Report for 2005NY66B: GIS-based riparian buffer management optimization for phosphorous and sediment loading

Publications

- Articles in Refereed Scientific Journals:
  - Richards, P.L.; M. Noll; 2006, GIS-Based Buffer Management Optimization for Phosphorous: A Field Test of Whether a Topographically-Driven Phosphorous Model Can be Used to Locate Best Management Practices, manuscript in prep for JAWRA.
- Conference Proceedings:
  - Richards, P.L.; R. Grimm; D. Cannon; October 8, 2005, Depression Storage In Land Uses Common to the Finger Lakes Region, in 1st Annual Conference of the Finger Lakes Institute, Geneva, NY.
  - Richards, P.L., R. Grimm; D. Cannon; 2005, Depression Storage In Land Uses Of Western NY, in Annual Conference, Rochester Academy of Sciences.

Report Follows

GIS-BASED BUFFER MANAGEMENT OPTOMIZATION FOR PHOSPHOROUS:

A Field Test of Whether a Topographically-Based Phosphorous Model Can be Used to Locate Best Management Practices

by
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ABSTRACT

A study of phosphorous runoff was undertaken in the Black Creek watershed to determine if a topographically-based loading model could be used to regulate buffer width and assign best management practices. Field measurements of overland flow and chemistry were undertaken at 12 sites over a one month period. The results suggest that while the model correctly identified the presence of some important areas of concern, it can't be used to rank these areas without additional field verification. The data indicate that four sites (Paul Rd, US 20 North, Casswell N and Byron Rd East) could be significant sources of phosphorous. All of these sites have a direct surface connection to Black Creek. Other sites that had measurable phosphorous loads and should be considered for best management practices include Clipnock Rd, the tributary at Casswell Rd which should be buffered, and the site at Rte 33.

Topographic based loading models are attractive for guiding best management practices in theory, but several technical issues need to be overcome before they can be used for this function without field verification. These issues include the resolution of available digital elevation model which is too large, DEM quality which impacts the location and size of flow accumulation, tile drains which can significantly modify surface flow paths, and historic modification of the topography which is not always reflected in the DEM.

INTRODUCTION

It is well known that sediment erosion can have detrimental impact on the water quality of estuarine and lake ecosystems. In addition to the changes in geomorphic processes caused by additional sediment loads, many pollutants (phosphorous, metals, some pesticides) are carried in particulate form. As a consequence it is essential to identify where in a watershed these sediments come from and where they are likely to be carried into the stream transport network. Contemporary modeling techniques (SWAT, AGNPS, GWLF) widely used in TMDL studies to identify areas of concern, treat the sediment transport phenomenon as a nonsource problem in which the type of soil and landcover are assumed to generate a more or less uniform flux of sediment. This allows us to rank parcels in terms of their propensity for generating sediment based on landcover and soil information. It is well established that this is a gross oversimplification.

Erosion in fact occurs in specific areas where the distribution of water energy, substrate and topographic characteristics causes enhanced erosion and transport. Such sites are considerably smaller in scale than the size of the parcels with which soil and landuse information is collected in. Inherent in the practice of predicting erosion from soil and landcover maps is an assumption that the frequency and distribution of micro-erosional environments is uniform within particular landcover-soil associations. This has never been tested, furthermore the size of the spatial assessment (parcels) is too large to locate structural best management practices (BMPs) in anything but the grossest way.

Our working hypothesis is that contemporary loading models commonly used in TMDL work are inadequate to identify areas of concern because of their course resolution and the difficult and arbitrary way that parameters for them must be supplied by contemporary GIS data. One way of enhancing contemporary loading models and improving buffer management is to use topographic information to identify locations within parcels that, by virtue of their slope and aspect receive the most material. This could allow a more accurate determination of buffer widths required for successful NPS regulation. It may in fact be possible to buffer specific areas to obtain an acceptable level of protection for the stream network. Several types of hydrologic models that consider topographic information which could be used for this purpose exist; TOPMODEL (Beven and Kirkby, 1979); weighted flow accumulation (Richards and Campbell, 2002); (Endreny and Wood, 2003) and ANSFOR. In the simplest of these models (weighted flow accumulation algorithm, Richards and Campbell, 2002) phosphorous (or sediment) load is calculated from a rainstorm using soil and landuse information. A "flow accumulation" analysis is than applied to the digital elevation model (which is weighted to the result of the phosphorous model) to yield locations of sites where slope and aspect are likely to cause significant phosphorous and sediment transport. The next level of complexity is the TOPMODEL approach where this flow accumulation is carried out using a topographic index, derived from a Darcy treatment of flowpaths extracted from gridded elevation data. In the original model (TOPMODEL), only water flow is calculated, however more sophisticated versions of this model exist which incorporate chemical interactions to estimate sediment and phosphorous loads. The model by Endreny and Wood (2003) is an example of one of these models that use the topographic index approach in conjunction with event mean concentration data to compute phosphorous loads. It is possible that these innovative terrain modeling techniques can be used to develop better approaches for identifying areas of concern from easily obtainable GIS data. Such sites will be places where structural BMP's will significantly reduce sediment loads, and in particular, reduce the size fractions of mobile sediments that are carrying the most detrimental kinds of pollutants. It is possible that a combination of targeted BMP emplacement and variable width buffer management strategies may reduce extent of buffering required for significant nonpoint source pollution reduction. A process that greatly reduces the costs for successful watershed management.

The purpose of this study was to apply one of these models to the Black Creek watershed to develop a starting point with which to prioritize stream segments for BMPs. The second objective of this study was to conduct an exploratory field survey of overland flow to test how accurate the model was. Do they provide information that is really accurate with the current best resolution of available GIS and gridded elevation data (10 meter for the latter in New York State). Would a more advanced model do a better job with the resolution of available GIS data? At what scale should management decisions be made and are there field observations that might be more useful than the modeling for guiding management decisions?

METHODOLOGY

Research Plan Design

Our methodology was to apply the (phosphorous) weighted flow accumulation model in Black Creek watershed to identify the extent and spatial distribution of (high) phosphorous flow paths. Twelve sites representative of different levels of phosphorous flow transport were instrumented with runoff collectors (Figure 1) to estimate water and chemical (including Phosphorous) fluxes over a one-month period. The limited resources for the project didn't allow us to precisely measure fluxes, however, we were able to measure instantaneous volumes with simple runoff collectors and field observations after every rainfall event to be able to estimate the following load-related variables for each site:

Approximate volume of overland flow and total phosphorous
Mean concentration of phosphorous
Frequency of active overland flow

These field variables are then used to rank sites for their propensity to deliver phosphorous load. Two simple tests for the usefulness of these topographically based loading models for making management decisions are:

1) Does the model correctly predict the presence of overland runoff paths?
2) Does the model rank these sites in the same order as what the field data suggests?

If the rankings do not agree, the model's usefulness for the latter is called into question. In addition to comparing the field results to the modeling, this study also collected associated information from each site in order to elucidate why the model doesn't work. Is it a scale issue where the resolution of the GIS data prevented the model from assessing the site, a flaw in the model cause by not considering one or more crucial parameters, or some combination of both. Auxillary information we collected at each site to help us interpret our results included:

Catchment area associated with the runoff flowpath
Slope of the dominant flow path measured at two different scales
Depression Storage
Land cover
Soil texture
Soil moisture changes after the event
Duration of ponding after the event

A nonparametric statistical correlation between the phosphorous model and our flux-related independant variables was conducted to determine if the model has predictive value in identifying areas where buffer width should be modified. The methodology of the field runoff assessment, including how these above parameters were measured, are discussed in the following sections.

Synoptic Survey

To guide our selection of sites, a field survey and GIS assessment of 25 sites took place throughout the Black Creek Watershed. Sites were photographed, located by GPS and then evaluated by overlaying the phosphorous model on 2002 aerial photographs. Local crop cover was noted from field observations and the type of topography (straight hill slop, convex, concave) was identified. Using this information, 12 sites were selected for the field analysis. These sites were chosen because they have a broad range of different model phosphorous transport rates, and are representative of the topographic and landcover characteristics of rural stream segments in the Black Creek Watershed. Sites are located in the heavily farmed southwestern portion of the watershed (Figure 1).

Phosphorous Modeling

The model (Richards and Campbell, 2002) identifies locations in the watershed where topographic and land cover characteristics cause them to receive large quantities of total phosphate. These locations are sites that, by virtue of their slope and aspect, intercept runoff flow paths from large areas. The key to identifying these sites is to isolate parts of the watershed where flowpaths drain areas that produce high phosphorous loads. Such areas will be places where urban/agricultural land cover cause high event mean phosphorous concentrations. Overland flowpaths are mapped on the surface by analyzing a digital elevation model (DEM), a matrix of numbers that describes the elevation of the earth along evenly spaced intervals. Such intervals can be thought of as cells. An analysis of elevation differences between adjacent cells can be used create a "Flow direction grid" which describes the azimuth that runoff takes as it flows across the ground. Further analysis of the flow direction grid can be used to determine the total number of cells that flow through every cell. This concept is called "flow accumulation". In a routine flow accumulation procedure every cell is given the same weight (1) so that the value represented by a flow accumulation grid is the number of cells that ultimately flow into it. The model modifies the flow accumulation procedure by weighting each cell by the amount of phosphorous that was eroded. The result is a grid that represents the total amount of phosphorous that passes through every point.

Total phosphorous in the model is calculated by determining the amount of runoff shed from the cell by a 1 year return storm event and multiplying this quantity with the average concentration of phosphorous that is characteristic of water in the vicinity of the cell's soil and land cover. For the Black Creek watershed a 1 year storm event is expected to yield 2.3 inches of precipitation in 24 hours (DEC, 2003). Runoff is determined by computing the fraction of the cell that covered by directly-connected imperviousness and using two separate equations to determine the contribution of runoff from the directly-connected imperviousness and non-impervious parts of the cell. Precipitation intercepted by directly connected imperviousness is assumed to completely runoff. The SCS curve number procedure (SCS, 1986) is used to determine runoff from the rest of the cell. To identify the amount of imperviousness in each cell, we used average values of total imperviousness characteristic of the type of land use determined by the Rouge River Project from aerial photography (Klutenberg, 1994). Directly connected imperviousness was computed from total imperviousness using a function suggested by Alley and Venehuis (1981). Flow weighted event mean phosphorous concentrations were obtained from field studies of stream chemistry in the Rouge River. GIS data used in this analysis are 10 meter 1:24k USGS digital elevation models, a 1992 landcover dataset that was improved by Autin et al (2003) and county level SSURGO soil data.

Land cover and soil data were gridded into 10m by 10m cells for the project area and runoff was computed from each. Phosphorus loads were calculated by multiplying the runoff from each cell with its characteristic phosphorous concentration and a conversion factor that transforms inches of runoff from each cell into liters. Since the units of the concentrations data are in mg/liter the resulting erosion computations are in units of mg per cell per day. A digital elevation model gridded in the same manner as the soil and land cover data was weighted by phosphorous erosion after which the flow accumulation procedure was applied. The resulting data is plotted on a map of the Black Creek watershed and color coded by the total kg of phosphorous transported through each cell. The best way to interpret the data is to highlight cells that have low (<0.2kg/day) phosphorous transport loads and identify where they intersect with streams. Cells with higher loads are usually natural stream segments.

Topographic Analysis

The loading model was supplemented with a topographic analysis to determine the extent of internally drained areas. The PCSA algorithm (Richards and Brenner, 2004) was used to map the extent of large-scale internally drained depressions in the watershed (Figure 2). Areas outside of these depressions are directly connected and are capable of delivering sediment and phosphorous to the stream network. Although not explicitly used in the assessment of the phosphorous model, the results of this analysis will be useful for prioritizing BMP strategies in the Black Creek Watershed.

Field Runoff Assessment

Sites were instrumented with runoff collectors (Figure 3) to measure the volume of active overland flow. Runoff collectors were located in a topographic lows showing signs of drainage in the vicinity of where the phosphorous model determined a high phosphorous transport path exist. The small size of the runoff collector containers caused them to overflow on occasion, requiring visits to the site shortly after rainfall events to measure flow rates by hand. These measurements were made by measuring the flow rate through the runoff collector tube and over the back edge of the runoff collector using a graduated beaker and stop watch. Sites were visited and measured daily after the event until active runoff stopped. The duration of ponding in front of the runoff collector was also observed. Typically the first flow measurement was made within 18 hours of the event. To estimate total flow during the event we assumed this measurement was made at the peak flow and that overland flow did not occur before the event. A simple triangle was used to integrate the runoff during the active runoff period which is assumed to be 24 hours. This approach is crude and underpredicts the true volume of overland flow, however since the timing of observations was frequent and regular we could rank sites relative to each other qualitatively by counting the number of times the runoff collector was active. Small rainfall events did occur where some of the runoff collector did not overflow. From this information we could further rank sites in their propensity for generating overland flow. Site A whose runoff collector did not overflow obviously received more runoff than site B whose runoff collector overflowed in the same storm.

Samples were taken for chemistry from both the runoff collectors and active flow measurements. Electroconductivity and pH were determined in the lab. Water samples were filtered and analyzed with a Dionex Ion Chromitograph to determine dissolved SO4, NO3 and Cl. Unfiltered samples were dissolved in nitric acid and analyzed in a Inductively Coupled Plasma Spectrophotometer for Total Phosphate.

The length of significant ponding in front of the runoff collector was determined from field observations. Significant ponding is defined as visible ponding in greater than 75% of the area around the dominant flow path. Length is measured parallel to the dominant flowpath from the front of the rainfall collector. Soil moisture measurements were taken at 10 foot intervals along the dominant flowpath using a Campbell Scientific TDR probe. Measurements are in units of % volumetric water content and are representative of the top 12 cm of the soil profile. Three measurements were taken at each length interval and then averaged to determine the soil moisture content. The TDR is accurate within the range of soilmoisture contents of the factory calibration curve, however in ponded and saturated situations it determined the soil moisture content to be less than 100%. The measurements however were very reproducible. For each site the soil moisture content at total saturation (fully ponded conditions) was determined.

Catchment Area

The drainage area associated with each runoff collector was computed from an 0.5 meter contour map developed from the digital elevation model. To evaluate the contributing area, the drainage area associated with the runoff collector was digitized onscreen using the contours as background. A polygon topology was built from this feature using ArcGIS to estimate the drainage area.

Soil Properties

Soil properties were obtained by locating the site on the Genesee County Soil Survey. Seven surface samples of soil were also taken at 10 foot intervals along the main flow path. Time and resources ran out before we could analyze these samples for grainsize, soil texture and average phosphorous concentration.

Depression Storage

Depression storage was estimated from surface microtopography digitized with a roughness clinometer (Figure 4). Depression storage was measured 6 times at 10 foot intervals along the main flowpath upslope of the runoff collector. Storage was evaluted for each topographic high using an algorithm that determines the equation of a line that extends horizontally from the topographic high to a point where the line intersects with the ground surface. The area between this line segment and the ground surface is estimated numerically using the trapezoidal approximation. Storage associated with all topographic highs were summed and divided by the length of the roughness clinometer to obtain depression storage volume, per unit width, per unit length of flowpath. The dimension of this parameter is a simple length unit that is comparable to mm of rainfall. Thus, a depression storage of 5.6 means that the equivalent of 5.6 mm of rainfall can be stored in the surface without any runoff happening.

Slope

Percent slope of the dominant flowpath into the runoff collector was determined using the DEM and the roughness clinometer. The latter was computed by taking an average of six slopes measured by the roughness clinometer. Measurements were taken at 10 foot intervals along the dominant flowpath.

RESULTS

Site characteristics

Figures 5-11 present detailed aerial photographs with modeled P flowpaths, runoff collector locations and runoff collector catchments superimposed. Mean depression storage varied from 5.7 to 15.6 mm with a typical standard deviation of 3.5. Furrows caused by plowing were a major cause of the depression storage. The PCSA algorithm determined that a significant portion of the watershed is internally drained away from the stream network (Figure 12). A closeup sample of the results of this model are presented in Figure 13. Slopes as measured by the roughness clinometer ranged from 0.6% to 4.7% at the runoff collector sites.

TABLE 1 **Characteristics of the sites determined from GIS data**

Site	Drainage Area (ha)	Soil Musym	Soil Hydro Group	Land Use	% Slope
Byron East	9.72	La	D	210	0.5
Byron West	18.22	La	D	210	0.2
Casswell N	0.53	La	D	210	1.1
Casswell NW	6.04	CaA	D	210	0.9
Casswell S	0.08	La	D	210	0.5
Casswell SW	0.11	CaA	D	210	0.5
Clipnock Rd	0.07	MoB	B	210	0.5
Paul Rd	9.68	Ma	D	210	0.3
Rte 20 N	7.82	Ee	B	310	1.5
Rte 20 S	0.04	Ee	B	310	1.6
Rte 33	0.06	LmB	B	200	2.2
Searls	0.06	MmB	B	210/300	1.4

Table 2 **Field characteristics of the runoff collector sites**

Site	Crop cover	Number of Measurements	Average Depression Storage (mm)	Stdev Depression Storage (mm)	% Slope
Byron East	Alfalfa	17	5.9	2.7	1.2
Byron West	Alfalfa	9	7.8	2.6	0.6
Casswell N	Alfalfa/Soy	15	4.2	1.9	2.7
Casswell NW	Alfalfa/Soy	6	8.7	4.0	2.9
Casswell S	Corn	6	11.4	5.9	3.5
Casswell SW	Corn	6	12.5	2.8	1.3
Clipnock Rd	Cabbage	6	15.6	4.9	4.7
Paul Rd	Corn	n/a	n/a	n/a	n/a

Rte 20 N	Weeds/Fallow	5	5.7	2.2	1.7
Rte 20 S	Weeds/Fallow	6	8.9	5.1	1.5
Rte 33	Fallow/Wheat	6	6.4	3.3	2.6
Searls	Soybean	6	7.6	3.3	1.4

Runoff Assessment

During the survey, a total of 3.99 inches of rain fell during the approximately 38 day period of assessment (the observation period varied between sites depending on when the runoff collector was installed). This rainfall occurred as 6 significant storm events and 4 smaller (<0.30 in) rainfall events that had no significant hydrologic impact (Figure 14). Observed overland flow discharge rates varied significantly between the twelve different sites, ranging from 0.006 l/sec to 21.6 l/sec. For the two sites where active flow measurements were abundant (US20N and Paul Rd), instantaneous flow measurements could vary as much as 4 orders of magnitude within the site implying significant temporal variability. Total runoff volumes were normalized by the total period of observation at each site to make the sites comparable. Flow measurements taken by current meter from Paul Rd (3 measurements) and Byron East (1 measurement) had to be adjusted by multiplying by a ratio of the width of the runoff collector over the width of the flow measurement. This needed to be done to make the values comparable to runoff collector measurements since flow measurements made by the current meter represent a larger width of the flowpath.

Table 3 **Flow estimates and saturation parameters for the sites**

Site	Period of Observation (days)	Log Runoff Volume (Liters/day)	Fraction of period when overland runoff occurred (days/days)	Ave. Length of ponding (ft)
Byron East	38	+ 2.0	0.29	13.3
Byron West	37	+ 0.9	0.22*	3.3
Casswell N	44	No runoff	0.00	0.0
Casswell NW	34	+ 2.1	0.12	23.3
Casswell S	37	+ 0.4	0.11	3.0
Casswell SW	34	+ 0.2	0.09	23.3
Clipnock Rd	33	+1.8	0.15	10.0
Paul Rd	31	+5.0	1.00**	86.7
Rte 20 N	30	+ 3.4	0.40	7.7
Rte 20 S	31	No runoff	0.00	0.0
Rte 33	33	+ 0.6	0.12	2.7
Searls	31	-1.3	0.06	0.0

*May be caused by groundwater inundation

**Active overland flow was observed on every visit to this site even during dry conditions.

Chemistry

Electroconductivity varied significantly between sites as well as flows within one site. The highest electroconductivities appeared to be associated with samples taken from the runoff collector. As these samples are biased to water at the start of the event, they include sediment washed off during "first flush". This material may have contributed to the high electroconductivities. Measurable levels (0.3 - 2.4 mg/l) of total phosphorous were found at all sites. Dissolved nitrate levels were fairly low (< 1 ppm) for most sites, except for Casswell SW and Clipnock Rd which had 10.3 and 7.6 mg/l respectively.

Table 4 **Overland flow chemistry**

Site	Number of Samples	EC	Ave. diss. Cl (mg/l)	Ave. diss. SO_4 (mg/l)	Ave. TP (mg/l)	Ave. diss. NO_3 (mg/l)
Byron East	13	1660	199	12	0.6	0.1
Byron West	6	2243	325	97	0.4	0.1
Casswell N	0	n/a	n/a	n/a	n/a	n/a
Casswell NW	3	418	9	23	1.5	1.0
Casswell S	4	255	17	34	2.4	0.3
Casswell SW	2	192	17	21	0.9*	10.3
Clipnock Rd	5	491	65	13	1.0	7.6
Paul Rd	7	430	15	35	0.3	0.4
Rte 20 N	10	610	70	28	0.4	0.5
Rte 20 S	0	n/a	n/a	n/a	n/a	n/a
Rte 33	3	117	3	3	0.7	0.4
Searls	1	n/a	0.5	3	1.53	0.5

* Only 1 sample analyzed for Phosphorous

Two sites (Byron E and W) had unusually high chloride, sulfate concentrations and electroconductivities. These sites were believed to be heavily influenced by groundwater. The runoff collector at Byron West in particular was located near the water table. The water table rose above the inlet tube for the runoff collector 4 days after the 10/26 storm event, this is long after the watertable dropped below the inlet of the Byron East collector. The berm associated with Byron rd, which is several feet higher than the ground, effectively prevents any surface runoff from the drainage area associated with Byron West. The homeowner who lives across the street from the site says that the site becomes a large pond for much of the early spring. Byron east has a culvert which enables surface runoff to leave the site. The chemistry is much more concentrated between Byron west and Byron east, despite their similarities in soil type, bedrock geology, and landuse. This suggests that the water collected by the Byron West runoff collector is more heavily influenced with groundwater than in Byron East. The high concentrations are not believed to be road salt contamination since both sites are upgradient of the road. Cl concentrations are interpreted to be caused by deep groundwater brines originating from a fracture associated with the Clarendon-Lindon fault. This feature has been mapped directly underneath the Byron road sites.

Field and Modeled Phosphorous Flux Estimates

Using are overland volume estimates and the chemistry data, we computed phosphorous fluxes for the period of observation when all sites were operating correctly (10/18 - 11/18; 32 days). Due to the crude nature of the overland flux measurements discussed previously, these values should only be used in a comparative way between sites.

Table 5 **Overland Phosphorous Flux Calculations**

Site	Log total P (g)	Log total P (g/day)	Log total P (g/day/ha)	Modeled total P Log (g/day)
Byron East	0.4	-1.1	-2.1	-1.7
Byron West	-0.9	-2.4	-3.6	-0.5
Casswell N	No Load	No Load	No Load	-1.9
Casswell NW	0.8	-0.7	-1.5	-0.3
Casswell S	-0.6	-2.1	-1.0	-2.0
Casswell SW	-1.3	-2.8	-1.9	-0.4
Clipnock Rd	0.3	-1.2	-0.0	-2.0
Paul Rd	+ 3.0	+1.5	+ 0.5	-1.4
Rte 20 N	1.5	0.0	-0.9	-2.4
Rte 20 S	No Load	No Load	No Load	-2.7
Rte 33	-1.1	-2.6	-1.4	-1.4
Searls	-2.6	-4.1	-2.9	-0.7

Modeled flux estimates were made by identifying the pixel nearest the runoff collector with the highest 24 hour phosphorous load. In some sites the DEM was poorly aligned with the stream coverage and aerial photograph, requiring an estimate of where the runoff collector ought to be in the phosphorous model results.

DISCUSSION

Overview

We found the model was useful in the field to identify the presence of ephemeral flowpaths, however the features were not always in the exact location. Bringing small plots of the phosphorous model superimposed on aerial photography in the field was found to be an effective way to find areas prone to flooding. Location errors were commonly larger than the spacing of the DEM (10 meters) indicating registration problems with the DEM or aerial photography. In some situations, the flow paths exist but are blocked by an anthropogenic feature or topographic high that is smaller than the resolution of the feature. Even the absence of finding the feature where the model said it should be was useful, because it indicated major flowpath changes occurring upslope. The geologic explanation for these aberrations often have significant implications for watershed management.

Site Rankings

For sites with active flow observations, flux calculations allow them to be ranked. Although we do not know the precise shape of the hydrograph, we can estimate it as a simple triangle and have assumed a time ordinate of 24 hours. We realize this is only semi-quantitative, however we believe the order of magnitude differences observed between sites enable us to use this technique to enable relative comparisions between sites. Sites with no active flow observations where the runoff collector overflowed are problematical because it is not possible to determine the volume of overland flow that occurred. We only know that the volume is larger than a gallon (the maximum amount of runoff held by the runoff collector) and smaller than the volume of flow required to sustain active overlandflow when the site was assessed (typically 12 to 36 hours after the event). To rank sites that only had runoff collectors that overflowed, we used three additional criterion to rank them relative to each other:

Fraction of days where overland flow was active
Extent (length) of ponding upslope of runoff collector 1 day after the event
Average soil moisture content relative to saturation 1 day after the event
Total estimated phosphorous flux

Table 6 shows the ranking of the sites from highest to lowest based on the above criterion. We feel confident of the top three rankings because of the large differences in total phosphorous loads. Byron East was ranked higher than Clipnock road because it was active at twice the frequency. Casswell S has 30% greater load than Byron West but the latter was active twice as much, although some of this activity may have been caused by groundwater inundation. Rte 33 was ranked above Casswell SW by virtue of the latters lack of overland flow activity. Searls, US20 South and Casswell North were ranked last because of the low phosphorous load and absence of overland runoff activity.

Table 6 **Site Ranking based on the observed field criterion**

Site	Log total P (g/day)	Fraction of period that overland flow was active (days/days)	Average length of ponding (ft)	Average Ø/Øsat after the 10/26 event
Paul Rd	1.5	1.00**	86.7	sat
Rte 20 N	0	0.4	7.7	0.84
Casswell NW	-0.7	0.12	23.3	0.86
Byron East	-1.1	0.29	13.3	0.89
Clipnock Rd	-1.2	0.15	10	0.70
Casswell S	-2.1	0.11	3	0.77
Byron West	-2.4	0.22*	3.3	0.85
Rte 33	-2.6	0.12	2.7	0.74
Casswell SW	-2.8	0.09	23.3	0.91
Searls	-4.1	0.06	0	0.58
Rte 20 S	No Load	0.00	0	0.56
Casswell N	No Load	0.00	0	0.65

*May be caused by groundwater inundation
**Active overland flow was observed on every visit to this site even during dry conditions.

According to the phosphorous model, the sites are ranked in the following sequence (Table 7) for their propensity of contributing phosphorous to streams.

Table 7 **Sites ranking based on the GIS-based Phosphorous Model**

Site	Log modeled total P (g/day)
Casswell NW	-0.3
Casswell SW	-0.4
Byron West	-0.5

Searls	-0.7
Rte 33	-1.4
Casswell N	-1.9
Clipnock Rd	-2.0
Casswell S	-2.0
Paul Rd	-2.5
Byron East	-2.7
Rte 20 S	-2.7
Rte 20 N	-3.5

Site Rankings Compared to the Phosphorous Model

The second question addressed in this study was to determine the effectiveness of a GIS-based phosphorous model in ranking sites appropriate for BMP's. From the practical point of view these models are benefitial for making BMP decisions if they can rank sites in a relative sense accurately. Precise flux calculations are not necessary. To determine this from our field data we performed a Kendall's Tau analysis between our flux parameters and the P model. Kendall Tau is a nonparametric significance test for correlation suitable for small (<20) datasets with outliers. What is evaluated in this test are to what degree the rankings (not the values) are correlated between our variables of interest. Like the Pearson correlation, a Kendall's Tau correlation ranges from -1 to 1 with 1 being a strong correlation between the rankings of the model and the field sites. A good model for making management decisions should have a high positive Kendall Tau between ranks. One would be perfect and indicate the order determined by the model is the same as the order determined by field data. A Kendall Tau correlation was found to be -0.17, a very weak negative correlation. A Z-test (dF = 12, α=0.05) for this test reveals this correlation to be not significant. The site rankings from the field observations do not follow the rankings interpreted from the phosphorous model. What could be the cause of the differences?

In the Byron Road case, the site at east Byron shows considerably more runoff and phosphorous flux then west Byron, despite the prediction of the model. Catchment area supports the phosphorous model assessment ranking for these two sites, with west Byron catchment area being twice as large. Since the landcover, soil hydrologic group are the same (Alfalfa and D, respectively), Byron West should deliver more phosphorous. One possibility may be the existence of tile drains, which according to George Squires (personal communication) could be taking material away from Byron West's drainage basin. The berm of Byron road effectively blocks any surface drainage from Byron West to Black Creek though the model does not detect it. Locating a BMP here is completely unnecessary. In contrast Byron East is directly connected to a drainage ditch that empties into the main stem of Black Creek.

In the Rte 20 case, the model correctly predicted that US20 S would not be a significant source of phosphorous and ranked it as unimportant, however it incorrectly ranked US20 N which field evidence suggest is the second largest contributor of the 12 sites. The cause was the presence of a small tile drain under a driveway which greatly extended the catchment area west of the site. Inspection of aerial photography and field observations suggest that drainage runs east along the road to the US20 N runoff collector. While a contour map of the DEM does show a gradual upslope grade and we were able to define by hand a large catchment for this runoff collector, the region immediately to the west was too low-sloped for the flow direction algorithm in the model to identify a large catchment for this runoff collector. Low slopes are problematic for flow direction algorithms because at the scale of the DEM, adjacent cells are sometimes given the same elevation. With the absence of a significant pour point or several pour points of equal value, the software will incorrectly assign it a flow direction which in this case led to a model catchment area that was significantly lower than the actual one. It is tempting to suggest a higher resolution DEM could have improved the model, however the driveway to the west of the runoff collector would still give the model issues because it is located on a high berm.

The model incorrectly ranked the site at Paul Rd which was found to be the largest contributor of phosphorous of all of the sites in the study. Inspection of aerial photography suggests the flow at Paul Rd was running along an abandoned channel that runs diagonal through the corn field. Black creek appears to have been rerouted historically to flow along the eastern edge of the crop field. The topography must have changed since the data for the DEM was acquired. In this case the DEM did not reflect historic changes in the topography which caused the model to incorrectly identify the position of an important source path of phosphorous.

The sites at Caswell Rd show mixed results. Casswell NW was ranked by the model as the most important contributor of phosphorous. In the observed data it was also ranked high (3rd largest contributor). The other sites were miss-ranked significantly. The rankings within the Casswell sites themselves were also misranked except for Casswell NW At the Casswell site all soils are soil hydrologic group D, thus the result of the model was controlled primarily by the area of flow accumulation. The performance of the model was interpreted to be caused by poor DEM registration and functional limitations (the model does not account for depression storage or slope, which vary significantly between the sites). Average depression storage was about 0.48 inches for Casswell SW compared to 0.16 inches for Casswell NW. These minor differences may have an impact on the response of these sites to small precipitation events. There was another odd aspect of the DEM at Casswell Rd, the slope computed from it was much lower than the slopes measured in the field. The poor quality of the DEM in the vicinity of Caswell rd has clearly limited the usefulness of the model for predicting precisely where the phosphorous flowpaths intersect the stream network.

Implications for Watershed Management

The results seem to indicate that the phosphorous model, while correctly identifying the presence of phosphorous transport paths, has limitations in identifying exactly where they are in the field and whether there is a direct hydrologic connection to the drainage system. While these models theoretically have to work, the 10 meter DEM we used doesn't seem to represent the slope and topography of hydrologically-relevant scale. Some of the problems stem from poor registry between the DEM and aerial photographs used in the analysis, as well as offsets between valleys in the DEM and the real position of stream valleys. Another problem is anthropogenic modifications in topography which occurred after the data for the DEM was collected or are too small to be captured by the resolution of the DEM. Our study suggests these subtle features can have a tremendous impact on surface drainage. It is important to note that the more advanced hydrologic models that utilize topography for routing overland flow are also subject to the same problems that made our model inaccurate. It makes no sense to apply these more sophisticated models when our simple phosphorous accumulation model will probably deliver the same result.

Tile drains, ubiquitous in the watershed, are problematic because they can greatly increase or decrease the effective catchment area associated with the flow path. USDA conservation districts commonly maintain detailed records of tile drains. Tile drain maps should be consulted when making onsite BMP decisions and when interpreting the results of topographically based loading models. Road berms which over many years of maintenance can build up in elevation. These features may block flow paths and can reroute overland flows over long distances. They may also impact the average watertable depth which can influence surface drainage. Byron W site is a good example of this. Topographically-based models should use DEMS that specifically take these into account. DEM's developed from some of the older 24K USGS contour maps (such as this study) will NOT reflect the subtle but significant changes in elevation caused by roads and other transportation infrastructure.

Besides the academic findings of the study, this research has identified four sites of concern that should be addressed with BMP's in the watershed. They are (in descending order of importance): Paul Rd West, US20 N, Casswell N and Byron East). The sites at Clipnock Rd, Casswell S, Casswell SW and Rte 33 are also contributing significant amounts of phosphorous. In the case of the Casswell sites, the Black Creek tributary has very little buffering. All are capable of contributing measurable loads of phosphorous and sediment to Black Creek. While this phosphorous model appears to be useful for identifying the presence of areas of concern, it does not appear to be capable of ranking sites relative to each other without extensive field observations. Regulating buffer widths based on this model without field checking seems unwarranted. It appears the best way to apply this phosphorous model is to use the output to identify multiple sites of concern, follow each up with field observations to winnow down the sites to the important ones and then address each site with the unique set of geomorphologic and field conditions that governs its hydrologic response. Each site should be evaluated for connectivity to the stream network. There is no point in regulating a wide buffer zone in a site where a road berm effectively stops all overland flow. Much can be learned by identifying through aerial photography or field observations, what kinds of anthropogenic features (roads, etc) intersect phosphorous flowpaths predicted by the model. So while the model is often inaccurate in identifying the location of phosphorous transport paths, understanding why it is wrong provides us with valuable information that is useful for assigning effective best management practices. Our model and field results have been presented to the Black Creek Watershed Coalition in digital form. We hope they find it useful as they prioritize best management practices for this watershed.

CONCLUSIONS

A field and modeling study of phosphorous was undertaken in 12 sites in the Black Creek watershed to determine if a phosphorous model could be used to regulate buffer width and assign best management practices. The study suggests that while the model correctly identified the presence of some important areas of concern, it can't be used to rank these areas without additional field verification. Measurements of overland flow and chemistry indicate that four sites (Paul Rd, US 20 North, Casswell N and Byron Rd East) could be significant sources of phosphorous. All of these sites have a direct surface connection to Black Creek. Other sites that should be considered for best management practices include Clipnock Rd, the tributary at Casswell Rd which should be buffered, and the site at Rte 33.

Topographic based loading models are attractive for guiding best management practices in theory, but several technical issues need to be overcome before they can be used for this function without field verification. These issues include the resolution of available DEM which is too large, DEM quality which impacts the location and size of flow accumulation, tile drains which can significantly modify surface flow paths, and historic modification of the topography which is not always reflected in the DEM.

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Impacts

Funding from the grant was also used to design the hardware and software of the Roughness Clinometer, a device used to measure depression storage, roughness and slope in the field. Details of the device can be found in:

http:\\vortex.esc.brockport.edu\~pauljr\inventions

REFERENCES

Alley, W.M. and Veenhuis, J.E. (1983) Effective Impervious Area in Urban Runoff Modeling. *J. Hydraul. Div., Amer. Soc. Civ. Eng*., **109**:313-319.

Autin, W, Noll, M. and Zollweg, J. (2003) *Black Creek State of the Basin Report*, Black Creek Watershed Council

Beven, K.J. and Kirkby, M.J. (1979) A Physically Based Variable Contributing Area Model of Catchment Hydrology. *Hydrological Science Bulletin,* **24**, 43-69.

Endreny, T.A. and Wood, E.F. (2003) Watershed Weighting of Export Coefficients to Map Critical Phosphorous Loading Areas, JAWRA, **39,** 165-181.

Kluitenberg E., (1994) Determination of Impervious Area and Directly Connected Impervious Area., Wayne County Rouge Program Office Memorandum.

NY State DEC (2003) *Stormwater Management Design Manual*, Center for Watershed Protection, 416pp.

Richards, P.L. and Brenner, A.J. (2004) Delineating source areas for runoff in depressional landscapes: Implications for hydrologic modeling. *J. Great Lakes Res*. **30(1)**: 9-21

Richards, P.L. and Campbell, H L. (2002) Strategies for locating BMP's in Glacial-Depressional Terrain; *Annual Water Resources Association Annual Meeting, Philidelphia, PA*

Richards, P.L. and Grimm, R. (2005) Depression Storage in Land Uses Common to the Fingerlakes Region, 1st Annual Conference of the Finger Lakes Institute, Nov. 10, 2005; Geneva NY.

Soil Conservation Service (1986) Urban Hydrology for Small Watershed. Tech. Rep no 55, 2nd ed. U.S. Department of Agriculture, Washington, DC.

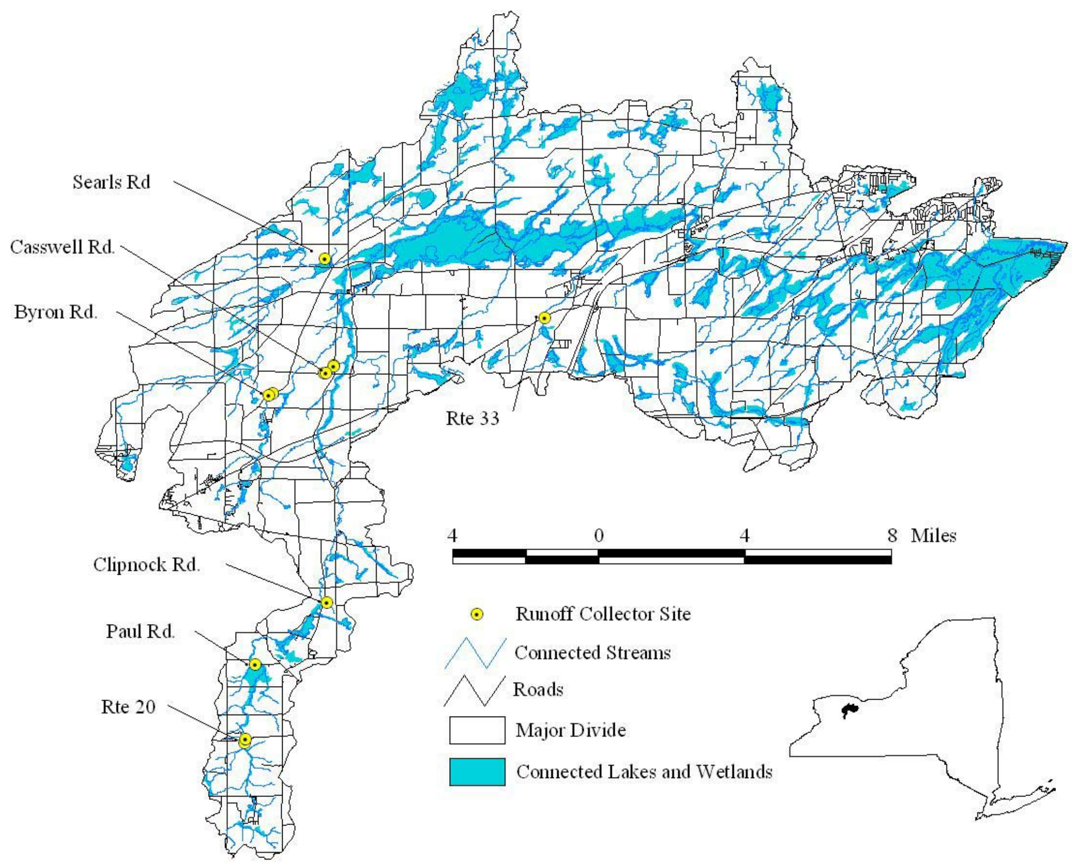

Figure 1 The study area, Black Creek Watershed, is located in western NY. A topographically-based phosphorous loading model was run over the entire watershed to identify sites on streams where, by virtue of slope and aspect, receive greater than normal phosphorous loads. The idea was to target stream reaches at these sites with wider buffers or other appropriate best management practices. Field measurements of overland flow and phosphorous fluxes were conducted on 12 of these sites to determine the validity of the model.

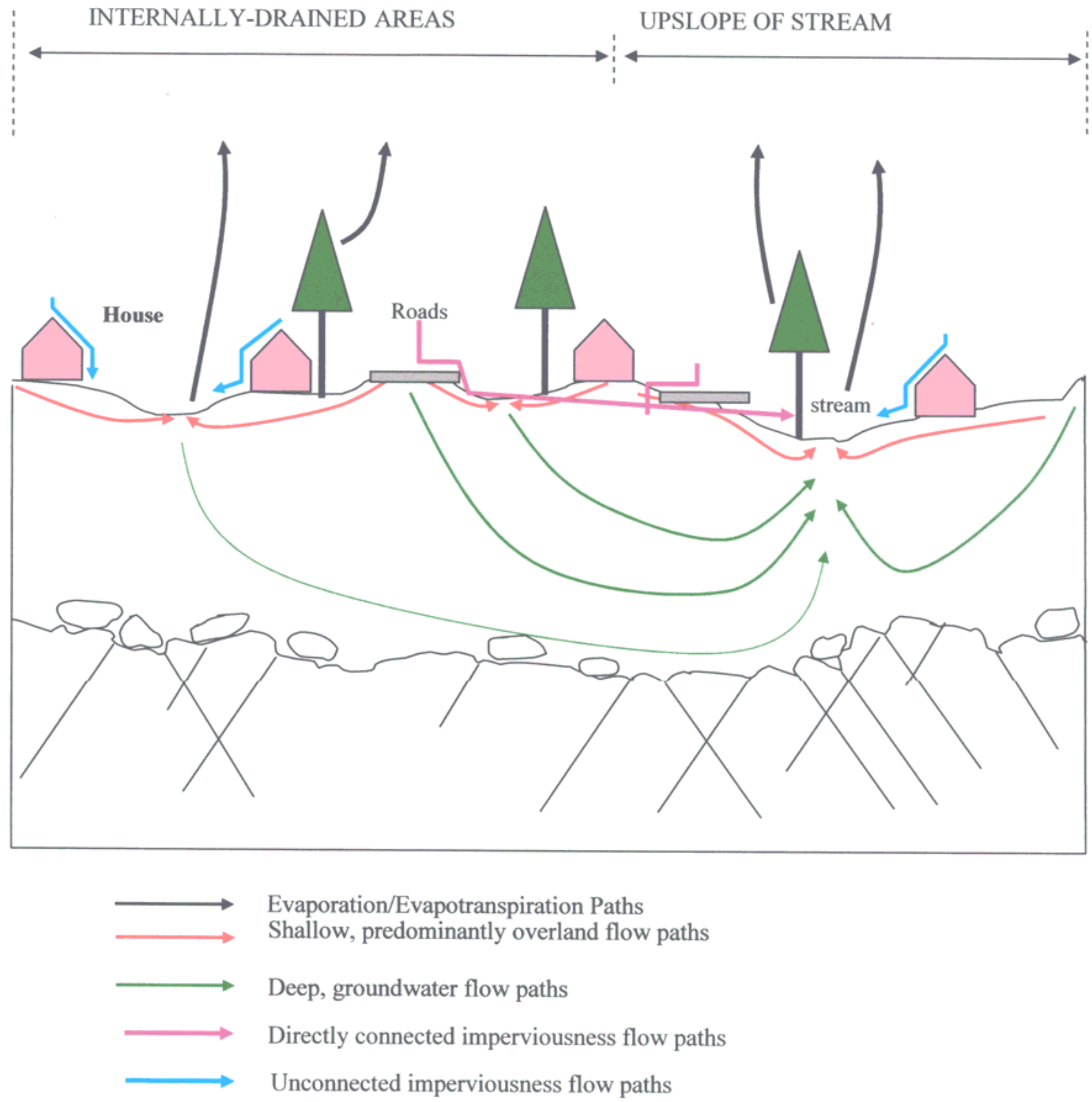

Figure 2 Schematic of watershed profile showing flowpaths associated with Internally-drained and directly-connected areas. These areas were mapped in the watershed using the PCSA algorithm (Richards and Brenner, 2004) to identify topographically connected areas where sediment and particulate phosphorous fluxes can possibly reach the stream network. Internally-drained areas are also important because they can be areas of enhanced groundwater recharge.

Figure 3 Runoff collectors designed for this study that were used to estimate overland runoff volumes. Overland runoff enters the hole at the front of the rain shield, flows through a collection tray and then into a 1 gallon water jug which is located in a 12 by 12 by 14 inch hole underneath. These collectors are accurate for small < 4.3 liter overland flow events. Higher volumes overflow into the hole. The design of the collector facilitates accurate measurements of active overland flow by allowing the user to measure discharge with a beaker and stopwatch.

Figure 4 Device (roughness clinometer) designed for this study that was used to measure depression storage and slope at runoff collector sites. The device is placed into the ground along the direction of maximum slope and dowels are lowered to touch the ground. Measurements of dowel displacement are then processed with software (rough4.exe, available at http:\\vortex.esc.brockport.edu\pauljr) to calculate depression storage, slope and surface roughness. Prior to using the instrument, the site is cleared of sticks and dead vegetation. Details of the device can be found in Richards and Grimm (2005) as well as on the above web site.

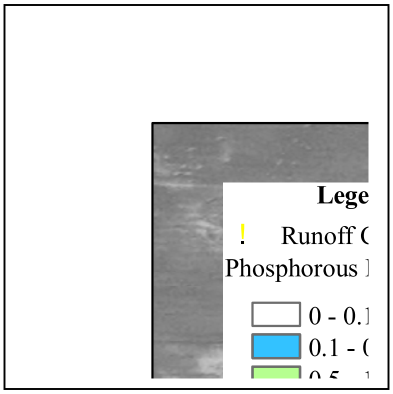

Figure 5 Modeled phosphorous flow paths superimposed on a 2002 aerial photograph of the Byron Rd sites. Runoff collectors for Byron East and Byron West are indicated. Note the drainage ditch that directly connects Byron East to Black Creek. Byron Rd effective blocks surface drainage from Byron West.

By

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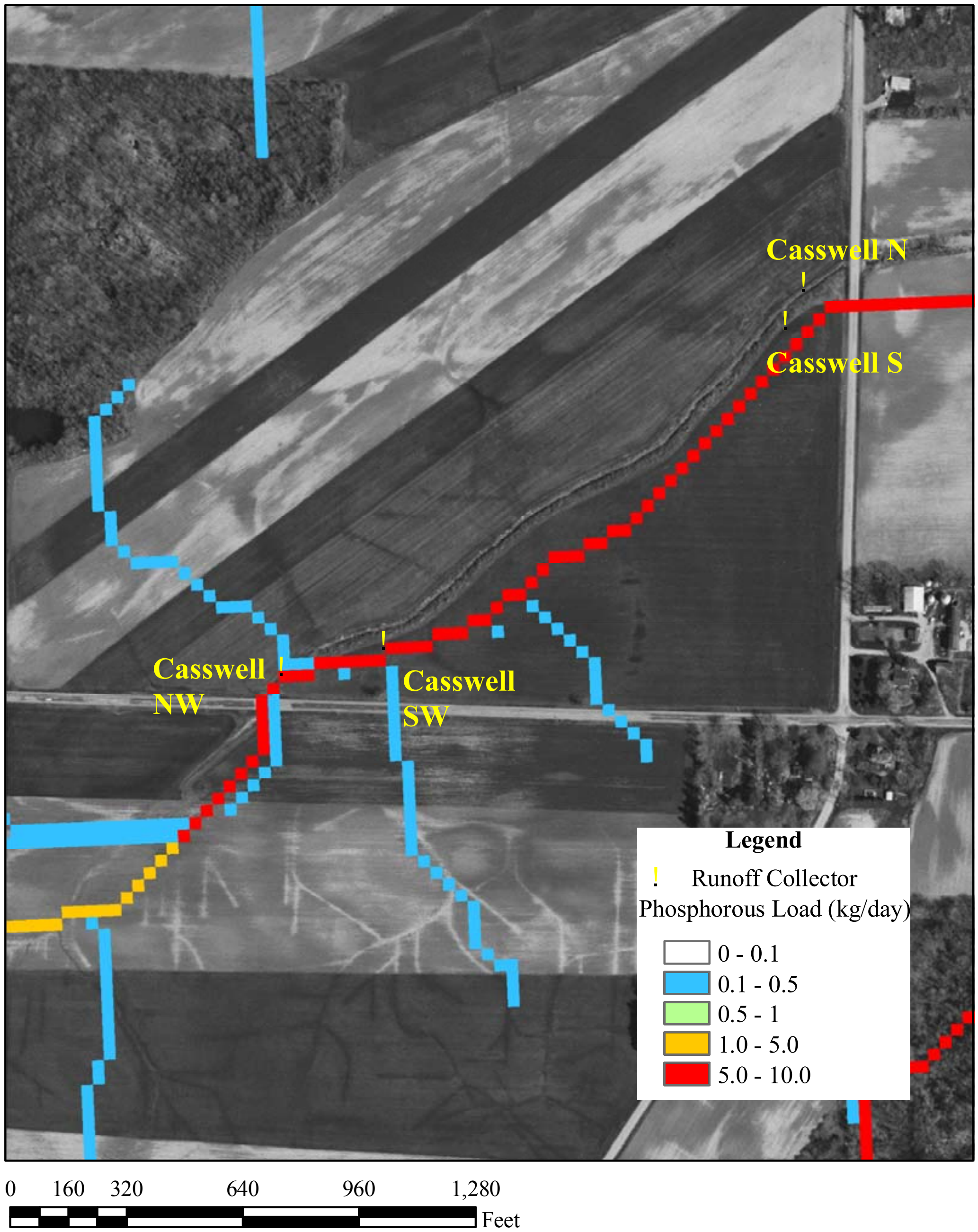

Figure 6 Modeled phosphorous flow paths superimposed on a 2002 aerial photograph of the Casswell Rd sites. Runoff collectors for Casswell N, Casswell NW, Casswell, S and Casswell SW are indicated. Note the offset of the model below the stream.

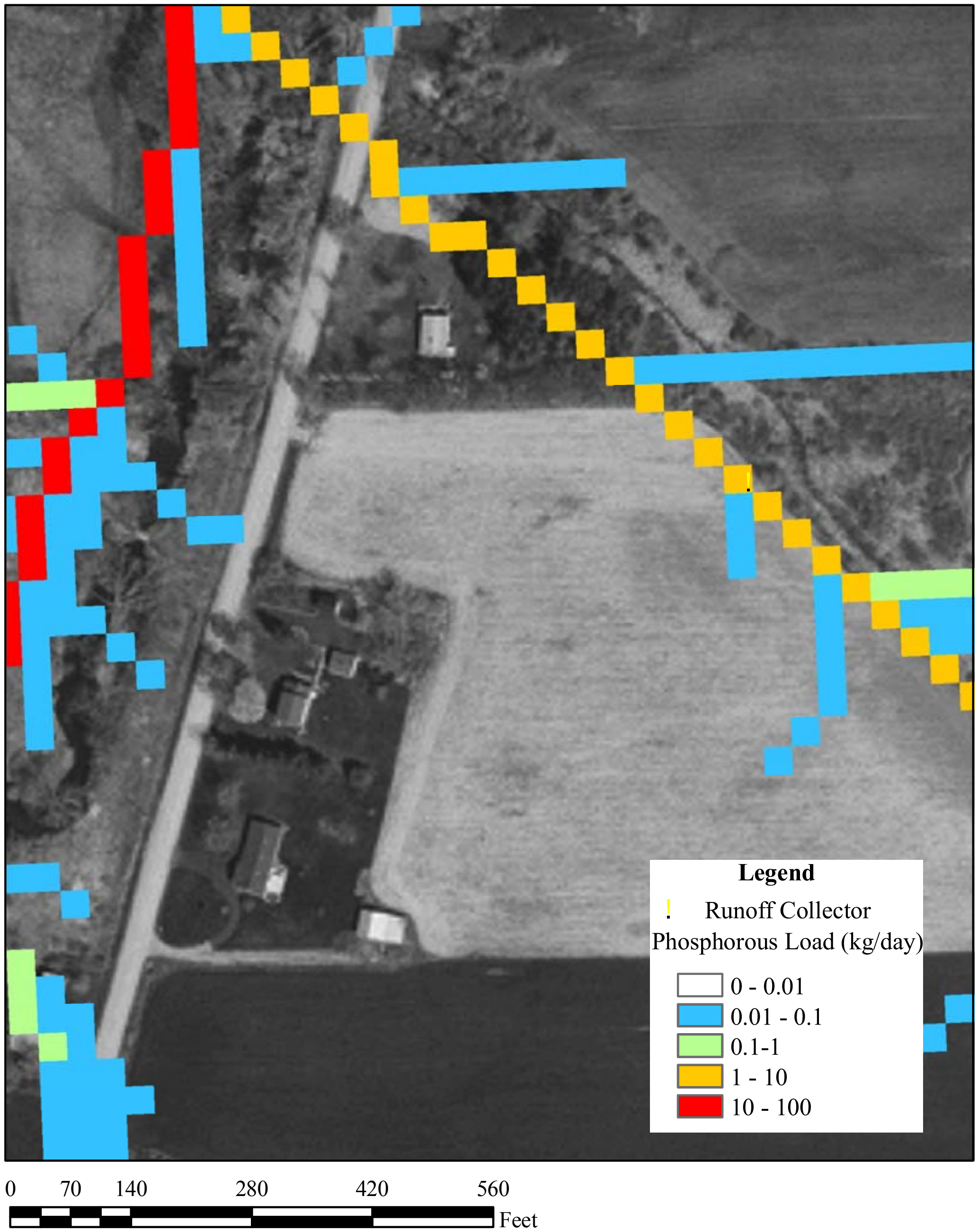

Figure 7 Modeled phosphorous flow paths superimposed on a 2002 aerial photograph of the Clipnock Rd site. The runoff collector for Clipnock Rd is indicated.