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Total Maximum Daily Load (TMDL) Development

- Nutrients (Total Phosphorus) -

For

Town Branch

(Fayette County, Kentucky)

Kentucky Department for Environmental Protection

Division of Water

Frankfort, Kentucky

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This report has been approved for release:

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Jeffrey W. Pratt, Director
Division of Water

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Date

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List of Contributors

Dr. Lindell Ormsbee, Supervisor

Patrick Blandford, Data Analysis and Report Preparation

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Town Branch

Key Features

Project Name:	Town Branch
Location:	Fayette County, Kentucky
Scope/Size:	Town Branch, watershed area 36.5 mi^2
Land Type:	Agricultural, Forest, Residential, and Urban
Type of Activity:	Nutrient Enrichment caused by Urban and Agricultural Runoff, Underlying Geology, and Wastewater Treatment Plant Discharges
Pollutant(s):	Total Phosphorus
TMDL Issues:	Nonpoint and Point sources Critical Condition: Low flow
Data Sources:	USGS Streamflow Monitoring, Commonwealth Technology Inc. Sampling Data, KGS Sampling Data, Watershed Watch Sampling Data, UK Department of Civil Engineering Data
Water Quality Standard:	(Title 401, Kentucky Administrative Regulations, Chapter 5:031, Section 1): In lakes and reservoirs and their tributaries, and other surface waters where eutrophication problems exist, nitrogen, phosphorus, carbon, and contributing trace element discharges shall be limited in accordance with (1) the scope of the problem; (2) the geography of the affected area; and (3) relative contributions from existing and proposed sources.
Control Measures:	Kentucky Watershed Framework Initiative Kentucky Pollutant Discharge Elimination System (KPDES) permits
Summary:	Town Branch was determined as not supporting the designated warm water uses of primary contact recreation (swimming) and warm water aquatic habitat use (aquatic life). Therefore, the creek was placed on the 303(d) list for Total Maximum Daily Load (TMDL) development. Town Branch has first priority status for TMDL development. The creek segment is characterized by depressed dissolved oxygen levels and algal blooms brought on by high loading levels of nutrients. Low-flow conditions exhibit these problems due to point source loading. South Elkhorn Creek immediately downstream from the confluence with Town Branch

is partially supporting of the warm water aquatic habitat use because of nutrients.

TMDL Development: An initial phased total maximum daily load for Town Branch was set so as to meet an allowable in-stream total phosphorus concentration target of 0.5 mg/L in South Elkhorn Creek during the summer period of May 1 through October 31 and a concentration of 1.0 mg/l during the winter period of November 1 through April 30. The in-stream receiving water target was set based on a consideration of stream dynamics of both Town Branch and South Elkhorn Creek as well as phosphorus levels associated with the natural geology in both the Town Branch and South Elkhorn watersheds. The 0.5 mg/L target value of total phosphorus during the low-flow period (when beneficial uses are most at risk) constitutes a significant reduction in current in-stream concentration and therefore loading (down from about 1.2 mg/L based on current conditions). Imposition of a 0.5 mg/L in-stream phosphorus concentration in South Elkhorn requires the reduction of either point or nonpoint phosphorus loads to Town Branch. A detailed monitoring study of Town Branch failed to identify any specific nonpoint sources of total phosphorus (during the critical condition, which is low flow, when beneficial use is most at risk) other than what is perceived to be natural background levels coupled with minor storm water discharge concentrations. The background level was defined as 0.25 and the storm water component was defined as 0.05 mg/L. The only other identified source (and the main source) of phosphorus input into Town Branch is from the Town Branch Wastewater Treatment Plant (WWTP) which typically provides discharges to Town Branch with total phosphorus concentrations of between 1 and 3 mg/L. In order to insure an in-stream phosphorus concentration in South Elkhorn of 0.5 mg/L, the discharge concentration of total phosphorus from the Town Branch WWTP should be restricted to a maximum daily average of 1 mg/L during the summer period and a maximum daily average of 2 mg/L during the winter. The TMDL is 299 lbs/day based on a Waste Load Allocation (WLA) of 250 lbs/day from the Town Branch WWTP and 5 lbs/day from the regulated wet weather storm water (the Lexington Phase 1 Municipal Separate Storm Sewer System), termed MS4. The Load Allocation (LA) is 44 lbs/day, based on 39 lbs/day background and 5 lbs/day from unregulated storm water sources. The storm water component was divided between the MS4 component (part of the WLA) and the LA component per current EPA regulations. However, there is little information upon which to make this delineation and this TMDL is targeting the low-flow critical condition. So, while the TMDL includes a minor runoff component, the focus was on low-flow conditions and the dominance of the Town Branch WWTP during low-flow conditions. This is the condition at which the beneficial use is most at risk. The proposed load reduction is 300 lbs/day. All of the reduction will be achieved through the Town Branch WWTP reduction in total phosphorus loading.

The same entity (the Lexington/Fayette Urban County Government (LFUCG) is the holder of the permits for both the Town Branch WWTP and the Phase 1 MS4. At this point, it is more appropriate to define a reduction for the point source discharger because the point source discharger (the Town Branch WWTP) is responsible for the most significant loading of phosphorus to the stream system during low-flow conditions.

The MS4 component of the WLA (5 lbs/day) and the LA component of 44 lbs/day total phosphorus represents the average conditions present during the lowest six-month period (May - October) within the time period, 1980 to 2000 (21 years). It is based on a concentration of total phosphorus of 0.30 mg/L. Low flow represents the critical condition when beneficial use is most at risk. However, increased flow conditions due to a rain event will result in an increase in load, even if the concentration of total phosphorus remains constant. This material will flush through the system. It is therefore more appropriate to focus on the concentration of total phosphorus instead of the load of total phosphorus. For this system, the target concentration of the MS4 component of the WLA and the LA component is 0.30 mg/L.

Implementation Controls: In order to meet an in-stream phosphorus concentration of 0.5 mg/L in South Elkhorn during the critical (low-flow) summer season and an in-stream concentration of 1.0 mg/L during the winter season, the KPDES permit for Town Branch WWTP shall be modified upon permit reissuance in order to meet a daily maximum total phosphorus concentration of 1 mg/L during the summer season of May 1 through October 31 and a daily maximum total phosphorus concentration of 2 mg/L during the winter months**.** Once issued, the wastewater utility will be allowed two full summer seasons to test and optimize its phosphorus removal systems. Phosphorus monitoring of the effluent will be required during the first two summer seasons, but an enforceable limit would not apply until the third summer season after start-up. Upon the third summer season, the limits of the KPDES permit will be fully enforced. Once the permit is reissued in five years, effluent data will be analyzed, in-stream water quality conditions will be reviewed, and the status of both the

KPDES permit and the associated TMDL will be examined. These will all factor into the discussions of the appropriate effluent limit to apply during the next permit cycle.

The proposed phased implementation plan provides the following benefits:

1) Significant phosphorus reduction in streams impacted by effluent.
2) Reductions without the immediate need for very expensive tertiary filtration.
3) Time to evaluate the treatment systems.
4) Time to study the water quality impact and the necessity of lower limits in the future.

The necessary Phase 1 MS4 reductions will be incorporated into the KPDES permit as best management practices (BMPs). The Phase 1 MS4 storm water permit already contains the language related to the storm water management program and the BMPs that the LFUCG is required to implement. The storm water management program is an integral part of the overall watershed management plan. Implementation of a program to effectively reduce pollutants (specifically total phosphorus) in discharges from municipal separate storm sewers should include:

- Reduction to the maximum extent practicable of pollutants associated with the application of pesticides, herbicides and fertilizers.
- Implementation of an ongoing education and information program management, use and disposal of materials which may contribute to pollutant loads in storm water.

The Phase 1 MS4 permit also requires annual reporting on any monitoring data accumulated during the year and information on the status of the implementation and proposed changes to the storm water management program to include assessment of controls and specific improvements or degradation to water quality. It is anticipated that BMPs will provide an additional level of reduction in phosphorus loadings beyond that already targeted through phosphorus reductions from the Town Branch WWTP.

This is a phased TMDL. The emphasis is to target a reduction in total phosphorus from the predominant source of phosphorus to the stream system (the Town Branch WWTP) during the critical flow period (low flow) when beneficial use is most at risk. Follow-up monitoring and evaluation will be necessary for this phosphorus TMDL on Town Branch. At the end of the first permit cycle, the permittee will conduct a biological survey of the stream system, using DOW protocols, to evaluate the biological health of the receiving stream. In particular, a biological assessment needs to be done at selected previously sampled locations on Town Branch (River Mile 6.1 and 8.9) and on South Elkhorn Creek at least 1.5 miles upstream and 1.0 miles downstream from the confluence with Town Branch to ensure that the TMDL is being implemented. After the results have been evaluated and if eutrophication continues to exist, a decision will be made whether additional reductions in phosphorus loading to the stream are necessary. If so, the TMDL will need to be re-evaluated.

In the future, if expansion of the Town Branch WWTP is needed, additional analysis of the TMDL will be conducted. Based upon this analysis and a review of water quality data and stream observations, an increase in load may be possible. However, the concentration limit of 1 mg/L would not be increased.

Introduction

Section 303(d) of the Clean Water Act (CWA) and the Environmental Protection Agency's (EPA) Water Quality Planning and Management Regulations (40 CFR Part 130) require states to develop total maximum daily loads (TMDLs) for their water bodies that are not meeting designated uses under technology-based controls for pollution. The TMDL process establishes the allowable loadings of pollutants or other quantifiable parameters for a water body based on the relationship between pollution sources and in-stream water quality conditions. This method exists so that states can establish water-quality-based controls to reduce pollution from both point and nonpoint sources and restore and maintain the quality of their water resources (USEPA, 1991). This report provides the nutrient TMDL for Town Branch.

Location

The Town Branch watershed is mostly contained within western Fayette County, in central Kentucky as shown in Figure 1.

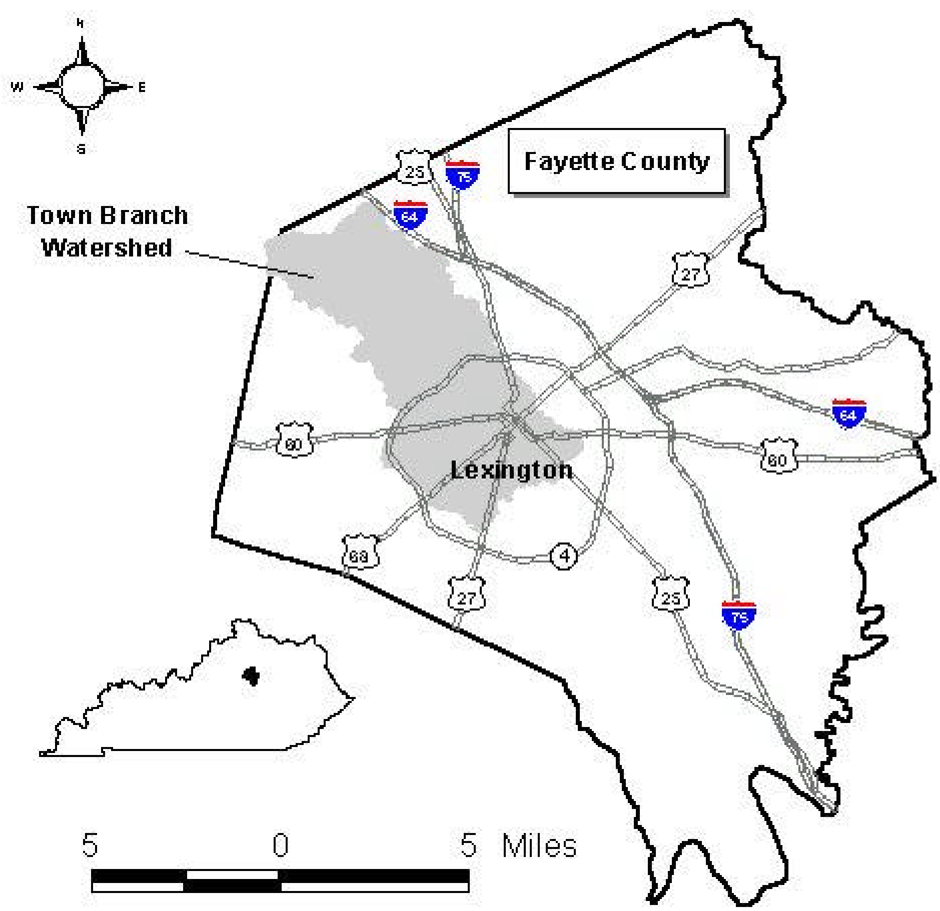


Figure 1. Location of Town Branch Watershed

Hydrologic Information

Town Branch is a third order stream that originates in downtown Lexington and flows northwest where it joins with South Elkhorn Creek at river mile 34.0. The Town Branch mainstem is approximately 18.5 km (11.5 mi) long and drains an area of 36.5 mi^2, most of which the upper part is urban development in the city of Lexington. The average gradient is 2.0 m/km (11.0 ft/mi). Elevations for Town Branch range form 283.5 m (930 ft) above msl in downtown Lexington to 240.8 m (790 ft) at the confluence with South Elkhorn Creek. As a result, Town Branch has a moderate grade slope which tends to insure good stream velocities. Because the effluent from the Town Branch Wastewater Treatment Plant constitutes the majority of flow in Town Branch Creek, phosphorus concentrations from the treatment plant dominate the phosphorus loads on the system.

The Town Branch creek system includes a major tributary named Wolf Run. Wolf Run is a second order stream that meets up with Town Branch at the 8.4 river mile. The Wolf Run mainstem is approximately 7.7 km (4.8 mi) long and drains an area of 10.1 mi^2, most of which is urban and suburban development. The Wolf Run creek system also includes Vaughn Branch.

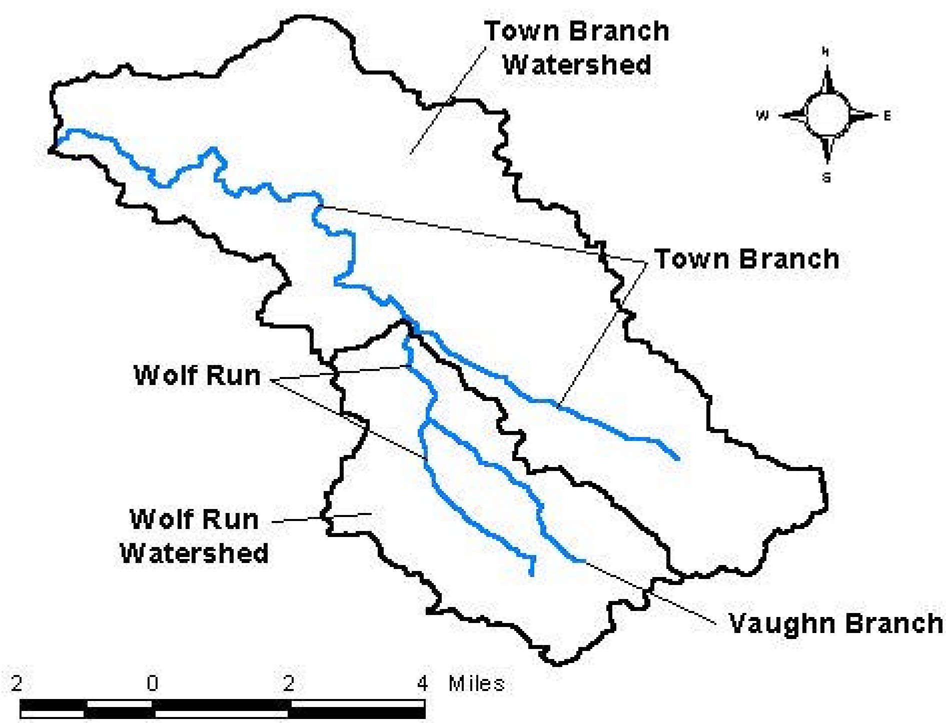


Figure 2. Major Stem and Tributaries of Town Branch

Geologic Information

The Town Branch watershed is in the Inner Blue Grass physiographic region. The area is underlain with the Lexington limestone formation of the Ordovician age. The Lexington formation is thin bedded shaly limestone and phosphatic in content. Figure 3 displays the various limestone locations and their spatial extent. The Tanglewood member of the Lexington

Limestone series is the most abundant and readily exposed to ground and overland surface waters and consequently attributable to soil laden phosphorus concentrations. Karst features like sink holes and springs also dominate the geology. There are also moderate amounts of shale and alluvium deposits in the region (Soil Surveys of Jessamine and Woodford, and Scott counties, USDA).

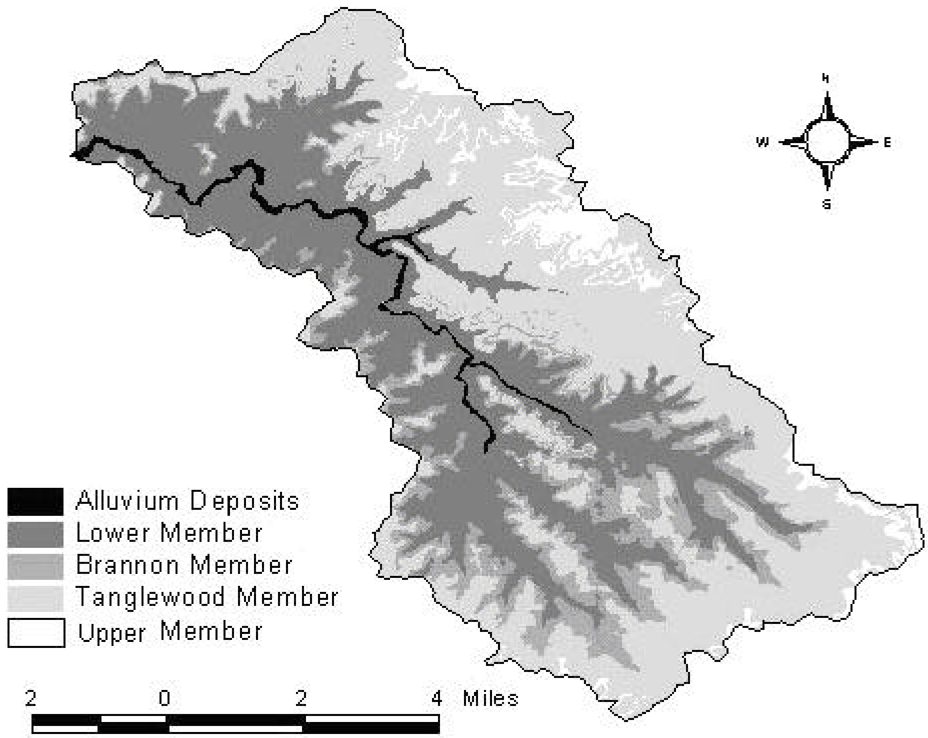


Figure 3. Geology of Town Branch Watershed

Land use Information

Land use in the Town Branch watershed is grouped into three main categories, urban (4.5%), rural (44%) and agricultural (50.5%). The headwaters of the basin are heavily impacted by urban and suburban areas of Lexington. The main agricultural resources of the area include tobacco and corn cultivation, while the livestock operations are dominated by thoroughbred horses and cattle. Forests are small and isolated and typically located along the waterways in the watershed.

Soils Information

The major soil groups for the Town Branch watershed are the McAfee-Maury and Maury-McAfee associations. The McAfee-Maury association is found predominantly at the tailwater of Town Branch. The rest of the watershed is dominated by the Maury-McAfee association. Both these groups are gently sloping to moderately steep, well drained soils. The soil profiles of the

McAfee and Maury soil series have silty loam material near the surface with silty clay loam and silty clay as depth increases, respectively. These soils are the result of weathered phosphatic limestone that underlie the area. The high fertility of the soils makes them excellent for grazing animals and raising crops, such as tobacco and corn. (Soil Surveys of Jessamine and Woodford, and Scott counties, USDA)

Watershed History

The Town Branch watershed offers many natural and cultural assets to the area. The streams in the watershed are home to diverse wildlife and vegetation that are unique to the Bluegrass and are excellent for fishing. The streams have supported the agricultural industry in the area through irrigation and livestock watering. Recreationally, the streams provide scenic canoeing and swimming.

The watershed is steeped in historical significance. Lexington can trace its beginnings to a settlement near Town Branch. Old gristmills, limestone fences and National-Register-of-Historic sites dot the landscape of the Town Branch creek system. South Elkhorn Creek, which receives flows from Town Branch, has even drawn the favored criticism of writer Walt Whitman (1860).

From a hydrologic historical perspective, the Town Branch creek has been the focus of sampling and monitoring since the late 1960s. There are two U. S. Geological Survey (USGS) stations in the watershed, which measure stage on a continuous basis. Both sites are still active and have real-time access to data. The USGS and STORET databases record nutrient sampling in the watershed as early as the 1960s. Table 1 is a brief history of phosphorus-related sampling in the Town Branch watershed. From Table 1 it is evident that high phosphorus values have always dominated the streams of the watershed. With the historically high concentrations and a general record of satisfactory water quality, the assimilative capacity of these creeks might be higher than normally expected.

Table 1. Historical In-stream Phosphorus Sampling on Town Branch

Stream	Date	Parameter	Result (mg/L)
Town Branch	12/6/67	Phosphorus as PO_4	4.6
Town Branch	3/22/68	Phosphorus as PO_4	2.1
Town Branch	8/27/81	Total Phosphorus	3.16
Town Branch	8/27/87	Total Phosphorus	2.8
Town Branch	8/11/88	Total Phosphorus	3.4

PO_4 - Orthophosphate

Problem Definition

The 1998 303(d) list of waters for Kentucky (Ky. Dept. for Environmental Protection DOW, 1998) indicates 11.3 miles of the Town Branch, from approximately the effluent zone of Town Branch WWTP (Wastewater Treatment Plant) to the confluence with South Elkhorn Creek does not meet its designated use of primary contact recreation (swimming) and warm water aquatic habitat (aquatic life). This section is impaired for aquatic life use support due to nutrient enrichment, specifically attributable to phosphorus loadings, and impaired for swimming use support due to bacteria (pathogens). The pathogen problems will be dealt with in a future TMDL report.

Nutrients such as phosphorus, nitrogen and carbon are vital to sustaining an aquatic ecosystem. However, an abundance of these nutrients will accelerate the natural eutrophication process of a water body. In eutrophication, the increase in nutrients leads to nuisance algae blooms or, more commonly, periphyton (attached algae) in swift-moving fresh waters. These algae blooms pose many problems for a body of water. The physical congestion prohibits recreational boating and swimming and degrades the visual aesthetics of the water body. The most detrimental effect is the oxygen demand created by the algae blooms during respiration, which chokes off macroinvertebrates and the less resilient and static zooplankton (small aquatic animal life) that cannot escape low dissolved oxygen areas. Human inclusions in the ecosystem by means of WWTP effluent and/or agricultural/fertilization practices are typical causes for the imbalance of nutrients in the ecosystem.

The Town Branch watershed is unique to the nutrient loading quantification, in the sense that background sources may play a major factor in nonpoint source load allocation. The geology of the area is dominated by highly phosphatic limestone that creates a significant background source component. This background contribution can yield high concentrations of total phosphorus during runoff events as well as during low-flow conditions. Phosphorus can be sorbed to sediment particles and transported to surface waters, or if conditions are favorable, phosphorus may be released from the sediment to the overlying water.

Target Identification

The goal of the TMDL process is to achieve a numeric nutrient loading within the assimilative capacity of the impaired creek under study that allows for the sustainability of aquatic life. However, the Kentucky water quality standard for nutrients is a narrative standard (Title 401, Kentucky Administrative Regulations, Chapter 5:031, Section 1). The regulation states: "In lakes and reservoirs and their tributaries, and other surface waters where eutrophication problems exist, nitrogen, phosphorus, carbon, and contributing trace element discharges shall be limited in accordance with (1) the scope of the problem; (2) the geography of the affected area; and (3) relative contributions from existing and proposed sources." Since the narrative standard does not identify a target parameter nor target value, professional judgement must be employed in the selection of water quality indicators and their corresponding values for the development of the TMDL.

The EPA's loosely defined "criteria guidance" for nutrients has allowed states to interpret their own nutrient standards, such as the use of a narrative standard in Kentucky. However, the EPA and the states are working on better standards for nutrient concentrations and their respective response to eutrophication. The new standards are being determined on a regional level to account for geography, climatic differences and the assimilative nature of various water bodies. As a result, the current TMDL may have to be revised in the future to incorporate any new standards.

Eutrophication is typically driven by a single nutrient that is less abundant than the other nutrients necessary for algal growth. Control of this limiting nutrient theoretically will lead to a resolution of the problem. Preliminary sampling of Town Branch has revealed that the nitrogen-to-phosphorus ratios in the impaired section of Town Branch were greater than 7.2, the nitrogen-to-phosphorus ratio found in biomass (Chapra, 1997). Other studies involving similar systems with similar ratios also provide evidence that phosphorus is the limiting nutrient and a suitable indicator of water quality for the proposed TMDL (Jaworski, 1981; and NOAA/EPA, 1988).

For most flowing streams in Kentucky, the KDOW believes that phosphorus is the limiting nutrient for algal production. However, the KDOW recognizes that other factors can be limiting in certain instances. The focus of this TMDL is on reducing phosphorus to the Town Branch/South Elkhorn Creek system to achieve the sustainability of aquatic life. Also, KDOW biologists have defined relations between total phosphorus concentrations and impairment for selected areas in the state, and this work is continuing.

Because phosphorus can exist in many chemical varieties in natural waters, a particular form of phosphorus needs to be selected to serve as the appropriate indicator. Figure 4 on the next page shows the phosphorus cycle with its portioned categories and their relation to one another. Available inorganic phosphorus (ortho-phosphorus) is the most readily used form of phosphorus for growth and energy production in plant life and is often referred to as soluble reactive phosphorus (SRP). Other forms may also contribute to vegetative uptake, but they must be converted into SRP first. The SRP determination method performed on a digested, unfiltered sample yields a measurement of all (total) phosphorus amount in the water (Chapra 1997). The total phosphorus measurement is a good means of indicating eutrophication because total phosphorus (1) includes all phosphorus forms that exist in both nonpoint and point sources, (2) does not exclude the in-stream particulate forms that can be reused, (3) has processes that are easier to simulate in the modeling environment, and (4) provides for more data to be employed than other species of phosphorus for Town Branch. Also as expected, preliminary stream sampling displayed a direct correlation of high orthophosphate levels (SRP) with high total phosphorus concentrations but more importantly additional evidence that reduction of total phosphorus will lead to reduction of SRP.

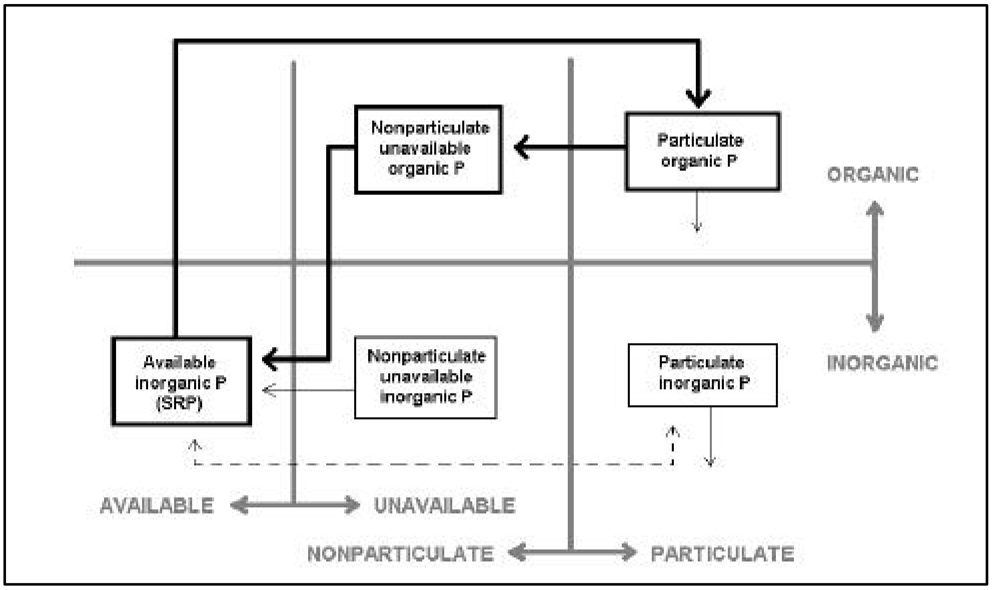


Figure 4. The Phosphorus Cycle (Chapra, 1997)

With the narrative Kentucky standard in place, federal standards and limits were looked upon as a starting point. The EPA previously suggested a maximum total phosphorus concentration of 0.1 mg/L in flowing waters to control eutrophication (USEPA, 1999). More recent EPA nutrient criteria suggests that 0.04 mg/L might be an appropriate target based on available information (USEPA, 2000). This target value does not represent a value that is linked to an impairment. It is a value that represents a very conservative estimate of background total phosphorus concentration. It is based on values collected from a large geographic area and should not be used where site-specific information and data are available. Total phosphorus concentrations in undisturbed groundwater samples collected in the watershed area during the years of 1997-99 by Commonwealth Technology Incorporated (CTI) range from 0.2 mg/L to as high as 0.38 mg/L. These well-water concentrations represent water quality conditions minimally affected by human activities and most likely the result of the area's geologic makeup and affinity for phosphorus-laden soils. Using the suggested EPA standard, even the least affected parts of Town Branch would be in violation due to background sources.

As a result of a consideration of the stream dynamics of both Town Branch and South Elkhorn Creek, as well as the natural background levels observed in the watershed, an initial in-stream maximum daily phosphorus concentration of 0.5 mg/L is proposed for South Elkhorn Creek during the summer season of May 1 through October 31, with the stipulation that the Total Maximum Daily Load of phosphorus to Town Branch shall be set so as to insure such an in-stream concentration during a prescribed set of critical flow conditions. The total maximum daily load for Town Branch may be determined using historical flows and concentrations observed during the "critical loading period." Since Town Branch is dominated by flows from the Town Branch Wastewater Treatment Plant, the critical loading period is expected to be one associated with minimum stream flows. However, in order to account for the potential interaction of lateral flows and associated loadings, the TMDL was determined using six months of daily flows and loadings associated with the critical period. For the proposed TMDL, the critical six-month period was selected to coincide with the period that yields the minimum six-month (May 1 through October 31) average flow for a prescribed frequency. For this study, a 20-year flow frequency is being used. This is more stringent than the 10-year low-flow frequency usually used in steady state wasteload allocations and provides a more conservative load estimate.

Source Assessment

Several in-stream (TB1, TB2, TB3, TB4-U, TB4-D, WR1) and treatment plant effluent (TB4-E) samples were collected from late June and early July of 2000 to determine the location and magnitude of potential phosphorus sources. The sampling was performed on three separate days, and the following parameters were tested: ammonia, Total Kjeldahl nitrogen, nitrate, nitrite, orthophosphate, and total phosphorus. The data was conclusive that a jump in nutrient concentrations on Town Branch did occur downstream of the effluent zone of Town Branch WWTP. The headwaters of Town Branch demonstrated very static nutrient concentrations over the time range of sampling. Uncontrollable background sources are most likely attributed to these upstream results. A map of the sampled sites is provided in Figure 5. Photographs of selected sites are provided in Figures 6a – 6d. Table 2 reports the results from the sampling. These results are visualized in Figure 7.

Point Source Loads

The only point sources are the Town Branch WWTP and the Phase 1 MS4 contribution. The plant is located at river mile 10.2 on Town Branch and has a design flow of 30 MGD (million gallons per day) and an average daily flow of 18.4 MGD. It is required to test weekly for total phosphorus under its current KPDES (Kentucky Pollutant Discharge Elimination System) permit. The Town Branch WWTP services approximately half of Lexington. Two factors contribute to the magnitude of impairment in Town Branch by this facility. The first is that the effluent exhibits a high total phosphorus concentration compared to the national levels EPA has determined for the onset of eutrophication, and the other is that the plant effluent accounts for most of the stream's flow throughout most of the year and more notably during the drier season. For example, the July 2000 plant average for daily effluent flow was 15.97 MGD. This flow, coupled with July's average total phosphorus concentration of 2.06 mg/L, yields a total phosphorus daily load of 274 lbs/day. The in-stream load prior to the Town Branch effluent zone is about 9 lbs/day (4.2 MGD flow with background total phosphorus concentration of 0.25 mg/L). Therefore, the discharge from the WWTP represents an increase of approximately 30 times the upstream total phosphorus load. Table 3 displays total phosphorus concentration of Town Branch effluent for May through October of 1999. This data was compiled from weekly sampling obtained from Town Branch WWTP's monthly operations report.

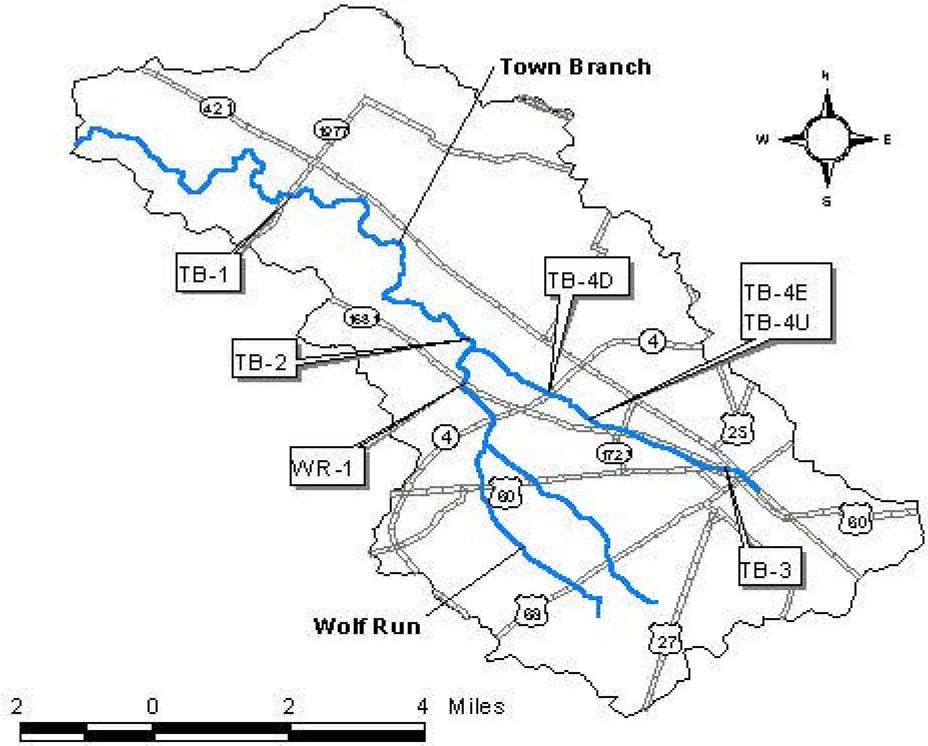


Figure 5. South Elkhorn Watershed Sampling Sites

Table 2. Total Phosphorus Results in the Town Branch Watershed

Sample ID	River Mile	6/26	6/29	7/6	10/18	10/26
TB-1	4.1	0.68	0.83	0.59	1.23	1.20
TB-2	8.3	0.77	1.27	0.69	1.45	1.39
TB-3	11.3	0.35	0.29	0.32	0.37	0.34
TB4-4D	9.4	-	-	-	1.50	1.45
TB4-4E	10.2	-	-	-	1.57	1.51
TB4-4U	10.3	-	-	-	0.31	0.37
WR-1	8.4 / 0.5	-	-	-	0.28	0.30

Figure 6a. Site TB1: Town Branch at Yarnallton Road (Site of USGS Gaging Station)

Figure 6b. Site TB2: Town Branch at Viley Road

Figure 6c. Site WR1: Wolf Run at Old Frankfort Pike (Site of USGS Gaging Station)

Figure 6d. Site TB3: Town Branch Downstream of Origin in Rupp Arena Parking Lot

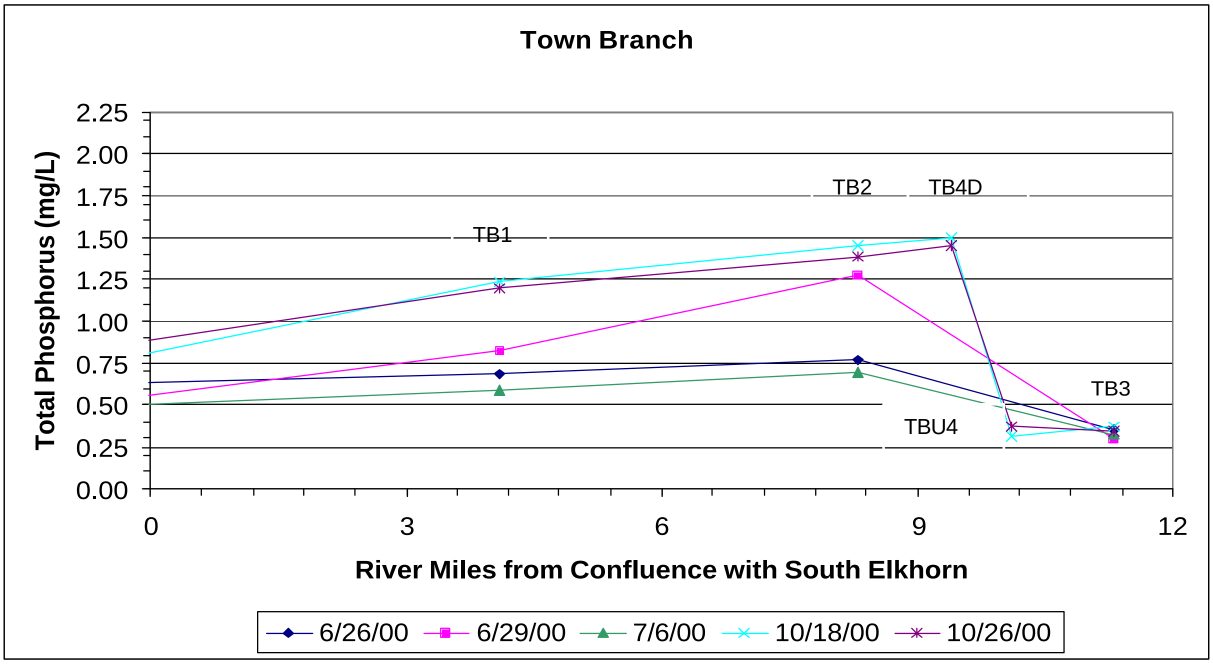


Figure 7. Total Phosphorus Results in Town Branch

Nonpoint Source Loads

Areas bounding Town Branch contribute in some manner and magnitude to nonpoint source loading. The watershed is made up of agricultural (51%), urban (5%) and rural/forested (44%) land uses. In the agricultural sector, storm runoff from cultivated fields picks up nutrients both sorbed in sediments and in particulate form and delivers these loads by overland flow to streams. Grazing animals, particularly thoroughbred horses and cattle, can adversely affect nutrient levels in these streams by their excrement, through either overland flow transport or direct contact with surface waters. While forested tracts typically contribute insignificant loadings, the urban environment can be responsible for elevated nutrient concentrations from lawn fertilizers carried off by runoff. The three loading sources; residential, cultivated land and pasture runoff, exhibit the most influence during storm events when the buildup of nutrients is released over a short time. (The available land use will be used to calibrate nonpoint source loading models.)

Background source loads may play a significant role in the total nutrient loading of Town Branch. As mentioned before, total phosphorus levels as high as 0.38 mg/L have been observed in undisturbed groundwater. It is hypothesized that the elevated phosphorus levels are due to contact with natural geology of the Inner Bluegrass area. The phosphatic limestone that underlies the area and that has deteriorated into the soil over geologic time contributes to the total phosphorus concentration in these creeks. The karst geology in the Inner Bluegrass also features springs and sinkholes, which can divert surface water underground and transmit highly contaminated water. However, during dry periods, the waters in upper Town Branch and its tributaries are primarily fed by groundwater. There is little data on soil phosphorus concentrations and groundwater delivery ratios available at this time, but instream concentrations in the least disturbed, unimpaired segments of these creeks are very consistent from location to location and season to season. Such observations tend to enforce the hypothesis that the background nutrient levels are due to the influence of highly phosphatic soils as opposed to surface loadings that are being transported to the stream through karst structures.

Model Development

In order to model the transport of nutrients through a stream system, some type of transport model is needed. In the current study, this is accomplished using a spatially distributed kinematic wave model. A distributed model like the kinematic wave model is good for routing since it determines flows in both time and space and is also useful in modeling streams where the lateral flows may constitute a majority of the total flow. By combining pollutant fate and transport equations with a kinematic wave model, both flow and pollutant concentrations can be simultaneously determined at various locations along the stream.

Kinematic Wave Theory

The governing equations for kinematic wave models are the conservation of mass and conservation of momentum equations. The conservation of mass states that the difference between the rates of inflow and outflow is equal to the rate of change in storage. The application of this principle with consideration to constant water density and prismatic cross-sectional areas yields the following conservative form of the continuity equation:

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q \tag{1}$$

where q is the lateral inflow with units in flow per channel length, Q is flow, and A is cross sectional area.

The full dynamic form of the momentum equation is based on Newton's second law and principles of conservation of energy and momentum. The law states that the sum of applied forces is equal to the rate of change in momentum plus the net outflow of momentum. The application of these principles, while neglecting wind shear and eddy losses and assuming the associated momentum correction factor is 1, yields the following conservative form of the momentum equation:

$$\frac{1}{A}\frac{\partial Q}{\partial t} + \frac{1}{A}\frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right) + g\frac{\partial y}{\partial x} - g(S_o - S_f) = 0 \tag{2}$$

Table 3. Town Branch WWTP Total Phosphorus Data

Sampling Date	Concentration (mg/L)	Flow (cfs)	Load (lbs/day)
5/10/99	1.34	21.68	156.6
5/12/99	2.3	25.82	320.1
5/18/99	3.05	23.73	390.1
5/24/99	2.25	24.84	301.2
6/1/99	2.68	21.55	311.3
6/7/99	2.4	20.22	261.6
6/17/99	3.55	20.39	390.2
6/21/99	3.48	18.99	356.2
6/29/99	1.88	39.73	402.6
7/7/99	3.13	21.21	357.8
7/12/99	2.98	20.92	336.0
7/19/99	3.15	18.89	320.7
7/26/99	2.88	19.35	300.4
8/2/99	2.43	25.45	333.3
8/9/99	1.1	18.67	110.7
8/16/99	2.03	19.94	218.2
8/26/99	1.13	22.62	137.8
9/1/99	1.3	19.22	134.7
9/13/99	2.53	18.36	250.4
9/28/99	2.15	24.61	285.2
10/4/99	0.93	22.08	110.7
10/11/99	1.3	26.14	183.2
10/18/99	1.35	21.1	153.5
10/25/99	1.9	21.85	223.8

where g is acceleration due to gravity, S_o is bed slope, and S_f is friction slope (Chow, 1988). The five terms in the momentum equation (2) from left to right include: local acceleration, convective acceleration, pressure force, gravity force and the friction force. In the kinematic approximation of a dynamic wave, the first three terms of local acceleration, convective acceleration and pressure force are assumed to be insignificant and therefore the gravity force balances the friction force, and

$$S_o = S_f \tag{3}$$

For a kinematic wave approximation, the energy grade line is parallel to the channel bottom, and the flow is characterized as steady and uniform within the differential length (Chow, 1988).

In application of this theory, flow is treated as a function of the cross-sectional area or depth and thus can be evaluated with a uniform flow equation like Manning's. Use of Manning's equation to approximate the friction slope yields the equation:

$$Q = \frac{1.49 S_o^{\frac{1}{2}}}{n P^{\frac{2}{3}}} A^{\frac{5}{3}} \tag{4}$$

Solving for cross-sectional area A yields the following form:

$$A = \left(\frac{nP^{\frac{2}{3}}}{1.49\sqrt{S_o}} \right)^{\frac{3}{5}} Q^{\frac{3}{5}} \tag{5}$$

or more succinctly as:

$$A = aQ^b \tag{6}$$

where a and b are coefficients defined for each cross section (Miller, 1984). For a rectangular channel these coefficients can be expressed as:

$$a = \left(\frac{nP^{\frac{2}{3}}}{1.49\sqrt{S_o}} \right)^{\frac{3}{5}}$$

and

$$b = \frac{3}{5}$$

where P is the wetted perimeter and n is Manning's coefficient of roughness. These parameters are assumed to be known and constant for a given differential length.

Differentiating the uniform flow relationship (6) with respect to time eliminates the area term, and substituting for $\partial A / \partial t$ in the continuity equation (1) yields the following composite kinematic wave equation:

$$\frac{\partial A}{\partial t} = abQ^{b-1}\left(\frac{\partial Q}{\partial t} \right) \tag{7}$$

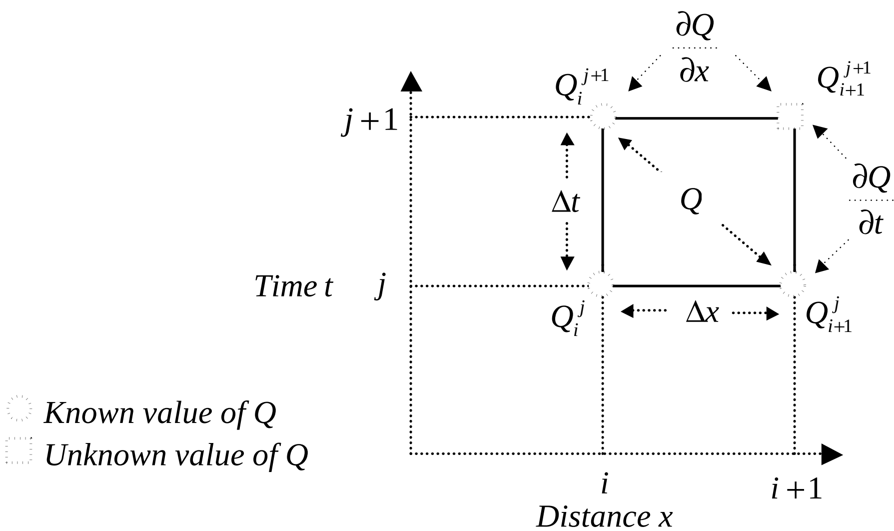
or expressed in terms of stream flow rate Q, as:

$$\frac{\partial Q}{\partial x} + abQ^{b-1}\left(\frac{\partial Q}{\partial t} \right) = q \tag{8}$$

Finite Difference Approximations

The partial differential equation (PDE) (8) for a kinematic wave model can be solved analytically or numerically for flow; however, the analytical solution can only be solved in a few special cases. With numerical methods, finite difference equations are developed from the PDEs of the continuity and momentum equations. With a computational grid placed over a uniformly segmented space and time (x-t) plane, flows and cross-sectional flow areas are then solved algebraically for incremental times and distances along this grid at each grid point. Previous solutions for the discharge provide initial boundaries for the next step of solutions and the process is then propagated throughout the entire domain.

Finite difference approximations for the partial differential equations are developed by application of a Taylor series expansion. Application of the Taylor series expansion results in a linear set of equations that approximate the original partial differential equations. This approximation results in a small truncation error that is minimized through the proper selection of the computational step. In the current study, the backward difference method is used to set up the finite difference equations. This associated computational grid is shown below.



The finite difference form of the space derivative is:

$$\frac{\partial Q}{\partial x} \approx \frac{Q_{i+1}^{j+1} - Q_i^{j+1}}{\Delta x} \tag{9}$$

Likewise the finite difference form of the time derivative is:

$$\frac{\partial Q}{\partial t} \approx \frac{Q_{i+1}^{j+1} - Q_{i+1}^{j}}{\Delta t} \tag{10}$$

Likewise, a linear form of discharge can be obtained by averaging the flows across the diagonal:

$$Q \approx \frac{Q_i^{j+1} + Q_{i+1}^{j}}{2} \tag{11}$$

Finally, the lateral inflows are determined by averaging the values over time at the current distance step, expressed as:

$$q \approx \frac{q_{i+1}^{j+1} + q_{i+1}^{j}}{2} \tag{12}$$

Substituting the finite difference forms (9-12) into Equation 8 provides a linear approximation to the kinematic wave equation:

$$\frac{Q_{i+1}^{j+1} - Q_i^{j+1}}{\Delta x} + ab\left(\frac{Q_{i+1}^{j} + Q_i^{j+1}}{2}\right)^{b-1}\left(\frac{Q_{i+1}^{j+1} - Q_{i+1}^{j}}{\Delta t}\right) = \frac{q_{i+1}^{j+1} + q_{i+1}^{j}}{2} \tag{13}$$

Equation 13 can now be rearranged for the unknown flow of Q_{i+1}^{j+1} as follows:

$$Q_{i+1}^{j+1} = \frac{\left[\frac{\Delta t}{\Delta x} Q_i^{j+1} + abQ_{i+1}^{j}\left(\frac{Q_{i+1}^{j} + Q_i^{j+1}}{2}\right)^{b-1} + \Delta t\left(\frac{q_{i+1}^{j+1} + q_{i+1}^{j}}{2}\right)\right]}{\left[\frac{\Delta t}{\Delta x} + ab\left(\frac{Q_{i+1}^{j} + Q_i^{j+1}}{2}\right)^{b-1}\right]} \tag{14}$$

This finite difference expression for the kinematic wave model may be solved explicitly or sequentially with known terms. However, the discretization of the x-t plane into a grid for the integration of the finite-difference equations introduces numerical errors into the computation (Chow, 1988). The errors can amplify as the solution progresses explicitly through the grid and therefore makes the relative grid size an important issue. The error can be minimized by observance of the Courant condition. For a kinematic wave model, the Courant conditions require that:

$$\Delta t \le \frac{\Delta x}{c_k} \tag{15}$$

where c_k is the kinematic wave celerity. The kinematic wave celerity is the velocity with which the wave travels and may be quite different from the average stream velocity. The celerity for kinematic waves is usually determined by:

$$c_k = \frac{1}{B}\frac{dQ}{dy} \tag{16}$$

where *B* is the channel width. Typically in kinematic wave models the Δx remains constant throughout the solution and therefore the Δt is adjusted at each computational step so as to not violate the Courant condition.

Pollutant Fate and Transport

As a pollutant enters a stream, many processes act upon or with the pollutant. These reactions are termed the fate and transport of the pollutant. The two physical transport processes that dominate the movement of the pollutant are advection and dispersion. Advection is the movement of the pollutant at the velocity of the flow. Dispersion is the spreading movement of the pollutant and is caused by molecular diffusion and/or velocity variations caused by shear stress (Runkel, 1995). Equation 17 represents the partial differential equation for advection and dispersion of a pollutant, expressed as:

$$\frac{\partial c}{\partial t} = -U\frac{\partial c}{\partial x} + E\frac{\partial^2 c}{\partial x^2} \tag{17}$$

where U is velocity, E is the longitudinal dispersion coefficient and c is the concentration of the pollutant.

While Equation 17 describes the movement of the pollutant through the system, other physical, biological and chemical processes can also occur to affect the pollutant concentration such as settlement or re-suspension (i.e. bed load). If both settlement and re-suspension processes are combined into a single term Θ, equation 17 can be modified as follows:

$$\frac{\partial c}{\partial t} = -U\frac{\partial c}{\partial x} + E\frac{\partial^2 c}{\partial x^2} - \Theta c \tag{18}$$

where Θ has units of time (1/day) and is positive if settlement > re-suspension and negative if settlement < re-suspension.

An additional potential source term that plays an important role in the concentration of the pollutant is lateral flow. In the particular system of interest, background concentrations can contribute a significant source of pollutant. This may be modeled by the addition of a lateral flow concentration term to the transport equation, expressed as:

$$\frac{\partial c}{\partial t} = -U\frac{\partial c}{\partial x} + E\frac{\partial^2 c}{\partial x^2} - \Theta c + \frac{q_L}{A}\left(c_L\right) \tag{19}$$

where q_L is the lateral inflow rate per unit length of stream, c_L is the concentration of pollutant in the lateral flow, and A is the cross-sectional area of the flow.

Since for Town Branch the flow velocities are relatively high, the dispersion effects are expected to be low relative to the advection effects. As a result, the dispersion term was dropped, resulting in the following PDE for the fate and transport of a conservative pollutant in the stream system:

$$\frac{\partial c}{\partial t} = -U\frac{\partial c}{\partial x} - \Theta c + \frac{q_L}{A}\left(c_L - c\right) \tag{20}$$

Application of finite difference approximations to Equation 20, along with a substitution of Equation 14, yields the following equation for in-stream phosphorus concentration at each grid point characterized by distance i and time j:

$$c_{i+1}^{j+1} = \left[\frac{\frac{Q_{i+1}^{j+1}}{A} c_i^{j+1} \frac{dt}{dx} - \Theta c_{i+1}^{j} dt + \frac{q_L}{A}\left(c_L - c_i^{j+1}\right) dt + c_{i+1}^{j}}{1 + \frac{Q_{i+1}^{j+1}}{A} \frac{dt}{dx}} \right] \tag{21}$$

Application of the Kinematic Phosphorus Model to Town Branch

The kinematic wave model and loading models explained in detail in the previous section were applied to the Town Branch creek system. A continuous flow path beginning from the headwaters of Town Branch through the confluence with South Elkhorn Creek was laid out horizontally in one-mile segments in a spreadsheet. To complete the spatial and temporal framework, a years' worth of daily dates were input vertically in the spreadsheet. The developed spreadsheet thus provided the computational grid for the solution of both daily flow and corresponding phosphorus concentrations using Equations 14 and 21. The layout of the stream system is depicted in the schematic in Figure 8. The five main input parameters were point flows, lateral flows, point concentrations, lateral concentrations and settlement factors. These were stored in other similar spreadsheet layers. Other constant parameters or relationships were coded internally in the program. They included channel characteristics like slope, Manning's roughness factor and width. Power relationship between flow and depth were obtained from the Kentucky Division of Water and used in the determination of the wave celerity. A *Visual Basic* code was written to process the necessary parameters and boundary conditions for each computational length and time and used to solve the finite difference equations developed earlier for flow and phosphorus concentration in an iterative fashion.

Tributary and Lateral Streamflow Estimates

Stream flows for the two tributaries and the upstream daily flow boundary condition for Town Branch were generated with United States Geological Survey (USGS) and Town Branch WWTP streamflow data. The upstream daily flows were generated using the flows from a monitoring station 0.1 miles upstream of the Town Branch WWTP. Flow data from USGS monitoring stations on Wolf Run and South Elkhorn Creek near Fort Springs, Kentucky, were used as input hydrographs for those respective streams. In the model, the portion of South Elkhorn Creek upstream of the confluence with Town Branch was treated as a point source of flow. Flows for this segment were generated by multiplying the South Elkhorn flows at Fort Springs by the ratio of the contributing watershed areas. Since the flow contributions of Town Branch WWTP make up a considerable amount of the flow in Town Branch, the plant's daily effluent discharges were directly input as a point source of flow. Lateral inflows for the differential lengths were again generated using the ratios of contributing watershed areas.

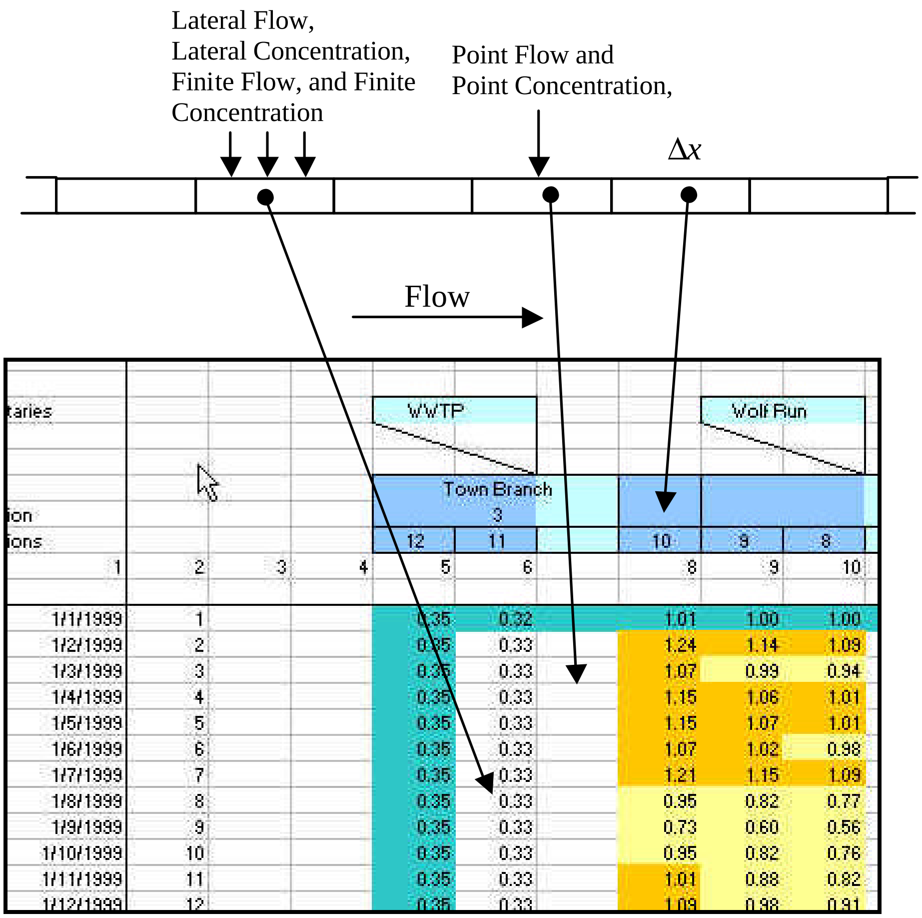


Figure 8. Schematic of Spreadsheet Model

Nonpoint Source Loadings

An attempt to develop lateral phosphorus-loading relationships for each stream reach was performed by analyzing the measured incremental flows and in-stream concentrations. This analysis failed to produce any consistent loading functions other than a fairly consistent and flow-independent background concentration. Therefore, for the purposes of model development, the lateral flow concentrations (i.e. C_L) for each stream reach were initially set at 0.3 mg/L.

Tributary Loadings

Concentrations for the point flows out of the tributaries and the lateral flow from the one-mile segments were determined from the sampling data. The total phosphorus values for upper South Elkhorn Creek, Wolf Run and upper Town Branch were static over the five days of sampling. As a result, a representative constant value of the sampling data was selected as the incoming concentration for each stream. The data showed no discernable amount of loading in relation to in-stream concentration for the length of the main stem except for the loading by Town Branch WWTP. As a result, a static lateral flow concentration of 0.3 mg/L was used in each one-mile to incorporate background and land use phosphorus contributions.

Point Source Loadings

Similar to the nonpoint source loads, a loading model of observed discharges from Town Branch WWTP and total phosphorus loads was attempted using plant discharge data from May-October in 1999. As with the nonpoint source loads, no direct correlation was identified between the two parameters. As a result, it was decided to make multiple applications of the model using a selected critical year of discharges with incremental variations in the plant effluent concentration. Using the historical daily flows, separate annual time series of total loads were obtained by holding the effluent concentration constant. The range of concentration values used was 0.5 mg/L to 3.0 mg/L using increments of 0.5 mg/L.

Model Calibration

Monitoring data from the summer and fall of 2000 was used to calibrate the model. A single set of model parameters was adjusted to better correlate simulated concentrations with measured data points for five separate monitoring events. The calibrated parameters included lateral flow values and settlement factors. Initial lateral flow values were based on observed stream flows at Wolf Run and contributing area ratios assuming that all 14 one-mile segments were homogenous in their land use. Site calibration was performed to reflect more lateral flow from segments with higher imperviousness. The settlement factors were adjusted to incorporate the varying depth along the stream and allow for more settlement at lower depths. Figure 9 shows the calibrated flow values at the Yarnallton gaging station for the period 6/23/00 – 7/11/00 which includes the time frame of the first three monitoring dates. Figures 10a – 10e show the results of the observed and predicted total phosphorus values for the five separate data sets using the same set of calibrated model parameters. These model parameter values were then used to predict the daily phosphorus concentrations and loads for selected critical periods using historical streamflow values.

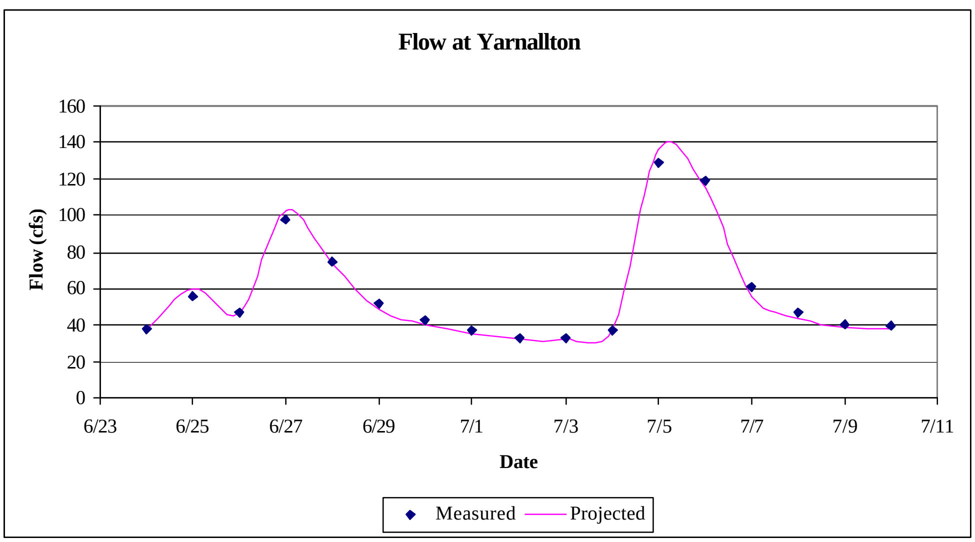


Figure 9. Observed and Modeled Flows at Yarnallton (Site TB1)

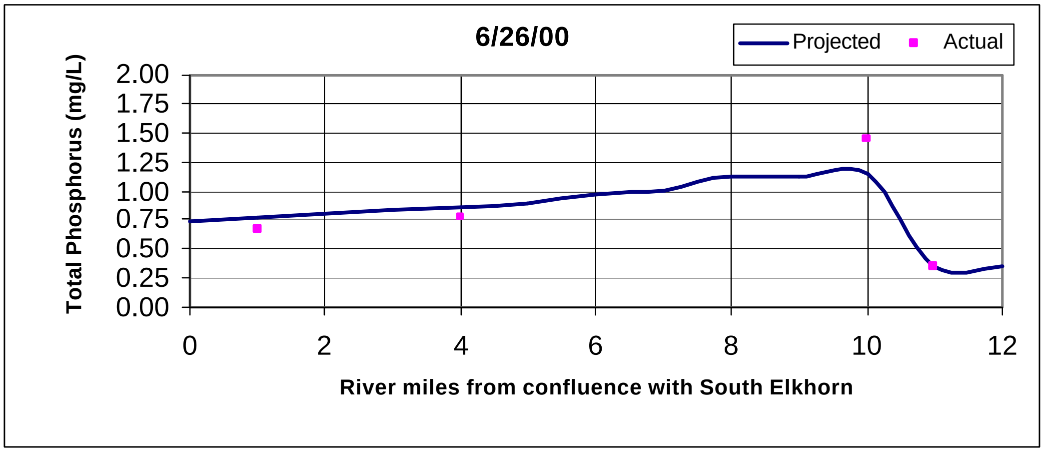


Figure 10a. Observed and Modeled Total Phosphorus Results for 6/26/2000

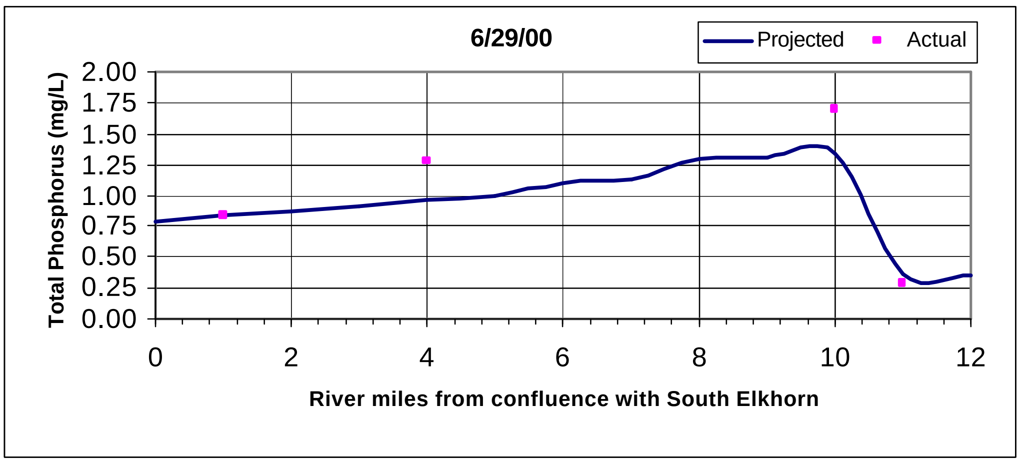


Figure 10b. Observed and Modeled Total Phosphorus Results for 6/29/2000

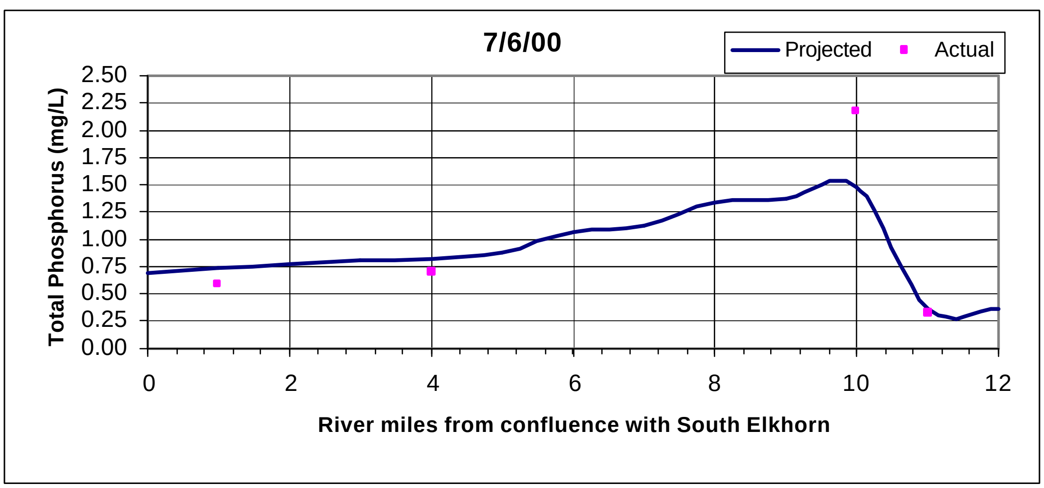


Figure 10c. Observed and Modeled Total Phosphorus Results for 7/6/2000

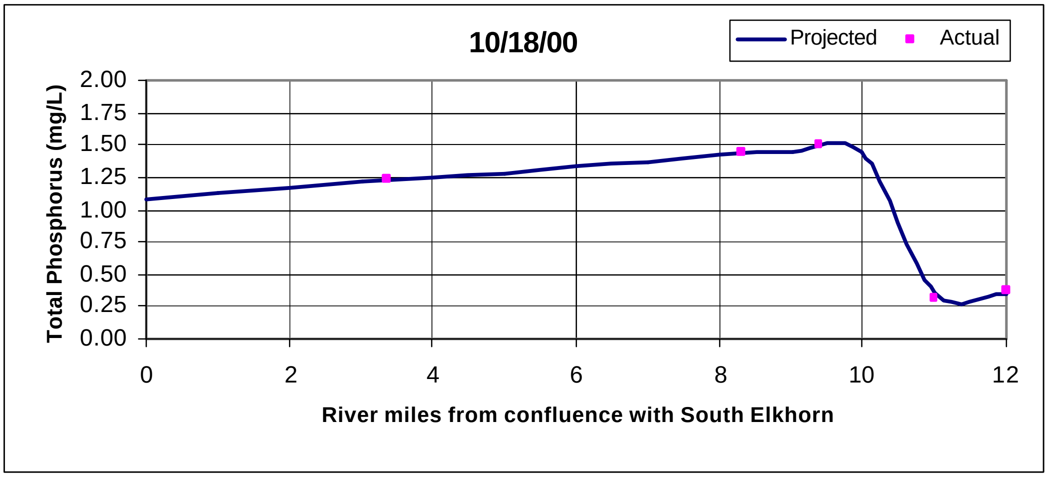


Figure 10d. Observed and Modeled Total Phosphorus Results for 10/18/2000

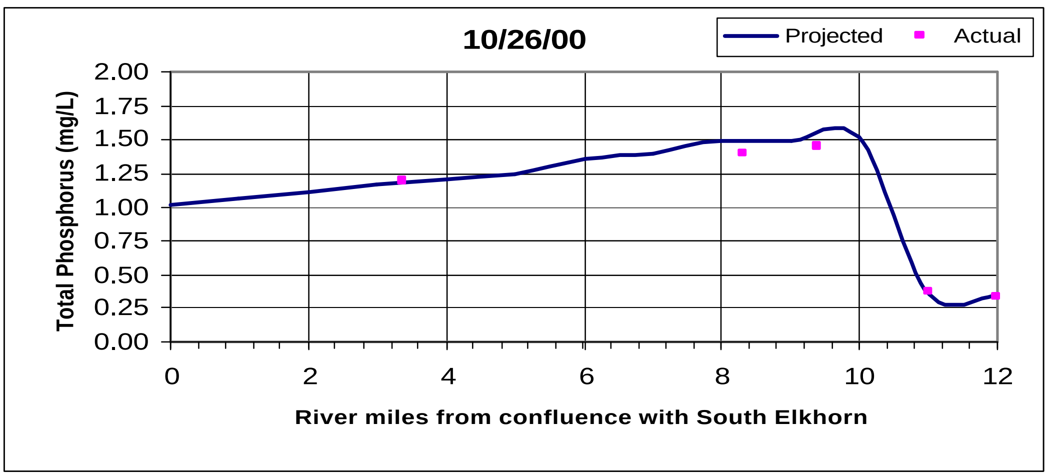


Figure 10e. Observed and Modeled Total Phosphorus Results for 10/26/2000

TMDL Development

Theory

The Total Maximum Daily Load (TMDL) is a term used to describe the maximum amount of a pollutant a stream can assimilate without violating water quality standards. The units of a load measurement are mass of pollutant per unit time (i.e. mg/hr, lbs/day).

Total maximum daily loads (TMDLs) are comprised of the sum of individual waste load allocations (WLAs) for point sources and load allocations (LAs) for both nonpoint sources and natural background levels for a given watershed. The sum of these components may not result in exceedance of water quality standards (WQSs) for that watershed. In addition, the TMDL must include a margin of safety (MOS), which is either implicit or explicit, that accounts for the uncertainty in the relation between pollutant loads and the quality of the receiving water body. Conceptually, this definition is denoted by the equation:

$$\text{TMDL} = \text{Sum (WLAs)} + \text{Sum (LAs)} + \text{MOS} \qquad (8)$$

Waste Load Allocations

The only point sources in the impaired segment of Town Branch are the Town Branch WWTP and the Phase 1 MS4 contribution. The Town Branch WWTP loads are directly related to the operational discharge and treatment efficiency of phosphorus. However, since no direct correlation between flow and concentration existed, potential loads were calculated using a stochastic approach using a range of possible concentrations and historical discharge values. The Lexington Phase 1 Municipal Separate Storm Sewer (MS4) discharges are incorporated under this category per current EPA regulations.

Load Allocations

Load allocations for Town Branch are assumed to be directly related to loadings associated with surface runoff or groundwater flows associated with each incremental one-mile river segment. However, the load allocations were hard to distinguish from current background total phosphorus contributions. During the critical period, the background loads associated with the groundwater are more likely to dominate the stream concentrations than the surface runoff loads. However, because the MS4 component needed to be defined, the LA component is broken into the background component and the unregulated storm runoff component.

Background concentrations fluctuated around 0.25 mg/L. An additional 0.05 mg/L was used to account for any other unregulated storm runoff component and the MS4 component of the WLA that was previously mentioned. Therefore, a total phosphorus concentration of 0.3 mg/L was used to account for the sources other than the Town Branch WWTP.

Margin of Safety

The margin of safety (MOS) is part of the TMDL development process (Section 303[d][1)]C] of the Clean Water Act). There are two basic methods for incorporating the MOS (USEPA, 1991a):

1) Implicitly incorporate the MOS using conservative model assumptions to develop allocations, or
2) Explicitly specify a portion of the total TMDL as the MOS using the remainder for allocations.

In the current TMDL, the MOS is incorporated implicitly through underestimation of flow (the lowest period in 21 years instead of 10 years) and conservative (low) phosphorus settling rates. During the flow calibration, it was decided to slightly reduce the observed values so as not to introduce more dilution than was observed. The settling rates derived from depth rating curves for the various flow regimes in the stream were set slightly higher than normal. This adjustment of settling factors allowed for less settlement of total phosphorus than expected, thus yielding slightly higher concentrations, especially at the end of the reach (see Figures 10a – 10e). These factors adequately subject the stream to more adverse conditions (i.e., higher total phosphorus concentrations) than probably actually occurs.

TMDL Determination

Current EPA guidance (1991) allows TMDLs to be based on either steady-state or dynamic water quality models. Steady-state models provide predictions for only a single set of environmental conditions. For permitting purposes, steady-state models are applicable for single "critical" environmental conditions that represent extremely low assimilative capacity. For discharges to riverine systems, critical environmental conditions correspond to drought flows. The assumption behind steady-state modeling is that permit limits that protect water quality during critical conditions will be protective for the large majority of environmental conditions which occur. It is not appropriate to attempt to define a single critical stream flow for wet weather problems that is analogous to the critical (low-flow) condition traditionally used with continuous point source discharges. Furthermore, even when continuous simulation is used for point source discharges, the appropriate method of analysis is to examine model-generated data (receiving water concentrations) in terms of frequency and duration rather than to examine concentrations at a critical flow.

Continuous simulation generates daily values of stream flow and pollutant concentrations. With a well-calibrated model, the simulated stream flows and pollutant concentrations represent real-world conditions. Continuous simulation, as well as other dynamic modeling approaches, explicitly consider the variability in all model inputs and define effluent limits, which will be in direct compliance with the associated water quality standard. This is achieved through selecting a critical period for which load allocations create the most stressful situation. The critical period for TMDL development corresponds to the "worst case" scenario of environmental conditions in the waterbody in which the TMDL for the pollutant will continue to satisfy water quality standards (USEPA, 1999). For point source loading of nutrients where eutrophication is the end result, this period typically is characterized by low-flow conditions and the biological growing season. Temperature, light and nutrient concentrations are the driving forces for eutrophication. Therefore, it is appropriate to select the months from May to October as the critical period. This six-month period reflects the lower flow periods of the year coupled with the highest temperatures for the year.

A long period of record, 20 years or more, is generally used to account for year-to-year variations in weather and resulting stream flows. Therefore, it is reasonable to conduct a 20-year analysis for the purpose of identifying the year that has the lowest flows. Frequency analysis can be used to determine the "worst case" event. The subsequent TMDL calculations and load reduction values can then be determined on the basis of this "critical year." In the current study, stream flow records of South Elkhorn Creek were assembled and analyzed for the period of 1980-2000 (21 years). Figure 11 displays the six-month average flows for the months of May – October for the period of analysis. The lowest flow occurred in 1999. On the basis of this analysis, 1999 was selected as the most critical year for analysis, and thus it was used in determining the TMDLs for both Town Branch and South Elkhorn.

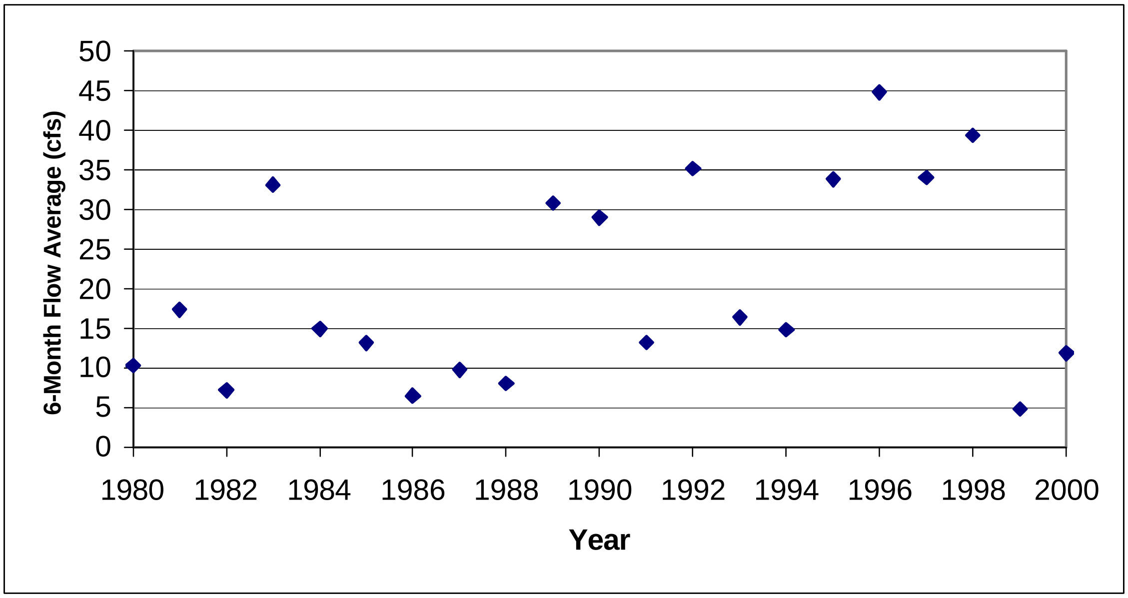


Figure 11. Six-Month Streamflow Averages for South Elkhorn Creek At Fort Springs, Kentucky

Once a critical year was selected, daily lateral inflow values (for the six-month model period) were determined for each model mile segment using the methods described previously. Daily average flows from the Town Branch WWTP were determined using historical records for the critical year. In order to assess the impacts of point source discharges from the Town Branch WWTP, the model was first used to analyze in-stream total phosphorus concentrations on South Elkhorn Creek one mile downstream of the confluence of South Elkhorn and Town Branch. This was accomplished by performing a series of six-month simulations in which the total phosphorus concentration discharged from the Town Branch WWTP was varied from 3.0 mg/L down to 0.5 mg/L using 0.5 mg/L increments. A plot of the maximum in stream concentration by river miles versus the Town Branch effluent concentrations is shown in Figure 12. From Table 3 and Figure 12, it can be observed that in order to achieve an in-stream total phosphorus concentration of 0.5 mg/L in South Elkhorn Creek, the Town Branch WWTP effluent concentration must be reduced from a six-month average total phosphorus concentration of 2.2 mg/l to approximately 1.0 mg/L. Using a maximum effluent concentration of 1.0 mg/L from the Town Branch WWTP along with the current permitted daily discharge of 30 MGD (46.4 cfs) yields a maximum daily load of 250 lbs/day.

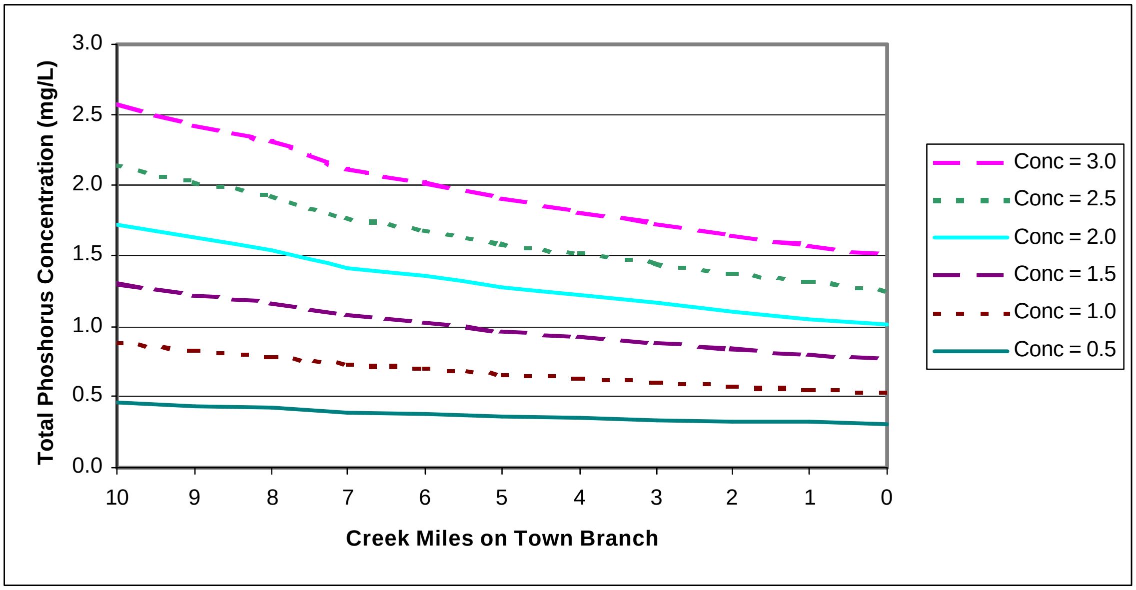


Figure 12. Maximum In-stream Concentrations of Town Branch WWTP Discharges

Waste Load Reduction Allocation

Due to the variability of the discharges and total phosphorus concentrations coming from Town Branch WWTP, it was not possible to identify a net waste load reduction for the Town Branch WWTP. However, based on the permitted discharge of 30 mgd and based on the 1999 summer average discharge phosphorus concentration of 2.2 mg/l, imposition of an effluent limit of 1.0 mg/l would result in a total load reduction of 300 lbs/day. As an alternative, it is recommended that the KPDES permit be modified so as to enforce load reductions that will result in a maximum daily effluent concentration of 1.0 mg/L during the summer period of May 1 through October 31, with additional associated reductions to ensure maximum daily effluent concentrations of 2.0 mg/L during the winter months (November 1 through April 30). All of the reduction (300 lbs/day) will be achieved through the Town Branch WWTP reduction in total phosphorus loading.

The MS4 contribution to the WLA is defined as 5 lbs/day. As mentioned previously, it was difficult to distinguish between background and surface runoff loads, but an estimate of this value is required. There is no load reduction associated with the MS4 component.

The same entity (the Lexington/Fayette Urban County Government [LFUCG]) is the holder of the permits for both the Town Branch WWTP and the Phase 1 MS4. At this point, it is more appropriate to define a reduction for the point source discharger because the point source discharger (the Town Branch WWTP) is responsible for the most significant loading of total phosphorus to the stream system during low-flow conditions.

Load Reduction Allocation

The load allocation (LA) for this TMDL is defined as 44 lbs/day. This load is based on a streamflow value of 30 cfs and a total phosphorus concentration of 0.30 mg/L, but minus the 5 lbs/day allocated to the MS4 component (included under WLA). The LA represents the unregulated nonpoint sources (5 lbs/day) and background sources (39 lbs/day). The LA of 44 lbs/day total phosphorus and the MS4 of 5 lbs/day (included under WLA) represents the average conditions present during the lowest 6-month period (May - October) within the time period, 1980 to 2000 (21 years). Low flow represents the critical condition when beneficial use is most at risk. However, increased flow conditions due to a rain event will result in an increase in load even if the concentration of total phosphorus remains constant. This material will flush through the stream system. It is therefore more appropriate to focus on the concentration of total phosphorus instead of the load of total phosphorus. For this stream system, the target concentration of the LA component and the MS4 component is 0.30 mg/L. There is no load reduction associated with either the LA component or the MS4 component. As previously stated, all of the reduction (300 lbs/day) will be achieved through the Town Branch WWTP reduction in total phosphorus loading.

Results

The TMDL is 299 lbs/day (total phosphorus) based on a Waste Load Allocation (WLA) of 250 lbs/day from the Town Branch WWTP (which corresponds to a total phosphorus concentration of 1.0 mg/L during the summer period) and 5 lbs/day from the regulated wet weather storm water (the Lexington Phase 1 Municipal Separate Storm Sewer System), termed MS4. The Load Allocation (LA) is 44 lbs/day, based on 39 lbs/day background and 5 lbs/day from unregulated storm water sources. The storm water component was divided between the MS4 component (part of the WLA) and the LA component per current EPA regulations. However, there is little information upon which to make this delineation, and this TMDL is targeting the low-flow critical condition. So, while the TMDL includes a minor runoff component, the focus was on low-flow conditions (the summer period) and the dominance of the Town Branch WWTP during low-flow conditions. This is the condition at which the beneficial use is most at risk. The proposed load reduction is 300 lbs/day. All of the reduction will be achieved through the Town Branch WWTP reduction in total phosphorus concentration and therefore loading. This value implicitly includes a margin of safety derived from conservative assumptions in settling rates, critical flow frequency and lateral flow estimates. These result in a higher in-stream phosphorus concentration. The TMDL was derived using the lowest flow conditions for a period of record of 21 years to recreate the worst-case scenario that would allow the attainment of the water quality target in all situations. The flows from the critical period were coupled with a constant WWTP loading to determine the impact the plant had on Town Branch and South Elkhorn Creek. Plant operation with a phosphorus concentration of 1.0 mg/L will successfully meet the TMDL's desired target value of 0.5 mg/L of total phosphorus in South Elkhorn Creek during low-flow conditions when beneficial uses are most at risk. The 0.5 mg/L target value constitutes a significant reduction in current in-stream concentration and therefore loading. The TMDL is to be implemented during the critical period from May through October where low flow and high temperature conditions exist and eutrophication is favorable.

This is a phased TMDL. The emphasis is to target a reduction in total phosphorus from the predominant source of phosphorus to the stream system (the Town Branch WWTP) during the critical flow period (low flow) when beneficial use is most at risk. Follow-up monitoring and evaluation will be necessary for this phosphorus TMDL on Town Branch. At the end of the first permit cycle, the permittee will conduct a biological survey of the stream system, using DOW protocols, to evaluate the biological health of the receiving stream. In particular, the location one mile below the confluence of Town Branch with South Elkhorn Creek needs to be evaluated to ensure that the TMDL is being implemented. After the results have been evaluated and if eutrophication continues to exist, a decision will be made whether additional reductions in phosphorus loading to the stream are necessary. If so, the TMDL will need to be re-evaluated.

In the future, if expansion of the Town Branch WWTP is needed, additional analysis of the TMDL will be conducted. Based upon this analysis, review of water quality data and stream observations, an increase in load may be possible. However, the concentration limit of 1mg/L would not be increased.

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