Sources and Sinks of Nitrogen in the Spring Creek Watershed

May 1995

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This page examines chlorophyll and finds that even at lowest flow (.25 m^3/sec) the residence time is only aft 33 hrs (based on total volume of lakes = 30,000 m^3), while the shortest doubling time for the most prolific phytoplankton (about 2 days), so the residence time is the factor limiting phytoplankton growth in the lakes.

If they were dredged, then, the residence time would be expanded, but it still probably would only allow 1 or 2 doublings which shouldn't be a problem.

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Abstract

As a follow up to a study done by the authors in 1994, nitrate concentrations in the Spring Creek watershed were mapped biweekly over an eight week period. The results were compared with the nitrate content of other systems, including rainwater, interflow water, spring water, other lakes and effluent nutrient levels from sewage treatment plants. Possible sources and sinks for nitrate within the watershed were explored. It was found that the nitrate levels in the creek were highest (75 ppm) where field tiling pipes were the main source of water. These levels decreased along the length of the watershed (3.75-10 ppm at lowest site). Data suggest that the primary source of the nitrate is diffuse agricultural pollution. The main sink is likely to be the wetland areas along the stream bed. It is probable that the high nitrate levels contribute to cultural eutrophication in Lyman Lakes and other lakes along Spring Creek. The low levels of phosphate and ammonia found in the water, and high algae growth in all the depression storage areas in the watershed suggest that nitrogen is not the limiting nutrient in the aquatic system.

Introduction

Lyman Lakes and Spring Creek are profoundly impacted by the changes humans have brought to them, specifically due to agriculture and other land uses. These waters have to be under careful management to maintain a healthy biotic composition. To understand the whole system one must understand the connections between the biosphere, the geosphere and human effects on both.

Orr and Pfeiffer (unpublished data, 1994) began to examine these relationships by attempting to make a water budget for Upper Lyman Lake and construct a nutrient budget from the water budget data. The project proved much bigger than what is feasible for a ten week study period. The developing a water budget and a nitrogen budget for the Spring Creek watershed would be equally difficult to accomplish in this short time span. Instead focus for this study was placed on observing the levels of nitrogen for a two months period over the length of the watershed. The primary objective was to determine sources and sinks for nitrogen in this area. In addition, an attempt was made to understand and present how nitrate in the system can affect the function of the water biota. Spring Creek nutrient levels were compared with data from other water systems (found both experimentally and in the literature: water table, rain, ground water, mirror lake, other studies, Nitrate waste from sewage) to gain some perspective on the pollution problem. Finally, further studies that could be done to understand the biologic and land management issues that impact Southeastern Minnesota were identified.

Nitrogen takes several forms at different stages in its path through an aquatic system. The three main forms to consider for this study are N_2 (nitrogen gas), NH_4^+ (ammonia), and NO_3^- (nitrate). The process that transforms ammonia to nitrate is nitrification and is carried out by bacteria, fungi and autotrophic organisms (Wetzel, 1983). Denitrification changes nitrate and other oxidized forms of nitrogen compounds, into nitrogen gas. Bacteria that carry out this process are mostly associated with the anerobic conditions of anoxic sediments at the bottoms of lakes and wetlands. These two processes often happen simultaneously in any aquatic system and they can rapidly change the ratio of ammonia to nitrate (Wetzel, 1983).

In this study all sources of water were considered as potential sources of nitrogen, therefore the hydrology of the stream is an important consideration. The watershed drains into two main forks, east and west. The ends of these forks are designated by SC-16 and CS-21 respectively on the Spring Creek Watershed map (see appendix 1). For a ten year flood event SC-16 is expected to run at 220 cfs compared to SC-21 which would be expected to run at 618 cfs. These numbers can be used to show each forks' contribution to the flow downstream of each. Approximately one third of the amount of water in stream coming into Lyman lakes is from the east fork and about two thirds is from the west fork. This is important when considering the possibility of dilutions in the final results.

Spring Creek is a gaining stream over most of the watershed. The water table and ground water contribute somewhat to the amount of water in the creek bed and little water from the creek is lost to the ground. Some water enters the creek bed as seepages from interflow or drainage from saturated soil. Overland flow, water that does not enter the soil before it reaches the creek bed, is most significant during rain events (Fetter, 1994). There were few heavy rain events on testing days during the study period and so overland flow was not specifically measured. It is possible that when there is a high overland flow, as during a heavy rain, soon after the fields adjacent to the creek have been fertilized that the nitrogen concentrations in the creek would increase. Direct rain into the creek bed probably contributes little to the actual flow rate of the creek, yet lightning is reported to fix nitrogen (Wetzel, 1983) so rain was explored as a nitrogen source.

Materials and Methods

Five sites along Spring Creek were selected for monitoring at the beginning of April. They were chosen to represent the physical parameters of the watershed. (See Appendix 1) Three sites were along the west fork, the primary drainage of Spring Creek Watershed. The upper west fork site was located just below the height of land that defines Spring Creek Watershed. This site is approximately 40 meters downstream from the origination of the west fork, two pipes that drain the tiled fields (Aldrich, personal communication), upstream of County Road 82 and south of the intersection with 125th Street E. The stream corridor contains trees, bushes, and grasses, approximately 5 to 10 meters wide. The surrounding area is farmland which was planted with corn in mid May.

The middle west fork site was down a steep hill about 1.5 miles from the first site just upstream of County Road 82 after the intersection with 115th Street E near the intersection with Route 246. Between these two sites the creek travels through a wooded area and along the edge of fields. At this site there is also visible field tiling drainage, but the drained fields are not as distinctly contoured as at the upper site. The hill next to the upper west fork site might suggest interflow into the stream bed near where measurements were taken, but no seepages were apparent.

The lower west fork site was about 3 kilometers downstream from the middle west fork site on the upstream side of Hall Avenue. The creek travels through farmland, with very little stream bank vegetation for most of it. After the farmland it passes through a residential area, here the stream corridor widens and consist mainly of grasses with some scattered trees and bushes. Shortly after this site the stream empties into a lake on the north side of Route 28. The east fork site is on the south side of Route 28 and also drains into the previously mention lake. The east fork originates about 100 m upstream at another set of field tiling pipes, and then runs through a wetland area of approximately 2,000 m^2. The final site was just upstream of the wooden bridge across Upper Lyman Lake on the Carleton College campus, about 2.4 kilometers downstream from the last two sites. From the lake where the east and west forks join the stream runs through the Northfield golf course, a residential area, and finally a small marsh just upstream of the Upper Lyman Lake site.

Colormetric CHEMet test kits (Nitrate, K-6902; Ammonia, Model AN-10, K-1510; Orthophosphate, Model PO-10, K-8510; CHEMtrics, Inc.) were used biweekly for seven weeks from early April to late May to measure nitrate, ammonia and phosphate levels. The nitrate test kit measured up to 5 ppm, since water concentration was frequently greater than 5, a 25:1 dilution with distilled water was used. This was done by measuring 24 ml of distilled water into sealed plastic vials in lab. In the field 1ml of sample water was added with a Pipetman to the vials and then the CHEMet test was completed as in the company instructions. Note: the CHEMet nitrate test works by reducing nitrate to nitrite so that the measurements that were made actually include both nitrate and nitrite concentrations in the figure. On several occasions the water downstream of high ammonia concentration was tested for nitrite, an intermediate for nitrification, and none was found.

To make a comparison to other systems several other sources of water were tested.

1) Spring water from the St. Peter Sandstone was tested at the Cannon Valley Wilderness Area using similar methods to those used at the stream sites.

2) Rain water was collected in clean, 5 liter plastic buckets set in a field where no obstructions would contact the water before it reached the ground. Water was collected at fifteen minute intervals and tested immediately.

Both the nitrate tests on the spring and rain water were done without dilution.

3) Ground water that contributed to base flow near the Upper Lyman Lake site was tested by drilling a shallow (~3 m deep) well 3 m from the stream bank. The well pump was primed and then the well was pumped dry. The well was allowed to refill for 15 minutes and then it was pumped again to obtain fresh samples. The water sample was tested immediately.

To determine if the nutrient levels fluctuated over the period of a day, an 11 hour monitoring system was set up. The Data Logger 600 was suspended under the water surface near the Upper Lyman Lake site. It was set to record its full set of parameters (temperature, ammonia, pH, turbidity, dissolved oxygen, and conductivity) once every hour. In addition, the methods described above were used to test phosphate and nitrate at the same times as the data logger. This was done from 7 am to 6pm.

The east fork site was located at the end of a wetland area. The stream water was measured before the wetland area from the field tiling drains and after the wetland area one evening. Due to difficulty reaching the tiling without walking on planted fields, these tests were done simultaneously on only one occasion.

Results

The nitrate measurement showed considerable variation from the top of the watershed to the bottom, with the nitrate levels decreasing from the top to the bottom of the watershed. The highest nitrate reading was 80 ppm. The east fork site showed considerable less nitrate than any other site, although it seemed to drain an area similar to the upper west fork. See Figure 1.

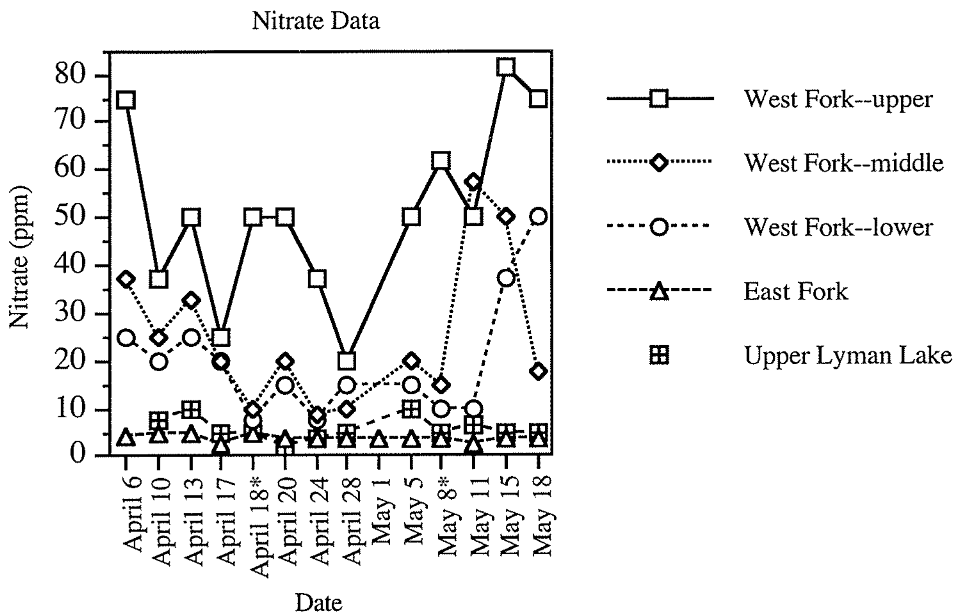

Figure 1. Extensive variation in the nitrate levels was observed. The nitrate levels were highest at the top of the watershed and decreased as the stream progressed down the watershed. Asterisked days indicate rainfall.

Low levels of ammonia (See Figure 2) and phosphate (see Figure 3) were found in the creek water. On April 18, a day of heavy rain, ammonia and phosphate spikes were observed at the middle west fork site. Smaller ammonia spikes were observed at other sites on different days.

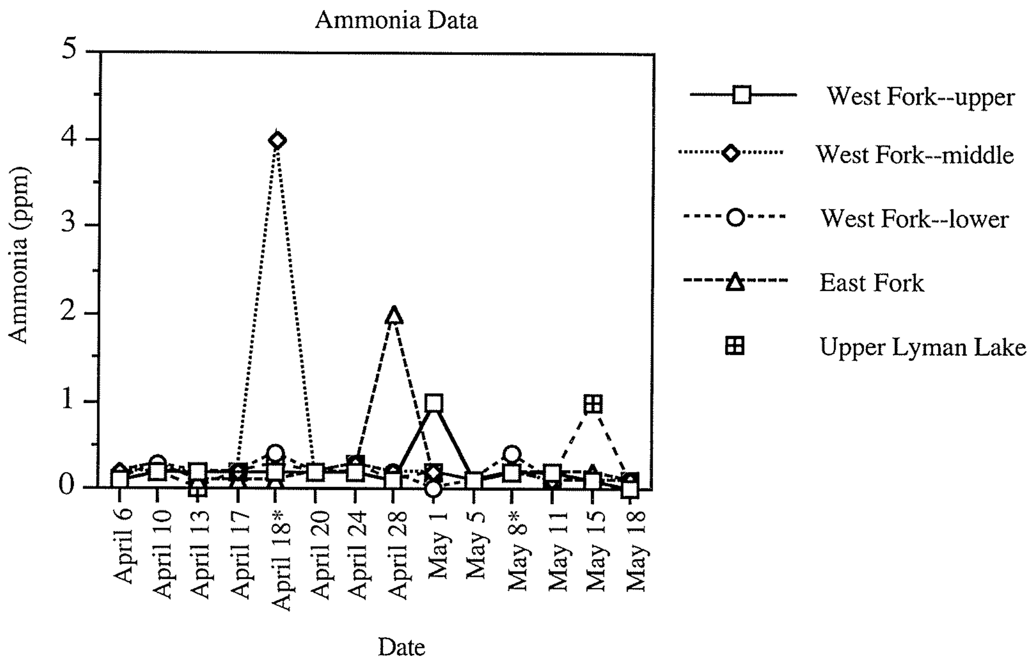

Figure 2. Ammonia was found at low levels at all sites. A spike was seen on April 18th, after heavy rain. Other smaller spikes were seen at different sites on different days. An asterisks indicates a rain date.

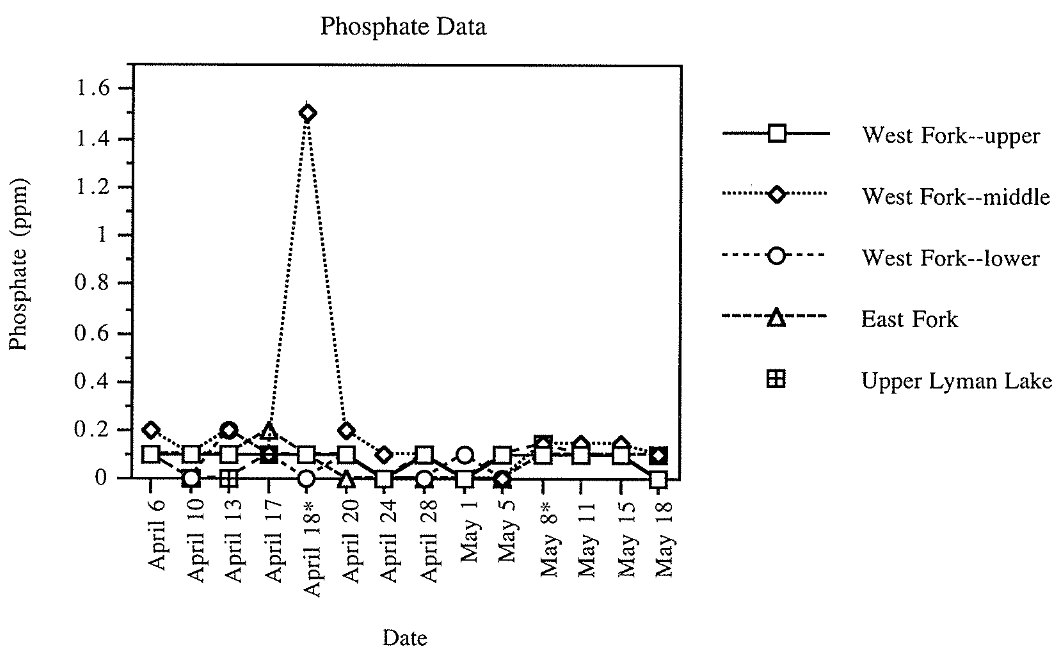

Figure 3. Low levels of phosphate were seen at all sites most days. One spike was observed on April 18th at the middle west fork site after heavy rain.

Water from the St. Peter Sandstone Spring, Rain, Rain--Lightning, and Interflow were found to have considerably less nitrate than Spring Creek, although the Interflow was distinctly higher than rain water and spring water (See Table 1).

Table 1. Nutrient levels in other sources of water. Levels of nitrate, ammonia, and phosphate were tested at a Spring in the Cannon River Wilderness Park, in rain water from buckets set out for 15 minutes, and from a 3 m well along the bank near the upper Lyman Lake site. Ammonia and phosphate could not be determined for the interflow measure due to sediment in the sample.

Source of Water	Nitrate (ppm)	Ammonia (ppm)	Phosphate (ppm)
Spring (aquifer)	0.15	0.2	0.1
Rain	0.0	1.0	0.0
Rain--Lightning	1.5	0.4	0.1
Interflow	2.5	could not test	could not test

The nitrate level for the east fork was 7.5 ppm before the wetlands and 2.5 ppm after the wetland.

Discussion

The nitrate levels found in the Spring Creek Watershed were consistently found to be high. Although the levels range from a mean of 50.3 ppm at the top of the watershed and drop significantly to a mean of 5.9 ppm at Lyman Lakes, 5.9 ppm is still high (higher than the test kits were designed to measure). In order to get some perspective on the significance of these results they were compared to results of other studies (See Table 2).

Table 2. Nitrate levels from a variety of water sources. Nitrate levels in the Spring Creek watershed were found range from 4 ppm to 80 ppm. The large values were found at the top of the watershed. As a comparison for the found nitrate levels the following nitrate levels are presented.

Water Source	Nitrate level (ppm)	Reference
Hog Farm Lagoon Effluent	84	Hammer 1992
Household septic tank with faulty absorption field	36	Steiner 1992
Typical untreated sewage	35	Novotny 1989
Drinking Water Standard	10	Novotny 1989
Urban Storm Water	3-10	Novotny 1989
Roof Runoff	0.5-4	Ellis 1986

The one site that had consistently lower nitrate levels than the others was the east fork site. It was determined that the water was first filtered by a wetlands area. Testing of the water before and after the wetlands areas showed more than 50% drop in the amount of nitrate. Although more study is needed, the literature indicates that wetlands are likely to remove 50% and more of the nitrate present. Other studies found:

1) In a Mesocosm study done by Crumpton Isenhear and Fisher, (after Moshiri, 1993) the Nitrate nitrogen concentration fell from 21 to 0 ppm in their constructed system in seven and a half days. "In experimental wetlands studies using 15N tracers confirm that denitrification is the dominant loss process in experimental wetlands.

2) Hammer, Pullin, McCaskey, Eason and Payne (after Moshiri, 1993) found that the nitrate levels in the hog farm waste water lagoon serving 500 animals effluent was 84.0 ppm which dropped to 3.5 ppm through their constructed wetland.

3) Steiner and Combs (after Moshiri, 1993) were creating a wetland system for treating septic tank effluent in a faulty absorption field. They calculated the nitrate ammonia to be 36 ppm straight from the septic tank, which was reduced to 20 ppm in one cell treatment.

These studies indicate that it is reasonable to hypothesize that the wetlands are mediating the nitrate levels. While wetlands can also store phosphates, they do not remove them from the aquatic system. Frequently phosphate is the limiting nutrient in aquatic systems. This is clearly the case in Spring Creek Watershed. The low level of phosphate found are significant, because they confirm the presence of this nutrient. It is probable that the actual levels of phosphate coming into the system are much higher, but that phosphate is being used very quickly by organisms in the water.

The low levels of ammonia are most likely ammonia that has not yet been converted to nitrate. The nitrogen spread on fields as a fertilizer is frequently anhydrous ammonia. Thus, the runoff is likely to contain ammonia which is converted to nitrate by bacteria in the soil and water.

Spikes of phosphate and ammonia were seen at the middle west fork after a heavy rain (2-3 cm). It is probable that the adjacent fields were fertilized shortly before the rainfall. The spikes did not appear down stream. There are several possible explanations: the rain diluted the high nutrient levels, the nutrients were used up or converted to nitrate in the case of ammonia, or the high levels had not yet reached the lower sampling site. The final option seems the most plausible. A study on water travel time for the creek would be useful to determine if this hypothesis is accurate.

Tests on the other sources of water for nutrients (see Table 1) support the hypothesis that high nitrate levels are due to agricultural runoff. The initial purpose of the study was to determine sources of nitrate in the watershed. Aquifer and rain water do not explain nitrate levels of 80 ppm or even 6 ppm. The interflow reading by Lyman Lakes also indicates that the source of nitrate in the lakes is from upstream. In fact the seepages just above the lake may be diluting the higher nitrate levels. Dilution from interflow may also partially explain how the nitrate levels drop from a mean nitrate level of 19.8 ppm at the lower west fork site to a mean of 5.9 ppm at the Lyman Lakes site. Although the nitrate level in the water flow to Lyman Lakes is diluted by the east fork, the east fork water accounts for only one third of the total stream water after they join. The mean nitrate level for the east fork was 3.9, not low enough to produce the level of nitrate found in the lakes. The interflow along Lyman is a possible dilution source, as the fields on the Carleton property have not been fertilized in over a year. (Easley, personal communication) There is also a wetlands area between the golf course and Carleton which is also likely to be reducing the nitrate levels. In the rest of the watershed the interflow is probably the greatest source of nitrate along with overland runoff during rainstorms.

Conclusion

In a study done on Mirror Lake in New Hampshire Likens (1985) explains the effects of agriculture in that watershed that are similar to the conditions found in Spring Creek.

> "Cultural eutrophication causes greater aquatic productivity by leading to a succession of undesirable algal species (blue green algae) or anoxic conditions. An understanding of this delicate interplay between physical chemical and biologic conditions and the underlying cause is an important management priority. While it is possible to identify the trophic level of a lake, the actual process of eutrophication is rarely studied because of the time frame for the process".

It is not possible in ten weeks to study the kind of ecological interaction described by Likens. However it is possible to study one aspect of a larger picture.

This study shows that the natural, or unintentionally created wetland systems in Spring Creek watershed may be mediate at least some aspects of agricultural pollution and that this process is as efficient as in wetlands constructed for this purpose. Wetzel, in Constructed Wetland Scientific Foundation Are Critical (1987), states that the balance of function and structure of a natural system should not be compromised in designing a constructed system because of the complex/multistep process involved in mediating pollution. In a nitrogen removing system it is desirable to maintain bacteria for nitrification and denitrification; plants that aerate the soil and support bacteria growth; plants that carry N_2 to the atmosphere; and a variety of species with different life cycles so that the standing crop does not suddenly diminish at any point in during a season.

In planning for future development in the Spring Creek watershed and for water quality improvement in the Cannon River Valley, the potential for natural areas to mediate diffuse pollution should be considered.

Further Study

This is a list of suggestions for other studies that could benefit the understanding of the Spring Creek system and augment this study.

1. Use water nitrate data to asses the return of different farming/fertilizing practices and council farmers on how to get the best results (least nitrate in the water) for the least amount of nitrogen. Also test rock and dry fertilizer versus anhydrous ammonia and test Fall versus Spring applications of fertilizer.
2. Specifically study the effects that the wetlands have on mediating the nitrates. See if a marsh is the same as a fen, etc. Some study has been done in this area.
3. See what would happen to the algae if phosphate is added to the system with the high levels of much nitrate available. This a suggested laboratory experiment, *not* a field study.
4. Figure out what the sources of phosphate for the Lyman Lakes algae are.
5. Find a similar creek in Southeastern Minnesota that has a different land use pattern and see if the relative change in ratio of farms to wetlands effects the water quality.
6. Use Global Information System and water quality data to project how much nitrogen is being put into the whole cannon river, then compare that to a water budget for the river.

7. Test the water coming from the water treatment plant and compare the nitrates there, to the levels in the upper reaches of the watershed. Use this data to make predictions in change of water quality during normal flow rate fluctuations.
8. Use florescent dye to learn about water travel time in the watershed and see if there is a correlation between holding time and nutrient removal in depression areas.
9. Drill 3 m wells at each site and take interflow samples to help determine where the water table is adding nutrients and where it is diluting the creek.

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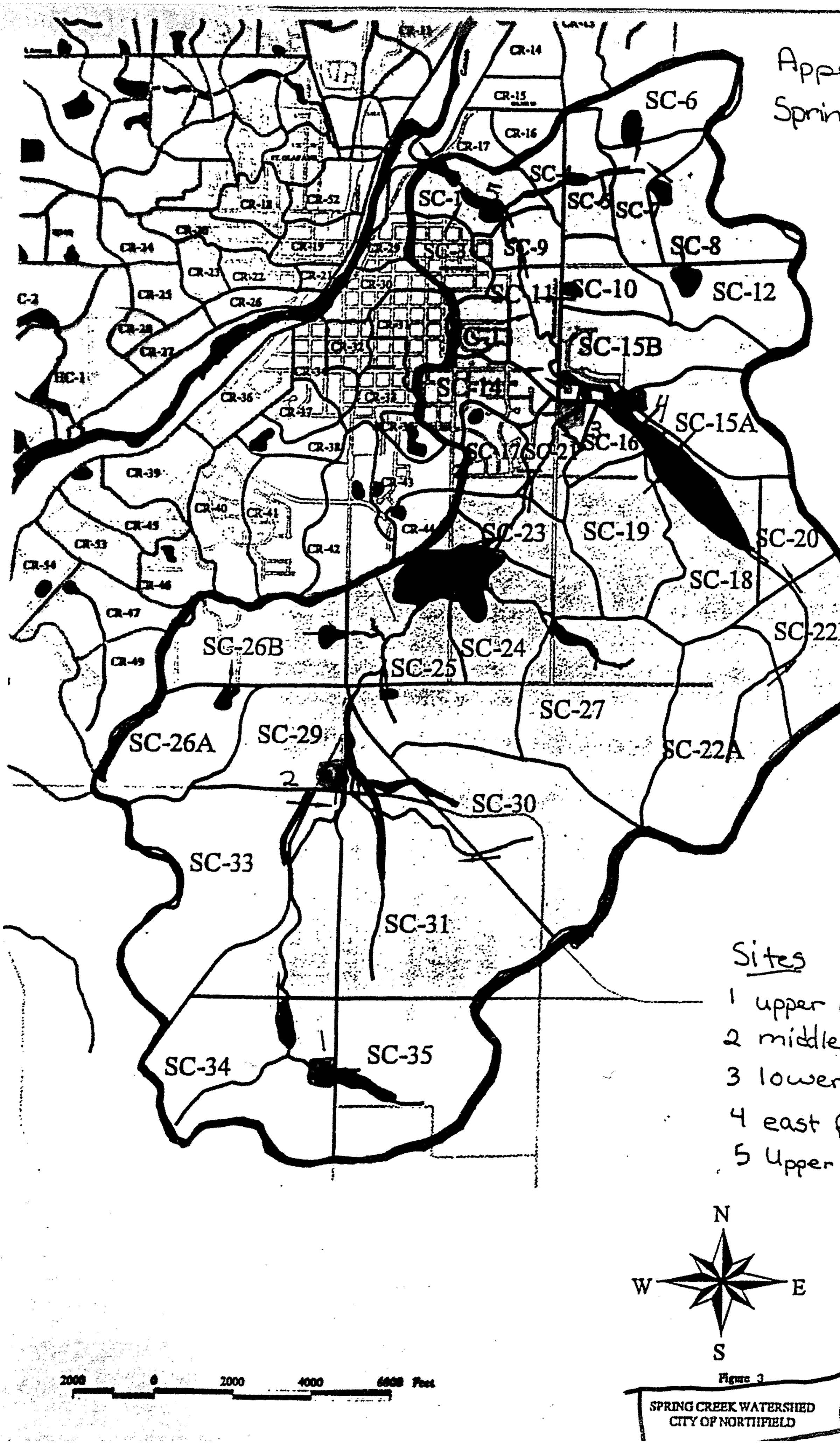
The authors would like to thank Tim Vick, Alison Unger, and Doug Foxgrover for assisting with equipment and discussing the project, and to Northfield City Hall for use of their watershed maps.

Appendix I
Spring Creek Wa[...]
She[...]



Sites
1 upper west fork
2 middle west fork
3 lowerwest fork
4 east fork
5 Upper Lyman Lake

Figure 3

SPRING CREEK WATERSHED
CITY OF NORTHFIELD