Appendix I: Response Summary to Public Comments on the Nimishillen Creek TMDL

Authors of Written Comments on the Draft Nimishillen Creek watershed TMDL Report

#	Date Received	Name	Organization
1	July 10, 2008	David Burchmore	City of Canton
2	July 7, 2008 (via email)	Larry Antosch	Ohio Farm Bureau
3	July 10, 2008 (via email)	Boris Slogar	Muskingum Watershed Conservancy District
4	July 4, 2008	Chris Borello	Concerned Citizens of Lake Township
5	July 2, 2008 (via email)	Mary Gibson	Citizen
6	July 2, 2008	Kathy Magel	Citizen

Following each comment the number in parenthesis denotes the specific commenter listed above.

The City of Canton submitted a number of comments on the TMDL. In order to avoid repetition of responses, the comments are grouped into four general areas; legal issues related to TMDL development, comments on water quality models utilized in the TMDL, the report and its format, and the applicability and appropriateness of nutrients, specifically phosphorus, as a pollutant. Comments from other groups or individuals are likewise separated by topic.

Legal Issues

Comment (1):
As an initial matter, the City objects to the development of a TMDL for total phosphorus for the Nimishillen Creek Watershed (NCW) because the it is not based on an applicable water quality standard promulgated in accordance with the State of Ohio's administrative procedure requirements, as required by the relevant provisions of the Clean Water Act (CWA) and U.S. EPA's implementing regulations. Section 303(d) of the CWA, and U.S. EPA's regulations implementing that provision, expressly require that, for any pollutant other than heat, a "TMDL shall be established at a level necessary to implement the applicable water quality standard." 33 U.S.C. § 1313(d)(1)(C). 40 C.F.R. § 130.7(c)(1) similarly requires TMDLs to be established at levels necessary to attain and maintain applicable narrative and numerical water quality standards. The State of Ohio has not adopted an applicable water quality standard for phosphorus and, therefore, the phosphorus TMDL for the NCW violates the CWA § 303(d) and U.S. EPA's implementing regulations.

Section 3.1 of the Draft TMDL ("Target Identification") indicates that, "[w]hile Ohio EPA does not currently have statewide numeric criteria for nutrients, potential targets have been identified in a technical report titled "Association Between Nutrients, Habitat, and the Aquatic Biota in Ohio Rivers and Streams (Ohio EPA, 1999)." Draft TMDL at 31. The draft also acknowledges that "these nutrient targets are not codified in Ohio's water quality standards." Id.

More importantly, the Ohio EPA guidance document entitled "Legal and Technical Basis for Nutrient Target Values Used in TDML Projects" (Ohio EPA, Water Quality Standard Guidance 4, November 27, 2000), clearly states that the target concentrations or "goal levels" identified in

the Association document are only "suggested guidelines," and that "some waters attain aquatic life criteria at higher levels." "Legal and Technical Basis," at 4. They are "initial target concentrations only and not codified in regulations," and they must be used with recognition of "the possibility of achieving aquatic life use attainment a concentrations in excess of the target values." Id. at 5. Because the "target values" identified in the Association document and utilized in the Draft TMDL have not been shown to be "necessary" to implement the applicable biological criteria for the Nimishillen Watershed, as a matter of law they cannot serve as the basis for the proposed TMDL for total phosphorus.

In its original identification of pollutants suitable for TMDL calculations, U.S. EPA stated that "TMDLs can only be calculated for water bodies and pollutants with a specified numerical limit based upon approved ambient water quality standards. Such numerical limits may be specified in the water quality standards or may be based upon the level of control necessary to prevent the violation of a quantitative or nonquantitative water quality criterion." "Total Maximum Daily Loads Under the Clean Water Act," 43 Fed. Reg. 60662, 60665 (December 28, 1978). Because the "target values" for total phosphorus used by Ohio EPA are neither specified in Ohio's water quality standards nor "necessary" to prevent a violation of the applicable biological criteria, they do not meet this requirement.

Comment (1):
As an alternative legal justification for the proposed phosphorus TMDL, Ohio EPA states that "excess concentrations" of nutrients may also fall under the prohibitions in OAC § 3745-1-04(D) or (E). OAC § 3745-1-04(D) states that all waters shall be free from nutrients "in concentrations that create nuisance growths of aquatic weeds and algae." OAC § 3745-1-04(E) provides that all waters shall be free from substances in concentrations that are "harmful" to aquatic life. However, Ohio EPA has never defined the level of phosphorus that will result in "nuisance growths" of weeds and algae, and it has never defined the level that is "harmful" to aquatic life. To the extent that a State may use a methodology or procedure to "translate" a narrative criterion into a numeric criterion or endpoint "target" for purposes of establishing a TMDL: (a) the methodology or procedure must be scientifically defensible; (b) the State must adopt the methodology or procedure in the applicable WQS, in accordance state administrative law requirements for the promulgation of such regulations; and (c) the State must adopt the "target" in the applicable WQS, in accordance with state administrative law requirements for the promulgation of such regulations.

The draft phosphorus TMDL for the NCW meets none of these requirements and therefore, if adopted, it would be in violation of CWA § 303(d), U.S. EPA's implementing regulations, and U.S. EPA guidance on the development of TMDLs for nutrients. State Courts in South Carolina, Tennessee and West Virginia have held that their state agencies acted improperly in establishing TMDLs or setting permit limits using similar approaches, because the target values being used had not been formally promulgated as rules in accordance with state administrative law requirements.

Comment (1):
In a recent decision, the D.C. Circuit Court of Appeals has ruled that the plain language of the CWA requires that all TMDLs must be expressed in daily terms, and not as monthly or seasonal averages. Friends of the Earth v. EPA, 446 F.3d 140 (D.C. Cir. 2006). "Nothing in this language even hints at the possibility that EPA can approve total maximum 'seasonal' or 'annual' loads. The law says 'daily.' We see nothing ambiguous about this command. 'Daily' connotes 'every day.' Jd. at 144.

In spite of this clear mandate, the Draft TMDL states, at 58, that "it is the long-term, or chronic, phosphorus load that is directly related to the degradation of water quality. For this reason TMDLs are developed on an annual basis" (emphasis added). With regard to the 1.0 mg/l limit proposed for all wastewater treatment plants in the watershed with design flows at or above 100,000 gallons per day, including the City of Canton POTW, the Draft TMDL further states that, "applied annually, this limit should provide ample instream nutrient reduction in order to make some improvements to aquatic life throughout the watershed" (emphasis added). The City submits that this manner calculating and expressing a TMDL for phosphorus on the NCW does not meet the plain language of the CWA or the dictates of the D.C. Circuit Court of Appeals in the Friends of the Earth decision.

Response

The TMDL established for phosphorus is meant to address impairment of aquatic life use as well as narrative or free from water quality standards found in OAC Rule 3745-1-04.

While Ohio has adopted numeric biological criteria for aquatic life use and has further adopted a number of chemical criteria for various pollutants to protect aquatic life, Ohio has yet to adopt a numeric chemical criteria for phosphorus to protect aquatic life.

However, Ohio EPA disagrees with the commenter that the absence of a specific chemical criteria precludes Ohio from developing a TMDL to limit phosphorus in the face of evidence that phosphorus is causing an impairment to aquatic life use. US EPA not only supports such an approach, it successfully defended an approval for similar TMDLs that the State of New York established for phosphorus in Natural Resources defense Council et al v. Muszynski 268 F.3d 91 (US Ct of App., 2nd Circuit, 2001).

In that case, the State of New York established TMDLs for phosphorus to address nuisance blooms of algae to protect a drinking water use. New York had not promulgated a chemical water quality standard for phosphorus to protect a drinking water use. Rather it had a narrative standard to prevent growths of algae, weeds and slimes that would impair the water for their best usages. This is essentially the same approach that Ohio has taken with this and many other TMDLs related to nutrients.

The Court found that you can set a numeric target for a narrative standard, as long as it is explained how it was done and why it is valid. In the absence of data regarding what levels would be needed to protect the drinking water use from excessive phosphorus, New York simply used a number that had been developed to protect the recreational use. They did this as an interim step recognizing that they may need to implement a tougher standard if this proved ineffective. This was approved by US EPA and upheld by the Court.

In the case of the TMDL for the NCW, Ohio used a document entitled “Association Between Nutrients, Habitat, and the Aquatic Biota in Ohio Rivers and Streams (Ohio EPA, 1999)" to guide its establishment of loads for phosphorus. The document was developed based on years of data and observations on the effects of nutrients on aquatic life in Ohio. While the commenter correctly points out that this is simply a guidance document and that there is the possibility of achieving aquatic life use attainment at concentrations in excess of the target values, Ohio EPA’s use of the

guidance document as applied to the field data collected and analyzed in the NCW, is an appropriate, scientifically defensible method of developing target concentrations.

Last, notwithstanding the guidance that the commenter has pointed to relative to the need for the guidance/methodology to be promulgated in rule prior to use in the development of TMDLs, US EPA has not taken the rigid interpretation of the guidance as suggested by the commenter and has not raised this as an issue in approving previous TMDLs utilizing the same methodology. Ultimately, the public, as evidenced by the comments received, does have extensive opportunities to comment not only on the TMDL but future actions, like NPDES permits, which will implement plans set out in the TMDL.

Daily loads are indeed developed for the Nimishillen Creek watershed for the total phosphorus TMDLs. Tables 5.1 and 5.2 on page 66 of the draft report show the existing conditions and implementation scenarios for abating total phosphorus problems on a kilogram per day basis.

U.S. EPA addressed this issue in a memorandum released on November 6, 2006 (Establishing TMDL “Daily” Loads in Light of the Decision by the U.S. Court of Appeals for the D.C. Circuit in Friends of the Earth v. EPA, et al., No. 05-5015, (April 25, 2006) and Implications for NPDES Permits):

EPA recommends that all TMDLs and associated load allocations and wasteload allocations be expressed in terms of daily time increments. In addition, TMDL submissions may include alternative, non-daily pollutant load expressions in order to facilitate implementation of the applicable water quality standards.

The report includes both daily loads and other time increments and explains the rationale for the various expressions

Water Quality Models Utilized in the TMDL

Comment (1):
The modeling sections of the TMDL also suffer from incomplete presentation of the supporting data. The "observed" data used for calibration and verification are not presented in a fashion where the collection methodology, QA/QC and other validation steps can be readily reviewed. If those data exist in some other documents they should be appended to the TMDL so that they can be reviewed by an outside observer.

The model used is an appropriate tool for allocating point source loads in steady state conditions on a stream but is not intended to reflect the dynamic year round conditions observed in northern Ohio. As such the loading estimates derived by the model predict resultant concentrations at a single set of flow conditions for each model run. Without running all of the possible flow conditions the model cannot estimate actual instream concentrations, and though it appears to calibrate very well upstream of the Canton WWTP the model overestimates downstream phosphorus concentrations in both the calibration and verification plots.

The model calibration for nutrients appears to have been performed with a single set of data collected in August of 2006 (which is not included in the TMDL except in the graph) and the

verification of the model was performed with a smaller set of grab samples collected in September of 2006. The report acknowledges that the model verification data set was probably inadequate. Given this small calibration and verification sample size the reliability of the model to predict what occurs at the two sites downstream of the Canton WWTP is suspect. The limited data presented suggests that the model possibly overestimates the resultant concentration by more than 20%. The modeling section of the report should contain some estimate of the error associated with the model estimate in terms of accuracy to real-world conditions. Given the small sample size the model is not as robust as are the conclusions drawn from it.

These comments have focused primarily on the relationship of the model to the nutrient phosphorus. The dissolved oxygen model is also supported by data that is not included for review in the TMDL report. Since that data and the predictions of the dissolved oxygen model also relate to whether or not phosphorus is a cause of non-attainment in the Nimishillen, detailed presentation of all dissolved oxygen data including all QA/QC should be included in or attached to the TMDL.

Response:
The TMDL modeling for total phosphorus (T.P.) is developed for a single day. Applying a limit annually to protect aquatic life use determined via modeling 7Q10 low flow conditions is similar to that in determining wasteload allocations for water quality criterion as defined in OAC Chapter 3745-2-05. Furthermore, practical reasons for applying a total phosphorus limit annually are explained in sections 4.3.1 and 5.1. For the Canton WWTP to be required to meet a T.P. limit of 0.4 mg/l (the value determined via modeling necessary to meet the in-stream target) during low stream flows and a higher limit during higher stream flows is viewed as a much less practical approach to meet this TMDL.

This model is run at low flow, 7Q10, summer conditions. The reason for this, and why other flows are not being examined, is explained above. Calibration and validation are considered more than adequate by the best professional judgment of the Ohio EPA modeling personnel. Regarding comments about the model over predicting T.P, as shown in the T.P. calibration and validation plots (Tables 4-4 and 4-7) the model actually slightly underestimates T.P. at the near mouth assessment site. It is at this site that T.P. decisions are being made regarding proposed limits (see Table 5-2 in the report).

An appendix will be added to the TMDL report supplying all of the raw data used in this model calibration, validation and low flow runs.

The QUAL2K model is designed to be calibrated with a single set of data (Chapra, personal communication, April 2005). This model is designed to be calibrated with a single set of data. The dataset used to calibrate the Nimishillen Creek QUAL2K model is very robust. All tributaries and sites in between tributaries were monitored and used in this dataset.

Regarding the comments about model verification, the Nimishillen Creek QUAL2K model is validated following the definition of the term as explained by Reckhow 1983. That is as a “comparison of model results with an independent data set (without further adjustment)”. Statements made in the report regarding lesser quantity and quality of data used for validation relative to calibration overstate the issue; minor revisions have

been made in the final report. To clarify, the calibration dataset is very robust. The validation data is not as robust, but still judged by MAS to be robust enough to be used as a calibration dataset (though here it is only used for validation). Water quality models submitted from consultants to Ohio EPA routinely have much less data used for calibration than either the calibration or validation dataset used for the Nimishillen Creek QUAL2K model. The best professional judgment of the section has determined this validation dataset to substantiate the model's predictive ability of the stream's natural system. Based on this, the quantifiably unsubstantiated comment of the model overestimating T.P. concentrations by greater than 20% is refuted.

The QUAL2K model does not contain an estimate of error quantification tool, nor is one typically used by the MAS.

Report and its Format

Comment (1):
Typically Ohio EPA uses a Technical Support Document (TSD) produced within the last 5 years to define the relationship of impaired conditions observed within a study basin. The Nimishillen Creek TMDL is supported by data collected over the period 2003 through 2005 presented in summary fashion. The detailed standardized presentation normally found in a TSD has not been prepared by Ohio EPA. Given the legal discussion of the status of phosphorus limits above, the absence of a scientifically valid presentation of the data for the Nimishillen Creek (as is normally found in a TSD report) does not support the selected "target" for phosphorus chosen and modeled in this watershed

Comment (1):
The data in this TMDL is in some instances insufficiently documented and in several instances poorly presented. The "raw" data presented in the appendices does not appear to be complete, for example, data cited in the biological attainment table (Appendix A) does not appear to be entirely included in Appendix G where the macroinvertebrate raw data is listed. The Appendix A table shows 40 ICI "scores" and only 32 data sheets are included. The chemistry data presented in Appendix D does not include the max, min and average data for dissolved oxygen presented in figure 4-3 and 4-6.

Comment (1):
The graphic presentation from upstream to downstream of various scores and metrics varies throughout the TMDL making interpretation of upstream to downstream trends difficult. Some of the graphs and tables show the mainstem of the Nimishillen in the middle of the set of data (Figure 2-17, 218, 2-19) Others show the mainstem at the bottom of the figure (Figure 3-1) but in reverse river mile order. These inconsistencies make interpretation of the upstream downstream relationships difficult and should be corrected. A standardized upstream to downstream presentation of the data should be established and carried consistently through the document.

Comment (2):
I would like to commend Ohio EPA on the use of graphics to portray water quality conditions in the draft TMDL report for Nimishillen Creek. Graphics are easier for the reader to understand than tables of numbers and their inclusion in the report really helps. I have attached updated

text for you to use in Section 7.2.5 of the report on page 105. The text represents the current structure and programs at the Ohio Farm Bureau and the Ohio Livestock Coalition. Feel free to contact me if you have any questions.

Response
Ohio EPA, as well as other external readers of the report feel that the presentation of data in the report is adequate.

A TSD report is not required to be developed as a precursor to a TMDL. The need for a TMDL in the Nimishillen Creek watershed is based on results of a comprehensive survey conducted from 2003 to 2005. This is the same data which would have been used should a TSD have been developed. Recognizing that a TSD had not been prepared for the Nimishillen Creek watershed, additional effort was dedicated to providing a summary of water quality information in Section 2, as well as including data from the survey in the appendices.

Historical trends are included when they can demonstrate improvement or decline in a watershed, such as the dramatic changes in the East Branch of Nimishillen Creek. A TMDL however, is focused on the current attainment status and improvement of impaired areas.

The ICI data was reviewed by our Columbus office and several clarifications were made in the Attainment Table in Appendix A.

Nutrients

Comment (1):
Even if Ohio EPA had a valid legal and technical basis for the proposed phosphorus TMDL, its development at this time is premature in light of the status of Ohio EPA's current work on nutrient criteria development. The City understands that the Agency is evaluating the results of a four-year study of data collected from Ohio rivers and streams designed to provide the empirical evidence necessary to develop scientifically defensible nutrient criteria, and that the Agency is still in the process of collecting data for larger streams. The study is evaluating the relationship between nutrients and productivity, and while it found that increases in total phosphorus and total inorganic nitrogen can result in increases of benthic chlorophyll a, the amount of canopy cover sometimes mediates the impact of nutrients by acting as a limiting factor. Canopy cover also acts as a limiting factor on diel swings of DO that can result from increased levels of chlorophyll a. Consequently, the Agency is considering whether a weight of the evidence approach would be appropriate for implementing nutrient criteria, with biological impairment triggering an evaluation of nutrient concentrations, DO swings and chlorophyll a concentrations to determine whether nutrients are contributing to the impairment before the numeric criteria are applied.

This procedure would be closer to an effects-based approach to nutrient criteria development than the reference site approach used to derive the "target values" in the Association document. Consequently, it is uncertain what limits would need to be imposed to ensure biological attainment in the NCW. It is unreasonable to require the City of Canton and other POTW dischargers in the NCW to expend substantial resources to implement controls that may have to be redesigned in a few years when Ohio EPA promulgates a final numeric criteria for phosphorus.

Comment (1):
The TMDL document does not adequately demonstrate any relationship between the nutrient phosphorus and observed biological impairment in the Nimishillen Creek. Furthermore, the evidence for impairment is neither clearly nor completely presented.

Comment (1):
The TMDL presents two parallel tracks of evidence for causes of impairment to the biota. Land use and the resultant instream habitat and "nutrient" impairment are both postulated as causes of impairment to fish and macroinvertebrate communities. Since many of the impaired sections of the watershed are upstream of the point source loads for phosphorus there appears to be stronger evidence that habitat conditions may be the proximal cause of most if not all of the biological non-attainment. Absent the detailed evaluation normally presented in a TSD report, the attribution of causes of impairment to specific stream reaches is not at all clear in the TMDL.

Comment (1):
The TSD report normally reports on the long term trends observed in a watershed. While figure 220 of the TMDL shows a trend for ICI score changes in one of the upper tributaries to the Nimishillen (where that trend has improved), no other historic comparisons are presented for other reaches or for other scores reported in the TMDL. The TSD report would normally document the trends for all of the biological indices so the pattern of recovery in the entire stream can be understood. Other sections of the stream might be recovering at a different rate than the one example presented and perhaps the downstream reaches which are subjected to cumulative stressors might recover at a slower rate. It is quite possible that the entire stream may be on a path towards attainment, even at current nutrient loads, but the data presented in the TMDL does not permit any analysis of those historic trends. A figure comparable to Figure 2-20 should be prepared and presented for all stream reaches and all biological and habitat scores.

Comment (1):
Unlike many other TMDLs that have previously been developed by Ohio EPA and approved by U.S. EPA, the Draft TMDL for the NCW does not contain an adequate implementation plan that satisfies either the requirements of the Ohio TMDL regulations or the U.S. EPA guidance on this topic. In particular, the Draft TMDL needs to include a description of the specific steps required for the development of controls needed to meet the proposed effluent limitations for POTWs and a timeline for implementing those measures, as well as alternative mechanisms for compliance such as source reduction and trading programs. For example, the TMDLs for the Upper Auglaize River Watershed (approved by U.S. EPA on September 23,2004) and the Upper Little Miami River Watershed (approved by U.S. EPA on July 2, 2002) contained sample compliance schedule language for permits designed to achieve the total phosphorus wasteload allocations associated with the TMDL for each individual permit holder in the watershed.

Comment (1):
While Ohio EPA historically has relied on the Associations document as a link between potentially excessive phosphorus concentrations and demonstrated impairment in aquatic life (albeit based on weak correlative evidence), current work by Ohio EPA staff on this relationship does not focus on these indirect effects to the fish community but rather focuses on more directly attributable relationships to primary production (measured as the plant pigment chlorophyll) and the related changes in observed dissolved oxygen concentrations. No chlorophyll data was reported within the data presented for this TMDL. The dissolved oxygen data included in the TMDL report is limited to a few samples included in the Appendix D and

some data reported on model calibration and verification graphs (figures 4-3 and 4-6) in the TMDL. The source data for those graphs does not appear to be included in the TMDL document in any other form.

Comment (1):
Bob Miltner of Ohio EPA has recently presented the results of his efforts to more clearly define the relationship of "excessive" nutrient concentrations and impairment of the Ohio Biological Criteria, in an outline entitled "Empirical Evidence Supporting Development of Nutrient Water Quality Standards for Rivers and Streams." His efforts, as mentioned above, indicate that a site-specific weight of evidence approach be used to evaluate whether a nutrient criteria is indicated for a watershed. His work suggests that excessive nutrient would support potentially excessive algal growth. He measures that relationship by sampling algal pigment (chlorophyll a) in samples scraped for natural substrates. In a relatively small set of samples he has defined several relationships between nutrient concentration and pigment concentration. He is in the process of trying to refine the definition of threshold effects where the resultant algal growth causes a nuisance condition. One of the strongest lines of evidence in his presentation is the day night change in dissolved oxygen concentration that results from "excessive" algal growth. Tentatively he has defined a threshold where if nighttime dissolved oxygen drops below 5 or 6 and if the magnitude of the change in dissolved oxygen is greater than 5- 7 mg/l day then nutrient enrichment should be investigated as a possible source of biological impairment. Figures 4-3 and 4-6 of the TMDL show that neither observed nor modeled dissolved oxygen in the Nimishillen Creek downstream of the Canton WWTP exceeds these thresholds. Figure 4-6 shows "observed" diurnal changes in dissolved oxygen upstream of the Canton WWTP to be greater than those observed downstream. If the measured and modeled dissolved oxygen does not demonstrate the effect that, according to Mr. Miltner's work, should be observed if nutrients were a cause of biological impairment, then the identification of phosphorus load as a cause of impairment is not supported by the data presented for this site.

Comment (1):
The TMDL relates biological impairment to nutrient loading solely on the basis of the weak correlations in the Associations document. While the biological indices in the TMDL certainly show areas where both fish and macroinvertebrate scores do not meet accepted criteria, there is no demonstrated relationship between those areas of non-attainment and the point source loads of the nutrient phosphorus. Many of the areas where both fish and macroinvertebrates do not meet the appropriate biological criteria and where Nutrients are listed in Table 4.1 as the source of impairment are upstream of the Canton WWTP discharge. The attribution of nutrients as the cause of that impairment is not substantiated by the data presented in areas either upstream or downstream of the point sources. However, it is impossible for nutrient loads from the downstream Canton WWTP point source to substantively affect upstream biological communities. The report attributes nutrients to impairment at RM 11.1 on the Nimishillen (2 miles upstream of Canton WWTP) on table 4.1 where the reported observed and modeled phosphorus concentrations are less than the target concentrations for phosphorus used in the TMDL. Clearly attainment of the target concentration at that site has not resulted in attainment of biological criteria. That fact strongly suggests that other stressors such as habitat may be responsible for limiting the biological community at RM 11.1 and that the assignment of nutrients as a cause of impairment was incorrect. The TMDL report is therefore inconsistent in applying the attribution of nutrients as a source of impairment. The proximal stressor for limiting attainment may be habitat or may in fact be some factor not addressed in the TMDL.

Comment (1):
The TMDL does not clearly demonstrate that phosphorus discharge from point sources is a cause of impairment in the Nimishillen Creek. The attribution of impairment of biological criteria

in this stream to point source discharge of phosphorus is not scientifically defensible. The discussion of habitat conditions and other sources of pollution presented in the TMDL seem to be as or more likely to be the proximal causes of nonattainment throughout many portions of this basin. The evidence for nutrient impairment is not consistent with Ohio EPA's definition of "Empirical Evidence Supporting Development of Nutrient Water Quality Standards for Rivers and Streams" as presented by Bob Miltner of Ohio EPA. Given those technical facts we would suggest that it is not appropriate for a load for phosphorus be calculated for the Nimishillen Creek as part of the TMDL program.

Response:
Ohio EPA respectfully disagrees with the above comments.

Initially it is important in this response to define the place of phosphorus in the TMDL and water quality science in general.

Phosphorus is a pollutant. The Clean Water Act defines a pollutant as:
§ 1362. Definitions
(6) The term "pollutant" means dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt and industrial, municipal, and agricultural waste discharged into water. This term does not mean

(A) "sewage from vessels or a discharge incidental to the normal operation of a vessel of the Armed Forces" within the meaning of section 1322 of this title; or

(B) water, gas, or other material which is injected into a well to facilitate production of oil or gas, or water derived in association with oil or gas production and disposed of in a well, if the well used either to facilitate production or for disposal purposes is approved by authority of the State in which the well is located, and if such State determines that such injection or disposal will not result in the degradation of ground or surface water resources.

This definition is also echoed in the Title 40 of the Code of Federal Regulations:
§ 122.2 Definitions.
Pollutant means dredged spoil, solid waste, incinerator residue, filter backwash, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials (except those regulated under the Atomic Energy Act of 1954, as amended (42 U.S.C. 2011 et seq.)), heat, wrecked or discarded equipment, rock, sand, cellar dirt and industrial, municipal, and agricultural waste discharged into water. It does not mean:

(a) Sewage from vessels; or

(b) Water, gas, or other material which is injected into a well to facilitate production of oil or gas, or water derived in association with oil and gas production and disposed of in a well, if the well used either to facilitate production or for disposal purposes is approved by authority of the State in which the well is located, and if the State determines that the injection or disposal will not result in the degradation of ground or surface water resources.

And the Ohio Revised Code:
6111.01 Water pollution control definitions.
(A) "Pollution" means the placing of any sewage, sludge, sludge materials, industrial waste, or other wastes in any waters of the state.

(B) "Sewage" means any liquid waste containing sludge, sludge materials, or animal or vegetable matter in suspension or solution, and may include household wastes as commonly discharged from residences and from commercial, institutional, or similar facilities.
(C) "Industrial waste" means any liquid, gaseous, or solid waste substance resulting from any process of industry, manufacture, trade, or business, or from the development, processing, or recovery of any natural resource, together with such sewage as is present.
(D) "Other wastes" means garbage, refuse, decayed wood, sawdust, shavings, bark, and other wood debris, lime, sand, ashes, offal, night soil, oil, tar, coal dust, dredged or fill material, or silt, other substances that are not sewage, sludge, sludge materials, or industrial waste, and any other "pollutants" or "toxic pollutants" as defined in the Federal Water Pollution Control Act that are not sewage, sludge, sludge materials, or industrial waste.

As well as Ohio EPAs TMDL regulations:
3745-2-02 Definitions.
(49) "Pollutant" means sewage, industrial waste, or other waste as defined by divisions (B) to (D) of section 6111.01 of the Revised Code.

As a pollutant, the TMDL regulations indicate that phosphorus need not be a pollutant with a water quality standard in order to have a TMDL prepared:

§ 130.7 Total maximum daily loads (TMDL) and individual water quality-based effluent limitations.
(c) (1) (ii) TMDLs shall be established for all pollutants preventing or expected to prevent attainment of water quality standards as identified pursuant to paragraph (b)(1) of this section. Calculations to establish TMDLs shall be subject to public review as defined in the State CPP.

As defined, phosphorus (originating from sewage), is a pollutant, and has been determined to be contributing to water quality standard non attainment as measured by the biological community indicies.

As a pollutant, phosphorus is also a nutrient. The literature is very clear that phosphorus and nitrogen are nutrients. As the science and understanding of nutrients in aquatic systems is expanding, it is also very clear that there is a definite distinction between nutrient impacts in lotic and lentic systems. Lakes (lentic systems) have been studied for years, nutrient impacts and sources of impacts are clear. Streams (lotic systems) on the other hand, are hydrologically dynamic and have been a more difficult to characterize, as indicated in your comments. You correctly indicate that indicators of phosphorus enrichment include greater diurnal dissolved oxygen swings and elevated chlorophyll a levels. These however are a result of elevated phosphorus levels. Our biological indices are able to detect impacts to communities, and have indicated that impacts do exist in the Nimishillen Creek watershed.

The literature is beginning to generate some common concepts of how these systems function and respond to increased nutrients.

Due to the short retention times offered by a flowing system, nutrient availability is one important issue. Nutrients from agricultural sources are generally input into streams during periods of rain and snow melt, consequently a time of elevated river flow. The seasonal nature of these discharges, spring and fall, do not completely coincide with the times when plants and algae need nutrients in the growing season. The agricultural phosphorus load also tends to be more particulate-based which is less immediately available. A sewage treatment plant, on the other hand, has a relatively constant discharge all year long. Phosphorus discharged by a sewage treatment plant is also already in solution and more available to ecological systems.

Specific to the Canton WWTP, a comparison was made between phosphorus loadings generated by the WWTP and those measured downstream at Howenstine Road. Canton WWTP flows were used to generate effluent loadings and flows at the Nimishillen Creek gage were used to generate stream loadings. The load data presented in Table I-1 includes only sampling events when both in-stream (Howenstein Rd. sampling site) and effluent data were available for the same day.

As can be seen in Table I-1, the Canton WWTP is the dominant source of phosphorus in the Nimishillen Creek at Howenstine Road.

A comparison of nutrient loadings and flow, based on the Canton WWTPs percentage of each is included in the graph (Figure I-1).

Table I-1. Phosphorus loadings

Date	Stream Flow (cfs)	WWTP Flow (cfs)	Effluent Conc (mg/l)	Stream Conc (mg/l)	Stream Flow (mgd)	WWTP Flow (mgd)	Stream Load (kg/d)	Canton Load (kg/d)	Canton % P Load	Canton % Flow
2/4/1998	128	36.494	2.4	0.36	82.7392	23.59	112.889	214.575	190.1%	28.5%
3/4/1998	203	40.083	2.73	0.35	131.2192	25.91	174.062	268.083	154.0%	19.7%
4/6/1998	128	37.175	2.83	0.44	82.7392	24.03	137.976	257.739	186.8%	29.0%
6/10/1998	110	37.299	2.46	0.66	71.104	24.11	177.860	224.787	126.4%	33.9%
7/15/1998	109	39.975	2.85	0.68	70.4576	25.84	181.583	279.111	153.7%	36.7%
8/5/1998	86	36.835	2.79	0.84	55.5904	23.81	176.978	251.769	142.3%	42.8%
6/28/1999	109	42.342	2.67	0.76	70.4576	27.37	202.946	276.965	136.5%	38.8%
11/22/1999	95	36.417	3.27	0.92	61.408	23.54	214.117	291.738	136.3%	38.3%
2/16/2000	277	44.724	1.94	0.21	179.0528	28.91	142.508	212.564	149.2%	16.1%
8/23/2000	297	49.505	2.66	0.62	191.9808	32	451.116	322.605	71.5%	16.7%
9/6/2000	106	41.213	2.73	0.69	68.5184	26.64	179.182	275.636	153.8%	38.9%
11/27/2000	186	40.578	2.52	0.44	120.2304	26.23	200.496	250.517	124.9%	21.8%
12/11/2000	132	38.382	2.98	0.77	85.3248	24.81	249.003	280.209	112.5%	29.1%
1/10/2001	110	37.856	2.550	0.580	71.104	24.47	156.301	236.490	151.3%	34.4%
3/21/2001	199	41.615	0.910	0.290	128.6336	26.9	141.381	92.775	65.6%	20.9%
5/24/2001	212	43.765	1.670	0.264	137.0368	28.29	137.114	179.056	130.6%	20.6%
7/11/2001	88	39.372	2.380	0.710	56.8832	25.45	153.067	229.564	150.0%	44.7%
11/19/2001	131	38.505	2.660	0.867	84.6784	24.89	278.247	250.926	90.2%	29.4%
1/22/2002	112	38.351	2.520	0.504	72.3968	24.79	138.289	236.764	171.2%	34.2%
5/15/2002	505	55.693	1.410	0.154	326.432	36	190.525	192.380	101.0%	11.0%
7/10/2002	104	37.902	2.380	0.595	67.2256	24.5	151.597	220.995	145.8%	36.4%
9/26/2002	64	34.236	3.250	1.110	41.3696	22.13	174.038	272.586	156.6%	53.5%
11/21/2002	128	40.826	2.680	0.743	82.7392	26.39	232.991	268.049	115.0%	31.9%
12/10/2002	89	36.417	3.080	0.846	57.5296	23.54	184.459	274.787	149.0%	40.9%
3/24/2003	197	48.190	2.090	0.363	127.3408	31.15	175.192	246.742	140.8%	24.5%
5/21/2003	794	60.922	1.600	0.251	513.2416	39.38	488.242	238.800	48.9%	7.7%
7/2/2003	658	61.138	1.820	0.325	425.3312	39.52	523.902	272.601	52.0%	9.3%
8/4/2003	360	60.844	1.570	0.238	232.704	39.33	209.904	234.025	111.5%	16.9%
9/15/2003	137	44.740	2.020	0.524	88.5568	28.92	175.870	221.406	125.9%	32.7%
11/12/2003	262	44.848	2.800	0.273	169.3568	28.99	175.228	307.642	175.6%	17.1%
6/23/2004	274	62.005	2.360	0.315	177.1136	40.08	211.447	358.492	169.5%	22.6%
7/1/2004	203	54.455	2.310	0.334	131.2192	35.2	166.105	308.172	185.5%	26.8%
10/18/2004	202	42.976	2.680	0.631	130.5728	27.78	312.264	282.167	90.4%	21.3%

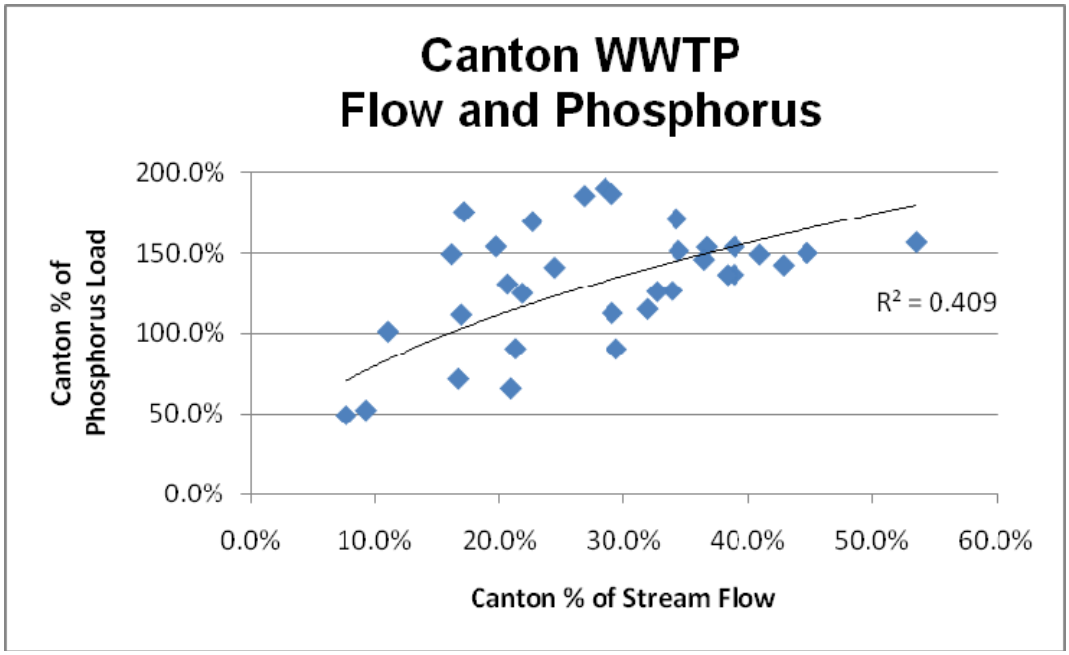

Figure I-1. Flow and loading comparison

The observable trend indicates that as the Canton WWTP comprises a greater percentage of the stream flow (during low-flow periods), it is the major source of phosphorus to the system. A link between stream phosphorus load and source is evident.

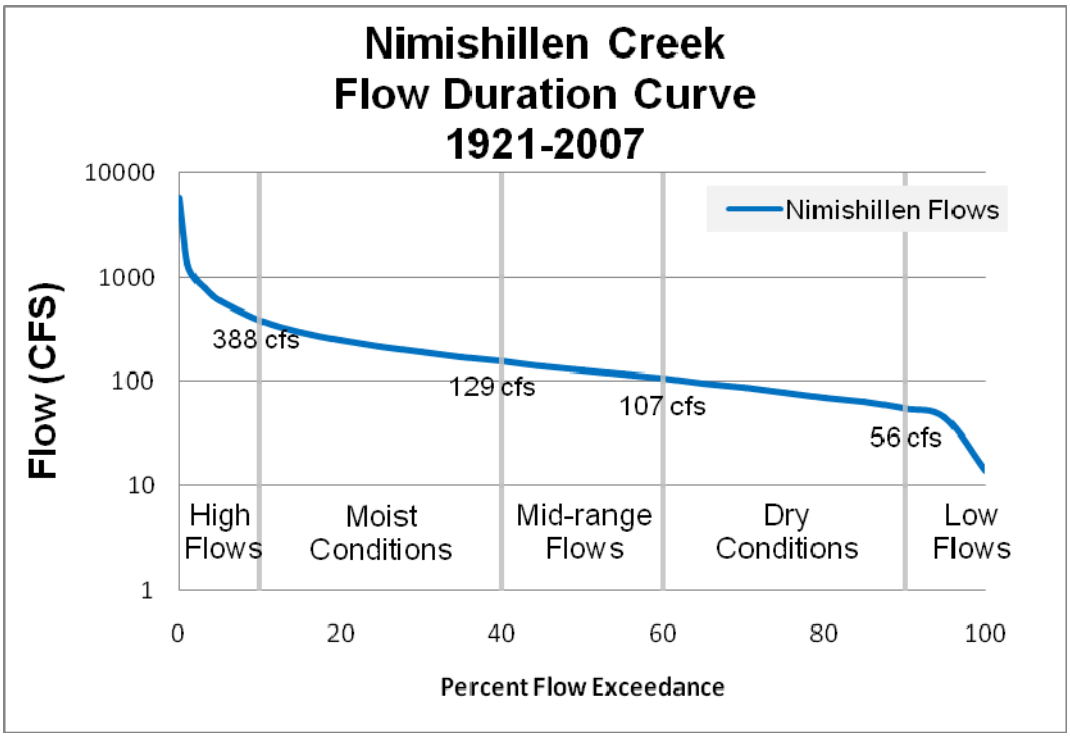

Figure I-2. Flow Duration Curve

Another way of visualizing data which is useful is the load duration curve. A flow curve (Figure I-2) is first generated utilizing historic flows at the Nimishillen USGS gage which has been in service since 1921.

Comparing this to Table I-1 it can be seen that the flow conditions during which samples have been collected are all greater than the low flow conditions. This is in part due to upstream dischargers influencing the gage measurements by artificially raising historic base flows, also seen on numerous other effluent dominated streams.

A load duration curve (Figure I-3) was developed based on the data to visually present phosphorus loadings in relation to allowable load. The allowable loading was based on the TMDL target concentration of phosphorus (0.10 mg/l). As can be seen in the graph, phosphorus loadings are consistently greater than target loadings over a wide range of flows. The Canton WWTP alone is also responsible for loadings greater than the target phosphorus load, independent of any other point or nonpoint upstream sources.

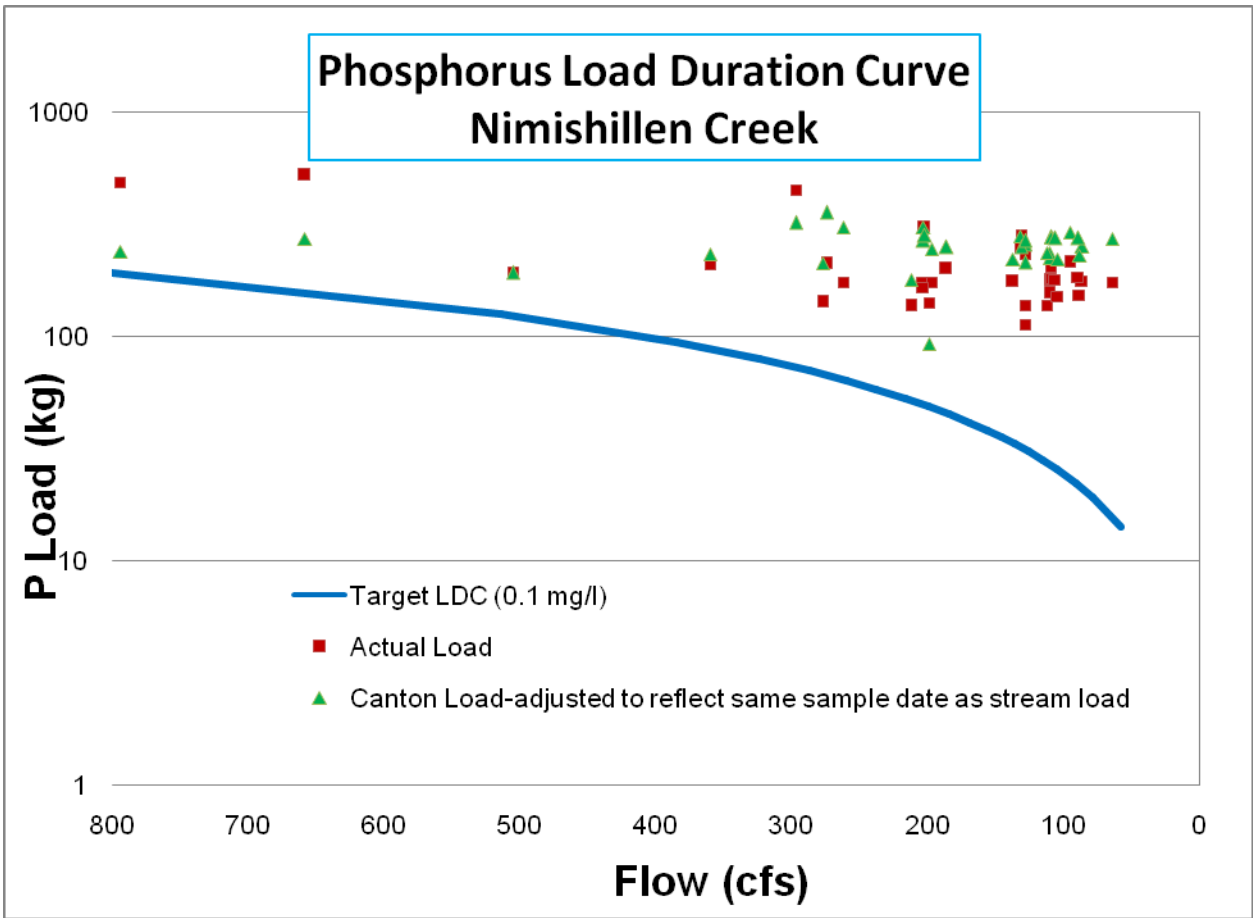

Figure I-3. Load Duration Curve

Phosphorus has clearly been demonstrated to be present in Nimishillen Creek above target concentrations, and the Canton WWTP is also correctly identified as a major source of this pollutant in this TMDL.

Phosphorus has been associated with decreased biological community performance as measured by the Index of Biotic Integrity in Ohio. The statistical association in Ohio between IBI scores and phosphorus was determined to be a statewide concentration of 0.10 mg/l (Ohio EPA, 1999). At no point in the TMDL report does it indicate that phosphorus is the only source of impairment to the watershed.

Ohio EPA has been conducting research into appropriate nutrient criteria and plans to begin a rulemaking to adopt nutrient criteria in the future. There is no guarantee when or even if nutrient criteria will be adopted. In the meantime, streams in the Nimishillen watershed are clearly impaired by nutrients.

The Associations document values are valid for use in TMDLs. Because they are not promulgated criteria, the values are being applied with maximum flexibility. For example, the wasteload value of 0.4 mg/l phosphorus, while technologically feasible to achieve, is not being recommended at this time. Rather, a relaxed value of 1.0 mg/l is being proposed along with a suite of stream habitat improvements that should result in attainment of the biocriteria. The City of Canton is free to experiment with including the factors emerging in the current research, such as canopy cover.

Similar studies outside of Ohio (Wang et. al. 2007) have also demonstrated a link between nutrients and fish community health. The study, which focused on Wisconsin streams, found biological impacts associated with phosphorus concentrations ranging from 0.04 mg/l to 0.09 mg/l. IBI impact associations were found at phosphorus concentrations of 0.06 and 0.07 mg/l. This study demonstrates similar concentrations of phosphorus which impact stream biology.

Other General Comments

Comment (4):

In response to the news article concerning your report to the Stark Health Dept. stating the water quality in the Nimishillen Creek is "very mediocre" (Canton Repository, July 2nd) rating it a 5, I was compelled to contact you yesterday about our long standing concerns about our IEL Superfund Site, which sits in very close proximity to two possible tributaries of your Nimishillen Creek water study area, asking you the question: IS our IEL Superfund site is contributing negatively to the water quality of the Nimishillen Creek Watershed, and worse, if that Nimishillen Creek water, is infact, being drawn into one or more N. Canton public well fields down stream, what are the people ingesting if this surface water quality is questionable? I referred you to the Ohio State report on N. Canton East Maple Well Field, which appeared to suggest up to 90 % of the water from this newer N. Canton well field could be derived from the surface water at and surrounding the Nimishillen Creek. You suggested that I submit comments by July 11th and you would address them. I stresseded to you that we want scientifically verifiable/ peer reviewable answers with supporting materials from actual field data measurements, vs. generic and speculative comments, as has unfortunately been the case in the past, after US EPA reneged upon doing actual field studies using pizometers,(much to the chagrin of Ohio EPA project managers.) Ohio EPA told us that without those measuresments, the true facts about the IEL landfill's relationship with the stream area would remain unknown. Frankly, we believe answers to these data gaps have remained allusive by design all these years.

Given that the IEL sits just north of the Nimishillen Watershed, the precise flow regime offsite, again, has been guesswork at best without the proper field studies/ pizometers once promised. It is our hope that new assessments can be done by OEPA, given your flexibility to order them under the Clean Water Act, if our concerns have the merit we believe. We are therefore providing you two very specific areas of concern with as much detail as possible. Because we have information from numerous sources regarding radiation at IEL, including IEL being listed on a 1994 ODH list as being "confirmed radiologically contaminated" for uranium, along with many EPA validated reports indicating deadly Plutonium at levels higher than the legal health-based action limit set at Rocky Flats, (one expert estimating there could be up to 1/2 ton of Plutonium buried at IEL based on groundwater test results from the PRPs) and findings in 2005 of the very water soluable fission material, Tc 99, in ALL offsite wells tested, we remain deeply concerned about the following possible hydrogeological interconnections that may exist between IEL and the following stream/ditch locations:

AREA OF CONCERN # 1 - Located Southwest of IEL along the Metzger's Ditch, in the vicinity of Cain & Wise Roads that straddle the Stark/Summit County line - KEY - as this area relates hydrogeologically to the headwaters of the Zimber Ditch (aka. "Dockus Ditch" in Greentown/Uniontown north of State St./Altman Rd.) Historical information obtained indicate that farmers from around the turn of the century simply dug ditches in this known wetland area of Cain and Wise Rds. in order to run the water off so they could farm this area. The difference in elevation is so slight as is believed to be of no consequence regarding the flow there turning and heading north on the Summit side, as claimed. Therefore, the concern remains that the headwaters - GROUNDWATER - feeding Zimber Ditch, just south of where Metzger's Ditch horseshoes at Cain and Wise may infact be interconnected. The Remedial Investigation contractor , Dr. Sid Paige, originally told over 200 residents at an IEL meeting that US EPA believed the flow went "exclusively southwest ALONG Metzgers's Ditch." So we are not simply talking about what went out IN the stream from IEL, but along it, in the groundwater flow path. The Canton city well fields along I - 77 are located just south of this area. Please provide scientific field data from pizometers to support any conclusions. NOTE: Please visit our website and see colored elevation map identified as "46 A" that shows IEL, the stream area SW and on down to the N. Canton fields - see color key for elevation drop. http://www.afsc.net/cclt/index.htm SEE REPORTS LINK.

AREA OF CONCERN # 2 - Located just Southeast of IEL - a sand and gravel area just above the intersection of Lake Center and Mogadore Ave. as well as see just due south of this intersection for location of drainage ditch that leads to your Nimishillen Creek. We will mail you a copy of the Stark County Dedicated Ditch Map, showing this area. Former IEL Ohio EPA project manager, Gary Gifford, informed me after going to work for Goodyear against us, (after I submitted information to Mr. Gifford/OEPA I obtained from a company dispatcher who told me "try 5 million gallons from Goodyear alone") .When I called to tell Gary at Goodyear that the 63 foot test well out from IEL's SE corner didn't show much of anything from our very first EPA testing ,(which appeared to contradict Gifford's previous belief about contaminates going Southeast from IEL,) Mr. Gifford responded that he wasn't at all surprised that nothing was found at 63 feet deep. He said, " We believe that it is going out very very light." Also significant was when the Ohio EPA reported in 1991 finding the radiation material , Tritium, at over one million pico curies in a 30 ' private drinking water well, (which one OEPA rep. said was like residents drinking waste water from a nuclear power plant). This finding was from a shallow well located SE of IEL near the Sod Farm, near Mogadore Ave. just north of Lake Center, right near the area of concern. Again, please see map that we are sending on the Stark Dedicated Ditches. USGS 's Dr. Scott Bair at the final 1994 meeting, October 11th, indicated the flow leaving IEL east would CONTINUE under Metzger's Ditch eastward, and then turn and go west , but he could not specify where exactly this turn would take place at. Originally Dr. Bair and

USGS had written about the radial flow from IEL, saying it particularly went "SE" and NW" Indeed, in OEPA's OWN critque of US EPA 's work in approx. 1988, the state questioned the Federal EPA in HOW it could say the flow was east to west, when the regional bedrock dip was to the SE....

Well, just a few months ago, we obtained this new map of the Stark Co. Dedicated Ditches, and it appears to show a ditch leading to your Nimishillen Creek from the IEL area just SE of the dump. IF Gifford was right about it going out "very very light" could this shallow groundwater be feeding the headwaters of this ditch that then appears to go on down to the newer public well field in North Canton at East Maple??? IF US GS was indeed CORRECT all along, coupled with the PRP contractors cited in the OEPA/ 2001 McCambridge report from 1997 and 1998, could materials be leaving IEL to the east, and then get into the ditches headwaters, and then travel south in just days or weeks, down to the N. Canton East Maple Well field completely UNDETECTED?

We will provide with the hard copy letter a signed statement from an eyewitness notorized of seeing the Army bring dozens of stainless steel canisters into IEL. If these break open, could they follow the pathways of concern outlined above? ATSDR's rep.warned me years ago that this national health agency on toxics believed that there "could be things in IEL that could wipe out" the whole town. Even Goodyear's then top consultant in 2001, Rick Laubacher, told me when he called me to learn what I thought about the N. Canton East Maple water scandal that at that time was on the front page of the newspapers regarding the mysterious source of the PCE contamination in this well field (located near your Nimishillen Creek, that the OSU commented could be deriving a large precentage of water from) the front page article was generated by the hysteria created by the Stark Health Dept. officials when they put out water alerts not to drink the water in a 14 square mile area - clear up past the IEL dump to route 619 in Uniontown), ...Goodyear's Laubacher said to me: "we would never know all that the Army dumped."

So, while your study seems concerned with how the fish, flora and fauna are doing along the Nimishillen Creek, frankly, while we care alot about nature and the environment, are first concern is for people, particularly the children who may be drinking, bathing or playing in this water. Should the public water wells in N. Canton, in truth, be designated as "groundwater under the influence of surface water?" Don't we all need to know about these possible ditch and groundwater connections, given EPA has allowed the IEL site, containing greater than 780,000 tons of "hazardous substances" according to your agency's submittal to EPA's Superfund NPL, to continue to flush freely into the watershed which ever way? And, given the supposed "monitoring" of the site done by the polluters now excludes 33 of our test wells, including shallow wells which were located along Metzger's Ditch on IEL's eastern boarder meant to intercept contaminants leaving in that direction, we cannot not even know through proper monitoring what may be leaving the site. One shallow test well now sealed, MW 4s along Metzgers Ditch, previously showed Gross Alpha radiation approx. 10 times over Federal Drinking Water Limits, the Beta radiation was 7 times over the Federal Limits.

Please respond in writing following the formal comment period to CCLT's
P.O. Box 123, Uniontown, Ohio 44685, or my e-mail address.

Response:

Our Division of Emergency and Remedial Response has been involved with the Industrial Excess Landfill for over two decades. Considerable effort has been expended to determine site conditions. Ohio EPA does not believe that there is a connection between the IEL site and the Nimishillen Creek basin.

Our Division of Drinking and Ground Waters and the director have designated the public water system serving North Canton as a ground water source.

For additional clarification on this site please see the attached May 15, 2008 Ohio EPA letter.

Comment (3):
I am writing with enthusiastic support for the draft Nimishillen Creek Watershed TMDL Report on behalf of the Muskingum Watershed Conservancy District (MWCD).

As Nimishillen Creek Watershed is located in te northern portion of the Muskingum River Watershed, the enactment of action plans included in the Nimishillen Creek Watershed TMDL Report will yield benefits for property owners and residents not only in the Nimishillen Creek Watershed, but also downstream and throughout the Muskingum River Watershed. In 2005, the MWCD received approval of the Amendment to the Official Plan of the MWCD and included in that plan of maintenance is the support of and potential partnership of the MWCD with watershed improvement programs, such as the one detailed in the draft Nimishillen Creek Watershed TMDL Report. A section in the Amendment to the Official Plan of the MWCD affirms this: "Watershed management through planning and assistance for local interest groups and private property owners with programs to reduce sediment and pollution."

Flood reduction, sediment load reduction, and water quality improvements detailed in the draft Nimishillen Creek Watershed TMDL Report will lead to benefits for property owners, residents and aquatic life in the watershed, as well as benefits for the system of reservoirs and dams in the Muskingum River Watershed that serve around 2 million residents and the owners of more than 700,000 parcels of property. The MWCD's Amendment to the Official Plan focuses on the maintenance of the system of reservoirs and dams for continued effective performance, and initiatives such as those outlined in the draft Nimishillen Creek Watershed TMDL Report would be a recognized portion of that maintenance if they are enacted. To date, the system of reservoirs and dams has saved more than $7 billion worth of potential property damage from flooding, according to the federal government. Programs that reduce downstream flooding, sediment loads and pollution in the watershed ensure the continued effective performance of the system of reservoirs and dams and aid in maintenance projects.

The MWCD is hopeful to enact its Amendment to the Official Plan in 2009 and will seek to meet with and learn more about potential partnering opportunities and participation with the interested parties in the Nimishillen Creek Watershed.

I would be pleased to discuss partnership opportunities and any questions you may have at your convenience.

Response:
Ohio EPA looks forward to a productive working relationship with the MWCD.

Comment (5):
It would appear that you are finally recognizing the problems of the Nimishillen Creek which has its headwaters in Marlboro Township, home of the sixty poultry buildings owned under the various family names of the Pastores. As I have worked on this issue for the last 15-16 years, this issue does not surprise me. I watched and photographed the excess manure from this operation being put on the fields many times during the years but could not, due to the power of this group get anyone to respond. I think they finally did as now they truck their waste to

Deerfield Farms a little late to stop what happened here. Could the excavation of the land on which the Triple J Farms sit also be a factor, it is adjacent to the what was once a quarry and is now back operating as a strip mine. Another factor could be the CAFO dairies in not only Stark but also closer down to New Philadelphia. Farm Bureau (I am a member) is back trying to get the EPA out of the jurisdiction for these CAFOS. Funny how for years they tried to lead the public to believe they had replaced the OEPA on this jurisdiction. While both the oepa and farm bureau failed to protect my property, I certainly would think that people would be better served by leaving the process in the hands of the EPA. I will note this to my legislators.

Response:
Thank you for your comments. The dominant sources of nutrients in the watershed likely arise from WWTPs as discussed above.

Comment (6):
*just completed reading your findings on the EPA web site. My name is Kathy Magel and I live in North Canton which is one of the cities mentioned in the Repository article. Is it possible you could call me at (*phone number removed for privacy by Ohio EPA*) to interpret some of the data?*

Response:
Ohio EPA did contact Ms. Magel.

References

Ohio EPA. 1999. Association Between Nutrients, Habitat, and the Aquatic Biota in Ohio Rivers and Streams. Ohio EPA Technical Bulletin MAS/1999-1-1. Columbus, OH.

Wang, L. et al. 2007. Linkages Between Nutrients and Assemblages of Macroinvertebrates and Fish in Wadeable Streams: Implication to Nutrient Criteria Development. Environ Management. 39:194–212