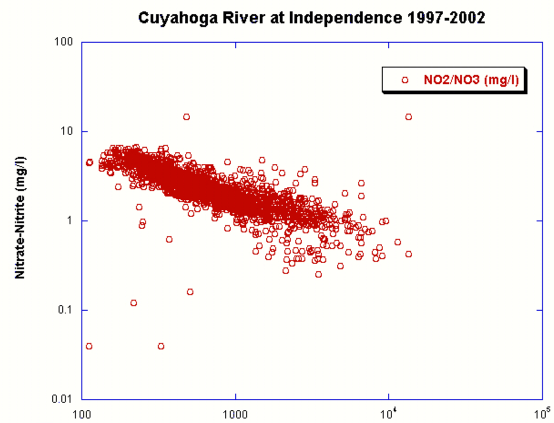


Figure 11

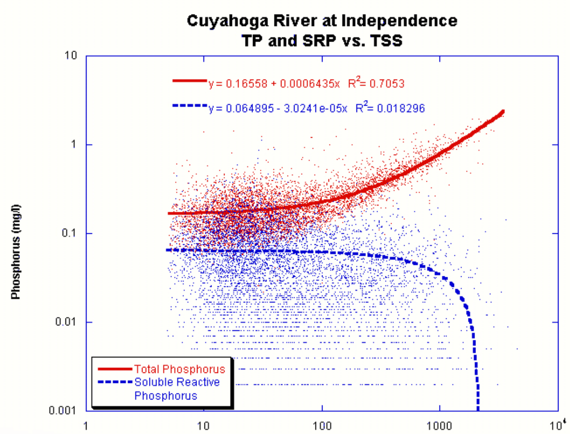


Figure 12

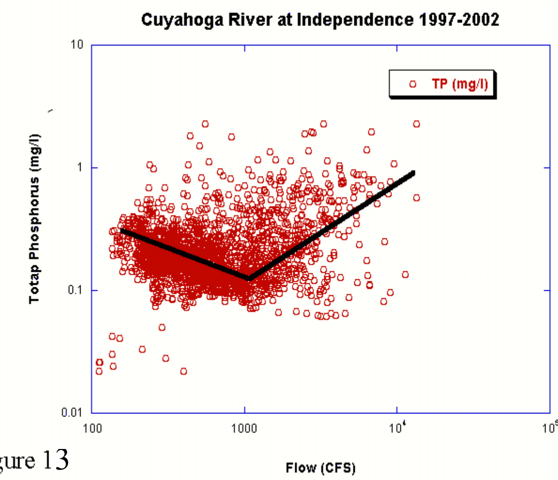


Figure 13

from landuse does not generally contribute to nitrate nitrite loadings although agricultural drain tiles can be a source of nitrate-nitrite, albeit delayed from the precipitation event. Thus, these compounds are highest under low flow conditions and are diluted during high discharge events to lower concentrations. This pattern repeats itself for phosphorus until runoff from the land is sufficient to carry phosphorus laden sediment from disturbed land or eroded stream banks into the river. Another source of phosphorus under elevated flows could come from CSO discharges. When these events occur, the loading from nonpoint sources overwhelms the dilution of the WWTP effluent under higher flows and total phosphorus in the system inceases (Figure 13). The data from Heidleburg (Heidleburg College, 2002) indicates relatively high SRP (presumably from WWTP discharges) under low flow, subsequent dilution of SRP under moderate flow and high TP/low SRP under high flows (presumably from sediment). This is shown in Figure 12 where TP is positively correlated with suspended solids ($r^2$ = 0.7053) and SRP is not ($r^2$ =0.0183). Thus both non-point and point source controls are needed to reduce total phosphorus loadings. WWTPs usually discharge total phosphorus in the dissolved form which is more readily available for biological activity. Dissolved phosphorus, combined with low flows that generally occur with higher temperatures and less turbidity, are much more likely to produce excess algal growth. Control of SRP has more benefit to Lake Erie, both in load and availability.

Annex 3 of the Great Lakes Water Quality Agreement states that the limit for WWTPs discharging more than 1 million gallons per day to Lake Erie should be a target of 0.5mg/l. However, a supplement to Annex 3 does some recalculations of anticipated phosphorus loads when all Lake Erie WWTPs are discharging at 1mg/l total phosphorus. The United States needed to achieve an additional reduction of 1700 metric tons per year. The supplemental language allows that some of this reduction could come from non point source programs. So, the accepted phosphorus reduction strategy over the years has used the standard of 1mg/l of total phosphorus for all WWTP >1 MGD, the phosphorus detergent ban and agricultural and urban NPS management practices. Phosphorus concentrations in Lake Erie and loadings to the lake were achieving goals until recently when increasing concentrations and blue/green alagae blooms in some areas, including nearshore Cleveland, were observed. It is unclear if the changes are related to zebra/quagga mussels, low lake levels or increased loadings from the tributaries.

**Summary and Conclusion**

Phosphorus is the limiting nutrient in the Cuyahoga River system. Cuyahoga River total phosphorus concentrations are elevated compared to reference values in the EOLP ecoregion, which creates enriched waters. Dissolved oxygen measurements, fish community responses and direct observation of aquatic plant communities are consistent with responses of aquatic systems to enriched nutrient conditions. Enrichment often contributes to non-attainment of Ohio's Water Quality Standards. Both non point and point source controls are needed to reduce phosphorus concentrations and loadings to the Cuyahoga River system in order to reduce eutrophication of the system.

USGS Water Quality Data 2000

| DATE | Time | DO | Temp | % Sat | NO2-NO3 | Total P | Diss P |
|---|---|---|---|---|---|---|---|
| 5/3/2000 | 8:30:00 AM | 8.5 | | 82 | | | |
| 5/4/2000 | 8:30:00 AM | 8.1 | 15.2 | 83 | | | |
| 5/11/2000 | 3:00:00 PM | 7.4 | 16.9 | 77 | | | |
| 5/18/2000 | 7:30:00 AM | 7.5 | 18.2 | 82 | | | |
| 5/24/2000 | 3:00:00 PM | 10 | 18.5 | 109 | 1.53 | 0.193 | 0.061 |
| 7/7/2000 | 9:35:00 AM | 8.1 | 21 | 91 | | | |
| 7/11/2000 | 12:00:00 PM | 8.2 | 22.7 | 99 | | | |
| 7/12/2000 | 8:00:00 AM | | | | | | |
| 7/17/2000 | 1:45:00 PM | 7.5 | 22.2 | 100 | 2.37 | 0.152 | 0.114 |
| 7/25/2000 | 3:20:00 PM | 10.7 | 23 | 129 | | | |
| 9/6/2000 | 10:00:00 AM | 9.1 | 20.4 | 102 | | | |
| 9/11/2000 | 2:45:00 PM | 8.4 | 22.6 | 99.29 | | | |
| 9/18/2000 | 2:15:00 PM | 10.6 | 18.5 | 115.54 | 3.5 | 0.3 | 0.242 |
| 9/25/2000 | 12:50:00 PM | 9.3 | 16.3 | 95 | | | |
| 9/26/2000 | 11:30:00 AM | 9.3 | 15.2 | 93 | | | |

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