RESEARCH ARTICLE

Dilution of Nitrates Due to the Confluence of Two Riverine Environments in the St. Joe River Watershed

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ABSTRACT: The researchers of this study aimed to investigate the change in nitrate concentration as Garrett City Ditch (GCD) empties into Cedar Creek. The research team studied pollutants in GCD, a ditch mostly composed of storm sewage and water treatment effluent discharge, and in Cedar Creek located near Auburn in northeast Indiana. Monitoring nitrate concentrations in the Cedar Creek watershed is critical in protecting Lake Erie against potential detriments which may lead to severe impacts on the ecology of the Lake Erie ecosystem. GCD had much higher nitrate concentrations than other surrounding drainage ditches, as did Cedar Creek. The goal of the study was to determine if sample data coincides with theoretically calculated dilution values of nitrate ion-specific levels. The study identified an increase in nitrate concentrations within Cedar Creek after the confluence of GCD, resulting in an average increase of 38.1%. The researchers found the calculated increase for one of the dates to be about 45.8%. These results show the detrimental effects human activity can have on a natural riverine environment.

KEYWORDS: Earth and environmental sciences; water science; nitrates; riverine environments; dilution; drain tile.

Introduction

Eutrophication is a major issue for riverine systems, with agricultural activity playing the primary role for high nitrates.[1-3] Recent research has shown that nitrates come from a variety of known human activities,[1-4] with some research demonstrating where those nitrates go after they enter these waterways.[5] The research team for this project focused on the transfer of the nitrates from one riverine system to another.

Water quality is periodically monitored by various entities for different purposes, including nitrates. Nitrates are key factors in monitoring environmental quality because of their correlation to eutrophication.[1] According to studies, over half of all coastal waters studied in the United States are affected by eutrophication.[6] The excess nitrates from human activity can lead to elevated levels of nitrates in waterways, leading to excessive plant growth which can create low oxygen levels ultimately leading to a decline in aquatic biota within the system.[6] Excess nutrients can also cause an abundance of algae which leads to less light penetration into the water, eradicating some wildlife.[7] Four hundred "dead zones" (areas of water in which wildlife cannot survive) have been reported around the world, and the origin of some is believed to be related to eutrophication.[7] The excess nutrients that humans empty into waterways can destroy environments such as Cedar Creek, as seen in other locations across the United States. Cedar Creek eventually connects to Lake Erie, which has experienced eutrophication issues in the past.[8] A study done in 2018 on the Seine and Loir rivers (France) and the Red River (Vietnam) found that nitrate levels above 2 ppm can cause hydrophyte biodiversity to decrease sharply.[9] Because of eutrophication's more significant impact on smaller environments, such as local creeks or ditches, the researchers focused the study on nitrates in an effort to understand and prevent eutrophication from occurring in a local environment, in this case Cedar Creek.

Studies have shown results demonstrating that agricultural fertilizer runoff is an influential factor in nitrate levels within waterways.[1-3] A study done by the Environmental Protection Agency in Nebraska's Platte River Valley found that less than 50% of synthetic nitrogen applied to agriculture in the United States is consumed by the intended crops.[10] This leaves over half of the 13 million tons of nitrates applied every year to the crops, to either seep into the ground or groundwater, be consumed by other plants, or runoff into nearby waterways.[10] Synthetic fertilizers are not the only source of nitrates; a study showed that natural fertilizers such as biosolids release nitrates as well.[3] Keeping consistent nitrate levels within a system is critical to the natural aquatic biota. With no human intervention, these waterways have been observed to maintain nitrate levels independently, but human factors like fertilizer runoff disproportionately impact nitrate levels. A study in North Yorkshire UK demonstrated that the greater the arable land use along the Derwent River, the greater the nitrate levels were.[1] This suggests that runoff from farming causes water contamination, as seen with nitrates. Applying this data to other rivers and waterways, the research team expects that both GCD and Cedar Creek will be similarly affected. According to the USGS, wastewater treatment plants that do not regulate the discharge of nitrate levels can also be a factor in water contamination.[4] The greatest discharge at the headwaters of GCD is directly tied to the City of Garrett's Wastewater Treatment Plant.

Extensive efforts have been made to stop the eutrophication process, including the use of different technologies in agriculture to try to prevent excessive fertilization. Project Sense is a program dedicated to improving Nebraska's farming by creating technology that can measure the wavelength of light shone onto crops.[11] The sensor uses this information to apply the minimal amount of fertilizer to a crop. This process ensures fewer nitrates are wasted, therefore limiting nitrate runoff. In

  DOI: 10.36838/v3i6.2

addition, farmers are spending less on fertilizer, allowing them to allocate financial resources to other aspects of their business. Another example of high-tech efforts to minimize runoff has been developed by a company called Air Scout. Similar to that of Project Sense, Air Scout can reduce the amount of unused nitrate running off the land. This is achieved by producing thermal imagery from planes to determine which areas of fields need nitrates more than others.[11] With the development and broader application of these technologies, eutrophication and water contamination may be less of a problem in the future.

■ Methods

The purpose of this research is to determine the dilution effect of the nitrates in GCD as it empties into Cedar Creek, downstream of Auburn, Indiana. Multiple testing sites throughout the overall length of GCD will establish a solid representation of the nitrate levels throughout the ditch. Additional testing sites in Cedar Creek include upstream and downstream of the mouth of GCD. The testing site upstream of the mouth of GCD will establish the nitrate levels in Cedar Creek without the influence of GCD (Figure 1-8). The test site downstream of GCD will provide insight into the chemical changes of water parameters based on the sole input of GCD (Figure 1-8). A comparison of nitrate concentration from the upstream location to the concentration at the downstream location will determine how much nitrate levels are increased due to the confluence of GCD. This then allows for the determination of the diluted nitrates in Cedar Creek when GCD empties into it. A theoretical value of nitrates was also calculated using upstream Cedar Creek's nitrate concentration and discharge as well as GCD's nitrate concentration and discharge. The following formula was used.

$$Q_{GCD} \bullet NO_3^-{}_{GCD}\,(mg/L) + Q_{Cedar\ Creek\ Upstream} \bullet NO_3^-{}_{Cedar\ Creek\ Upstream}\,(mg/L) = Q_{Cedar\ Creek\ Downstream} \bullet NO_3^-{}_{Cedar\ Creek\ Downstream}\,(mg/L)$$

$$(89\ L)_{GCD} * (13.791\ mg/L)_{GCD} + (187\ L)_{Cedar\ Creek\ Upstream} * (2.957\ mg/L)_{Cedar\ Creek\ Upstream} = 1780.4\ mg_{NO_3^-}$$

$$1780.4\ mg_{NO_3^-} = (276\ L)_{Cedar\ Creek\ Downstream} * (NO_3^-\ mg/L)_{Cedar\ Creek\ Downstream}$$

$$(NO_3^-\ mg/L)_{Cedar\ Creek\ Downstream} = 6.451\ mg/L, or\ 6.451\ ppm$$

The research team initially used a LaMotte AM-12 The TesTabs® Water Investigation Kit to determine the levels of available nitrogen within GCD and Cedar Creek. This kit uses two different tablets dissolved into the sample. The process includes retrieving a sample from the source and measuring out 5 mL of the sample into a test tube. The first tablet was added to the sample and this sample was stirred until the tablet had fully dissolved. The researchers then added a second tablet and stirred for two minutes. At the end of this process, the samples rested for another five minutes. After five minutes the sample was compared to a color slide to determine the approximate available nitrogen concentrations. The values on the color slide were 0, 5, 20, and 40 ppm. This did not give the research team enough preciseness to be able to determine any accurate results. This process is also considerably time-consuming and produces low-resolution results. The available nitrogen recorded for GCD through this pro of the researchers' equipment, they were not able to draw any valid conclusions. The team found results from a Vernier Go Direct® Nitrate Ion-Selective Electrode much more precise and consistent. This tool can be used on-site, providing precise data in a matter of seconds. The researchers collected data using the sensor, relaying the data to a smartphone. Researchers measured nitrates directly on-site, allowing a 20-30 second wait time. The average nitrate concentration over this period was recorded as the nitrate concentration. Three data sets were recorded at each site during the day on four different dates spanning the months of September and October (09/21/20, 10/02/20, 10/16/20, and 10/30/20). To get a complete representation of dilution rates more studies must be done throughout the entire year. At each site, a Garmin GPSMAP 64th was used to record each of the locations of the site in latitude, longitude, and elevation.

The researchers tested three sites along GCD and two along Cedar Creek. The first of the three sites along GCD was located 50 meters from the headwaters of GCD, located at 41˚20'24.3"N 85˚07'46.0"W. The headwaters originate from five drainage tiles (See Figure 3) emptying into the ditch. The three westernmost tiles heading east are 1) the storm sewers for the city of Altona, 2) storm sewers of the south side of Garrett, and 3) the north side of Garrett. The fourth tile empties the wastewater treatment plant effluent discharge into the ditch. Finally, the easternmost pipe emptied another small section of Garrett's storm sewer. The headwaters site has an agriculture field on the west bank, and on the east, there is a grassy field (See Figure 4). The second site along GCD was located 4.75 kilometers from the headwaters at the intersection of County Road 23 and GCD (41˚20'20.5"N 85˚04'42.7"W). This site has two residences on the northwest and southeast corners and agricultural fields reside on the northeast and southwest corners (See Figure 5). This site was chosen because it was located roughly halfway between the headwaters and mouth of GCD. The last site location is at the mouth of GCD as it enters Cedar Creek (41˚20'12.2"N 85˚03'55.0"W), roughly 6 kilometers from the headwaters. As seen in Figure 6 this site is surrounded by a wooded area. Researchers originally expected the nitrate concentrations to be consistent along the length of GCD based on the preliminary results from the LaMotte TesTabs® kit. However, the Vernier sensor demonstrated that nitrate levels decreased along the length of the ditch. The last two sites on Cedar Creek were located 50 m upstream and downstream of GCD's mouth Figure 7 and 8 respectively. The upstream location served as a control sample site prior to the influence of GCD; the downstream location was allotted for thorough amalgamation of pollutants from GCD without the direct influence of other sources. According to a study on y-shaped confluences, there are areas of contaminant concentration after two systems combine, and this is why samples were taken along the width of the ditch and creek.[5]

■ Results and Discussion

The researchers hypothesized that the nitrates would increase from upstream GCD to downstream GCD due to runoff from the surrounding fields. The data opposes the researcher's hypothesis of increasing nitrate loading and also presents

DOI: 10.36838/v3i6.2

a trend of lowering concentrations of nitrates throughout the stream of GCD. The researchers attributed this to an influx of additional water from runoff or other sources with lower concentrations of nitrates emptying into GCD. The research team found a modest increase, averaging 1.243 ppm, in NO_3- concentrations in Cedar Creek after the influence of GCD. The researchers also found that the average percent change in nitrate concentrations to be 38.1%. It must be noted that while the increase of 1.243 ppm is nearly negligible, it still constitutes a significant percent increase in nitrate concentrations.

Figure 1: Reference Map.

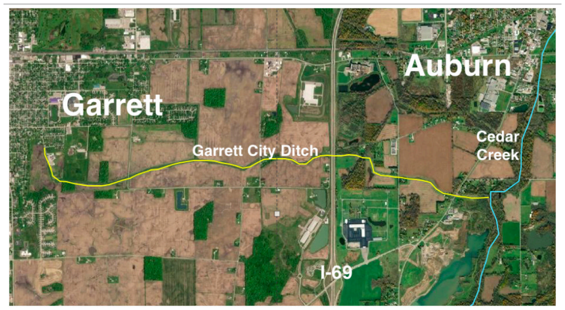

Figure 2: Detailed Map.

Figure 3: GCD Drainage Tiles Looking North.

Figure 4: GCD Headwaters Looking West.

Figure 5: GCD CR 23 Intersection Looking South.

Figure 6: GCD Mouth Looking South.

Figure 7: Cedar Creek Upstream Looking East.

Figure 8: Cedar Creek Downstream Looking East.

GCD Nitrate Concentrations:

The research team began monitoring the available nitrogen in the water of GCD in the spring of 2019 with consistent results of over 40 ppm, using the LaMotte TesTabs® kits. At the onset of investigation for this project, measurements throughout the ditch continued to be at 40 ppm and beyond. These measurements led the research team to believe that the actual values of nitrates within the water were not changing. However, this conclusion was based on the limitation of the test kit itself. The LaMotte TesTabs® kit provides a color matching scale divided into three categories (0 ppm, 5ppm, 20 ppm, and 40 ppm). This did not provide the desired resolution the researchers had hoped to find. The research team

DOI: 10.36838/v3i6.2

then used the Vernier GoDirect® Nitrate Ion Selective sensor for measurements (See Table 1).

Table 1: Nitrate Concentration Values (ppm) of Collection Sites based on Collection Date.

	Sample	GCD Headwaters	GCD CR 23	GCD Mouth	Cedar Creek Upstream	Cedar Creek Downstream
09/21/20	1	15.331	NA	10.729	1.891	2.551
	2	16.387	NA	10.565	1.612	2.224
	3	15.358	NA	9.637	2.277	3.077
	$\bar{x}$	15.692	NA	10.310	1.927	2.617
	σ	0.602	NA	0.589	0.334	0.430
10/02/20	1	26.286	14.407	13.504	5.646	7.52
	2	24.106	15.109	14.008	5.347	6.838
	3	24.23	15.074	14.416	5.33	6.887
	$\bar{x}$	24.874	14.863	13.976	5.441	7.082
	σ	1.224	0.396	0.457	0.178	0.380
10/16/20	1	21.3	11.72	9.918	3.015	4.087
	2	22.142	12.125	11.571	3.296	4.745
	3	22.803	13.021	12.096	3.554	4.797
	$\bar{x}$	22.082	12.289	11.195	3.288	4.543
	σ	0.753	0.666	1.137	0.270	0.396
10/30/20	1	23.977	15.57	12.924	2.486	3.911
	2	25.409	17.222	14.202	2.894	4.487
	3	27.033	17.924	14.247	3.491	4.625
	$\bar{x}$	25.473	16.905	13.791	2.957	4.341
	σ	1.529	1.209	0.751	0.505	0.379

The measurements in Table 1 show that the concentration of nitrates decrease in GCD along the length of the ditch (moving downstream). In addition to testing the water within the ditch, the researchers also tested the water discharged from each of the drainage tiles as seen in Figure 3. Each of the tiles had low nitrate levels (< 3 ppm). However, the drainage tile from the Garrett City Waste Treatment plant was ~55 ppm. It is evident the elevated nitrate concentration within GCD is a direct result of effluent from the waste treatment plant. It should also be noted that the nitrate concentrations within GCD are considerably higher than surrounding drainage ditches as well. The research team had measured the nitrate levels using the Vernier GoDirect® Nitrate Ion Selective sensor in another drainage ditch, which measured at 0.136 ppm. Table 1 also shows a consistent decrease in nitrate concentration between the headwaters of GCD and its mouth. Based on the observation dates, the average decrease was 9.712 ppm, or roughly a 43% change over 4.75 kilometers. The research team believes this to be because of dilution throughout the ditch. As more water with lower nitrate concentrations runs off into the ditch, the overall value of nitrates within the ditch lowers with it.

Discharge of GCD and Cedar Creek:

Table 2 displayed the discharge of both GCD and Cedar Creek. The value for Cedar Creek was found on a USGS database,12 while the discharge for GCD was calculated by the researchers. The discharge of GCD was found by measuring both the cross-section and the velocity of GCD. The cross-section was calculated by measuring both the depth of the creek and the width at that same cross-section. These numbers were used to calculate the cross-section by acting as the major and minor axis of an ellipse, resulting in 0.36m². The velocity of GCD was calculated by measuring the time it took for a flotation device to float downstream 5m. This process, repeated three times, showed that the GCD flow was 0.24 m/s, resulting in a discharge of 0.089 m3/s.

Table 2: Discharge in (m³/s) of GCD and Cedar Creek (2020-10-30)

	Discharge (m^3/s)
GCD	0.089
Cedar Creek	0.187

Theoretical and Empirical Nitrate Concentration Dilution Values:

The calculated discharge values were used to determine the theoretical concentration of nitrates downstream by finding the overall nitrates and then determining the concentration downstream from that data. The research team learned through direct measurement using the Vernier GoDirect® Nitrate Ion Selective sensor that the concentration of nitrates downstream from GCD was 4.341 ppm, as shown in Table 3. The theoretical value of concentration should have been 6.451 ppm, resulting in a percent error of 32.7% and a discrepancy of 2.109 ppm. Multiple sources of error could have skewed our results. The discharge for Cedar Creek upstream was based on the USGS stream gauge data website.[12] The nearest stream gauge for Cedar Creek is in downtown Auburn, Indiana, approximately 3 km upstream from the sample site. The research team also struggled with measuring the discharge of GCD with accuracy due to the lack of capable equipment. In the future, streamflow meters are suggested to compare results between the different methods of stream flow determination.

Table 3: Theoretical and Empirical Nitrate Concentration Dilution Values.

	Upstream (ppm)	GCD Mouth (ppm)	Cedar Creek Discharge (m³/s)	GCD Discharge (m³/s)	Calculated Theoretical Concentration of Downstream (ppm)	Empirical Concentration Downstream (ppm)
10/30/20	2.957	13.791	0.187	0.089	6.451	4.341

Conclusion

Nitrate levels measured in Cedar Creek were greatly affected by the high concentration of nitrates within GCD entering Cedar Creek. The phrase "dilution is the solution" could lead some to argue that the influence of nitrates from GCD had a negligible effect on the concentration within Cedar Creek. Our study found that the average NO_3^- increase in Cedar Creek due to GCD was only 1.24 ppm. This increase is undetectable using the LaMotte AM-12 The TesTabs® Water Investigation Kit, perhaps leading to a false conclusion that the incoming nitrates from GCD result in a negligible change in nitrate ion concentrations within Cedar Creek. However, an alternative conclusion could be reached if one considers not

DOI: 10.36838/v3i6.2

simply the increase in nitrates, but rather the percent increase. The same data used to show the increase of 1.24 ppm results in an average percent increase of 38.1% and a maximum percent increase of 57.3%. It is important to make this distinction within this localized environment because GCD represents just one of many drainage ditches that feed into Cedar Creek. The increase, whether viewed as a nominal increase or percent increase, could potentially feed further increases downstream as other ditches contribute further pollutants. GCD eventually empties into Lake Erie making GCD a contributor to unhealthy nitrate concentrations in Lake Erie, causing eutrophication.[8] The research team plans to continue their research on GCD to determine the effect on the natural environment and ecosystem. The nitrates can greatly affect the natural ecosystem of a creek or ditch because of humanity's effects of the natural nitrate concentrations, and it is humans' responsibility to take care of the environment. Researchers need to observe and take note of the world around them to make sure it can function. Keeping the natural environment within the community protected and preserved should always be the goal of environmental scientists.

Acknowledgements

I would like to acknowledge Mr. Anthony Thomas for his support throughout the entire research and editing process of this article. I would also like to thank him for inspiring me to take on this challenge and to expand my repertoire as a young scientist.

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