Poultry Litter and Stream Health

Matt Sutton

Nebraska Farmers Union Foundation

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ACKNOWLEDGEMENTS

This study would not be possible without the relationships between Graham Christensen and many other individuals interested in determining the local impact of animal waste from the Costco network of poultry barns in the vicinity of Fremont, Nebraska. Over the past several years, Christensen and others have come together from a variety of backgrounds and experiences in order to increase awareness of environmental and public health risks associated with the development of concentrated animal feeding operations.

Funding has been generously provided by a local community foundation and other private donors. A special thanks is owed to the Nebraska Farmers Union Foundation for serving as the fiscal sponsor of the study, to the University of Nebraska at Lincoln Department of Civil Engineering for sharing maps of waste application sites, and to Nebraska Communities United and GC Resolve for their work motivating citizens to remain vigilant in protecting waterways and toward ushering in a more sustainable future based in regenerative agriculture principles and practices.

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PURPOSE

This study seeks to understand the impacts of a vertically integrated poultry operation in the area surrounding Fremont, Nebraska. The purpose of this study is to create a pre-operational baseline and to identify post-operational impact on stream systems running through properties where waste poultry litter, i.e., feces, is designated for regular application as a fertilizer source. In response to rising concerns about heavy nutrient and pathogen loads in area waterways, this report also makes recommendations for protecting watershed integrity and public health. It is intended as a guide for Nebraskans and those who depend on shared water resources, providing a roadmap to farmers, government agencies, and elected officials for monitoring and minimizing the impact to water quality caused by mismanagement of livestock waste. The applied methods can provide a framework for others interested in evaluating environmental changes resulting from similar projects elsewhere.

TESTING LOCATIONS AND METHODS

Testing sites were chosen based on information obtained from publicly available state permits. Nutrient management plans provided in these permits contain fields designated for Costco poultry litter application. Criteria for study inclusion were that a waterway crossed through a single property where poultry litter was earmarked for application on both sides of the waterway. This allowed for upstream and downstream observations and ensured that contamination could be attributed to a single land management plan. Seven locations with a wide geographic spread were chosen, encompassing Burt, Butler, Dodge, Seward, and Washington Counties. Exact locations have been omitted to preserve opportunity for continued study.

To determine nutrient levels, samples were evaluated for total nitrogen (TN) and dissolved orthophosphate. Several bacteria species were selected for observation, with total coliforms, E. coli, and enterococci chosen as a measure of general water quality, and campylobacter and salmonella presence as an indicator of poultry source contamination. Midwest Laboratories provided all lab services and results.

EXECUTIVE SUMMARY

This paper is broken up into three parts. First, an introduction is provided to familiarize the reader with the project background and to contextualize observed quantities of nutrients and pathogens. Justifications are provided for the inclusion of specific nutrients and pathogens in interpreting stream health and how they may be used to identify poultry litter as a likely source. Following the introduction is the results section, detailing the findings of the present study, comparing observations with federal advisory criteria, and making interpretations. Finally, recommendations are made to encourage future exploration and initiatives, for broadening strategic partnerships to better deal with Nebraska's worsening water quality issues, and to provide guidance for solutions aimed at contaminant mitigation.

Data obtained in this study shows that stream health is compromised. Pathogen counts violated the acceptance limits established by the United States Environmental Protection Agency (U.S. EPA) in almost eighty percent (80%) of samples handled throughout the course of the study. Orthophosphate was present at rates up to ten times as high as background levels of total phosphorus (TP). Concentrations of nitrogen were found to exceed background levels by even greater factors. The examined nutrients were consistently higher than regional standards listed by the U.S. EPA.

For most of the study period, pathogens associated with poultry litter, i.e., campylobacter and salmonella, were absent. Importantly, the number of positive identifications from the most recent testing season doubled the total amount discovered throughout the entire course of study, and also aligned with the highest levels of phosphorus during the same period, which together suggest a poultry-based addition. By this most recent season, Costco grow barns had been operational for over two years, which was the time lapse estimated before initial field applications began. Thus, it appears evident that the increased levels of nutrients and pathogens may be attributed to the Costco project.

Data is only as useful as the action it generates. The findings of this study are intended to familiarize the reader with the conditions of local waterways already impacted by intensive agriculture projects, and which will be further impacted by the Costco poultry operation. Study implementation coincided with the beginning of litter accumulation and results during initial testing seasons are assumed to represent streams prior to field application of the poultry waste. A foundation is provided herein on which future results can be compared and assessments of change can occur. However, comparisons will only remain reliable for as long as regular data of a similar nature is maintained.

Matt Sutton

INTRODUCTION

Background

It was announced in April 2016 that Costco would be opening a vertically integrated poultry operation in Dodge County, Nebraska, overseeing the annual production, processing, and distribution of 85,000,000 broiler chickens, a number later revised upward to over 100,000,000.[1] This comprises the largest network of poultry barns ever developed in the United States and is the first time a retail company has controlled all operational aspects from the feed supply through to processing and sale. The project broke ground in 2017 and, with a capital investment of several hundred million dollars, has been estimated to have a $1.2 billion yearly economic impact.[2] The processing plant opened in September 2019, exceeding half its capacity by April 2020, receiving 1,000,000 birds weekly.[3] Criticisms within local communities and difficulties securing enough growers and permits slowed plans to reach capacity, and it is unclear if the plant has achieved its overall goal. Regardless, the number of chickens in the surrounding area is continuously rising along with their waste.

In a letter from the John Hopkins Center for Livable Future to Fremont Mayor Scott Getzschman and the Fremont City Council, dated September 19th, 2016, it was estimated that 3,910,000 pounds of animal waste would be generated each day, equaling twice the amount of human waste produced daily from the nearby city of Omaha, the largest city in Nebraska. While litter is a natural and invaluable fertilizer, quantities of this magnitude – concentrated over a small geographic area – represent a significant public health and ecological hazard.

A review of poultry operations of similar type and scale in the U.S., Europe, and Australia show that overapplication of poultry litter is a primary contributor to reduced ecosystem diversity caused by excess nutrient-related overgrowth of algae and cyanobacteria, i.e., eutrophication.[4] Nutrients accumulate in lakes and streams, crossing watersheds until they eventually empty into coastal systems, where oxygen levels deplete from phytoplankton growth and produce oceanic dead zones, a condition known as hypoxia. In the US., eutrophication-based hypoxia occurs yearly in the Gulf of Mexico, a catchment for the Missouri River watershed where streams impacted by the Costco project will ultimately empty.[5] The already worsening situation there will be amplified over time by this addition of poultry waste.

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[1] Shen, L. (2016, April 18). Costco is starting its own chicken farm. *Fortune*. https://fortune.com/2016/04/18/costco-chicken-farm/. Retrieved 10 August 2022.

[2] KETV Staff Report. (2017, March 01). Greater Fremont Development Council announces completion of land purchase for Costco, Lincoln Premium Poultry project. *KETV NewsWatch 7*. https://www.ketv.com/article/greater-fremont-development-council-announces-completion-of-land-purchase-for-costco-lincoln-premium-poultry-project/8991943. Retrieved 10 August 2022.

[3] Des Moines Register. (2020, April 12). See inside the plant that soon will process 2 million chickens a week for Costco Chicken. *Des Moines Register*. https://www.desmoinesregister.com/videos/news/2020/04/12/see-inside-plant-processes-1-million-chickens-week-costcochicken/2866441001/. Retrieved 10 August 2022.

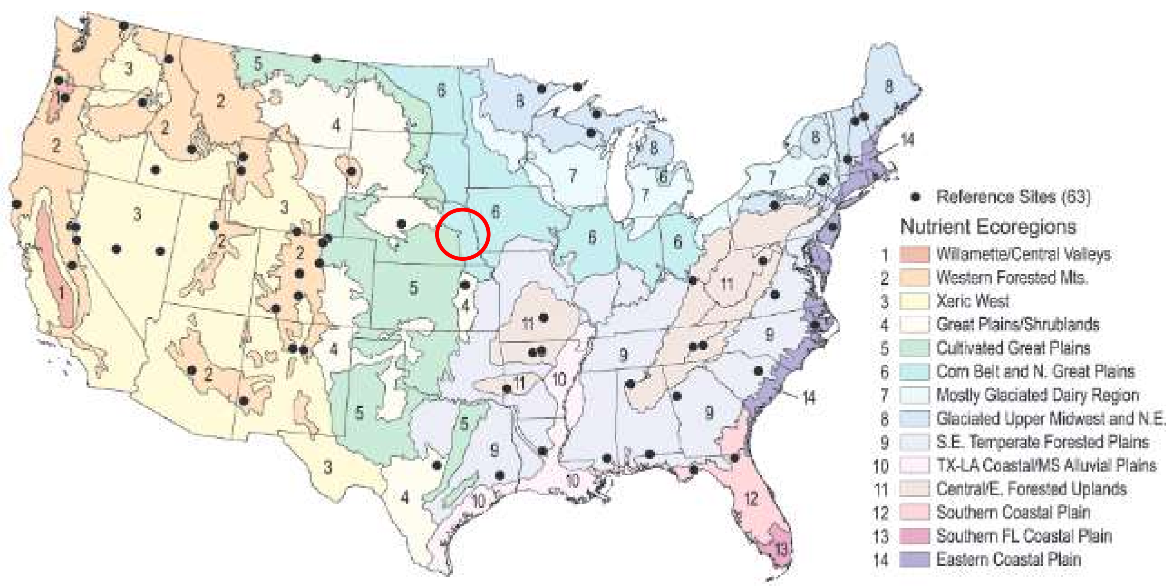
[4] Atapattu, N. (2006). Eutrophication and poultry industry: Issues, challenges and opportunities. *Proceedings of the International Forestry and Environment Symposium 2006 of the Department of forestry and Environmental Science, University of Sri Jayewardenepura, Sri Lanka,* 39 – 40: 39.

[5] Malone, T.C. and Newton, A. (2020). The globalization of cultural eutrophication in the coastal ocean: Causes and consequences. *Frontiers in Marine Science, 7*: 670. DOI:10.3389/fmars.2020.00670.

Nutrients

Before human influences, the average background level for total nitrogen in streams found in the U.S. is estimated at 0.14 milligrams per liter (mg L), ranging from 0.03 to 0.65 mg L. For total phosphorus, background levels average 0.023 mg L with a range between 0.015 and 0.080 mg L. These ranges represent the different ecoregions established by the United States Geological Survey (see Figure 1). Within the Corn Belt and Northern Great Plains ecoregion, where this present study occurs, estimates for median background limits for TN and TP are 0.35 mg L and 0.050 mg L, respectively. United States Environmental Protection Agency reference sites, which attempt to replicate background levels but are often subject to some level of anthropogenic influence, have found numbers in this region that average 2.00 mg L for TN and 0.08 mg L for TP. Indeed, within the targeted ecoregion, these reference sites contain amounts of TN and TP above even the 90th percentile of estimated background limits, indicating anthropogenic contributions.

Figure 1: USGS ecoregions. Red circle indicates affected study area.



Pathogens

Identifying all pathogens in a body of water is too tedious and costly to justify. For this reason, specific bacteria are chosen as indicators for water quality. To assess general water quality in this study, total coliforms, generic E. coli, and enterococci were selected. Campylobacter and salmonella were also tested for given their notoriety as indicators of poultry-based contamination. Campylobacter, E. coli, and enterococci all share moderate persistence in water supplies, surviving at 20C for 7 to 30 days.[6] The U.S. EPA recommends E. coli limits of 126 colony forming units

[6] World Health Organization. *Guidelines for drinking-water quality, Vol. 1*, WHO Press: 122. ISBN 92 4 154696 4.

(CFU) per 100 milliliters (mL) and a threshold of 35 CFU per 100 mL for enterococci.[7] These figures are used as reference points for stream health. Established limits aren't set for campylobacter and salmonella and only their probable presence or non-presence was detected in this study.

RESULTS

Nutrients

Samples returned total nitrogen concentrations ranging from 0.5 mg L to 10.2 mg L, equating to a minimum factor of about 1.5 to a maximum of almost 30 above background levels (0.35 mg L). Orthophosphate loads spanned 0.05 mg L to 0.52 mg L, on the lower end matching background levels (0.050 mg L) but exceeding them by up to a factor of 10 at the higher end.

Only one location (Big Blue River North) consistently returned TN values (0.5 – 0.7 mg L throughout entirety of study period) aligning with the ecoregion median. All other sites significantly and regularly exceeded this median (3.9 – 10.2 mg L). Orthophosphate concentrations tended to be several times higher than background estimates, excepting a single season (spring 2021), when half of the sites hovered around background amounts before spiking upward.

A strong unimodal distribution emerged for TN concentrations with most samples settling between 5.5 and 7.5 mg L (see Figure 2). Between annual seasons, these numbers generally remained consistent, ebbing and flowing as seasons alternated, peaking during the spring (see Figure 3). This contrasts with orthophosphate loads which tended to be higher in the fall (see Figure 4). Each stream tended to maintain relatively constant nutrient loads at moments of sample collection. In other words, there was not significant variation among individual locations between upstream and downstream concentrations.

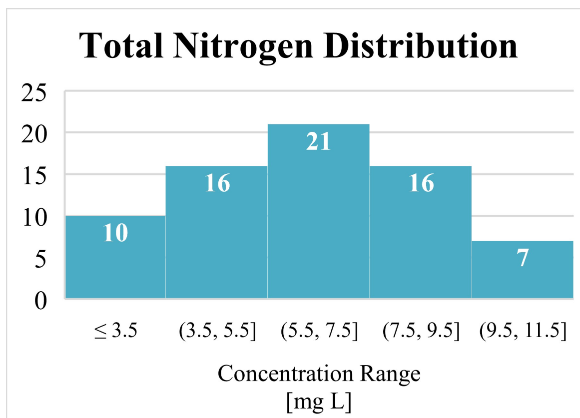


Figure 2: TN concentrations for all sites throughout study period showing a near-symmetrical unimodal distribution. n = 70

Importantly, a downward trend emerged within the orthophosphate data set for most test locations, lowering between the first session in fall 2019 through spring 2021 before spiking again in the most recent fall 2021 testing session to quantities above those observed in the first session.

[7] U.S. EPA Health and Ecological Criteria Division (2012). *Recreational Water Quality Criteria*. U.S. EPA Health and Ecological Criteria Division, Office of Science and Technology: 6.

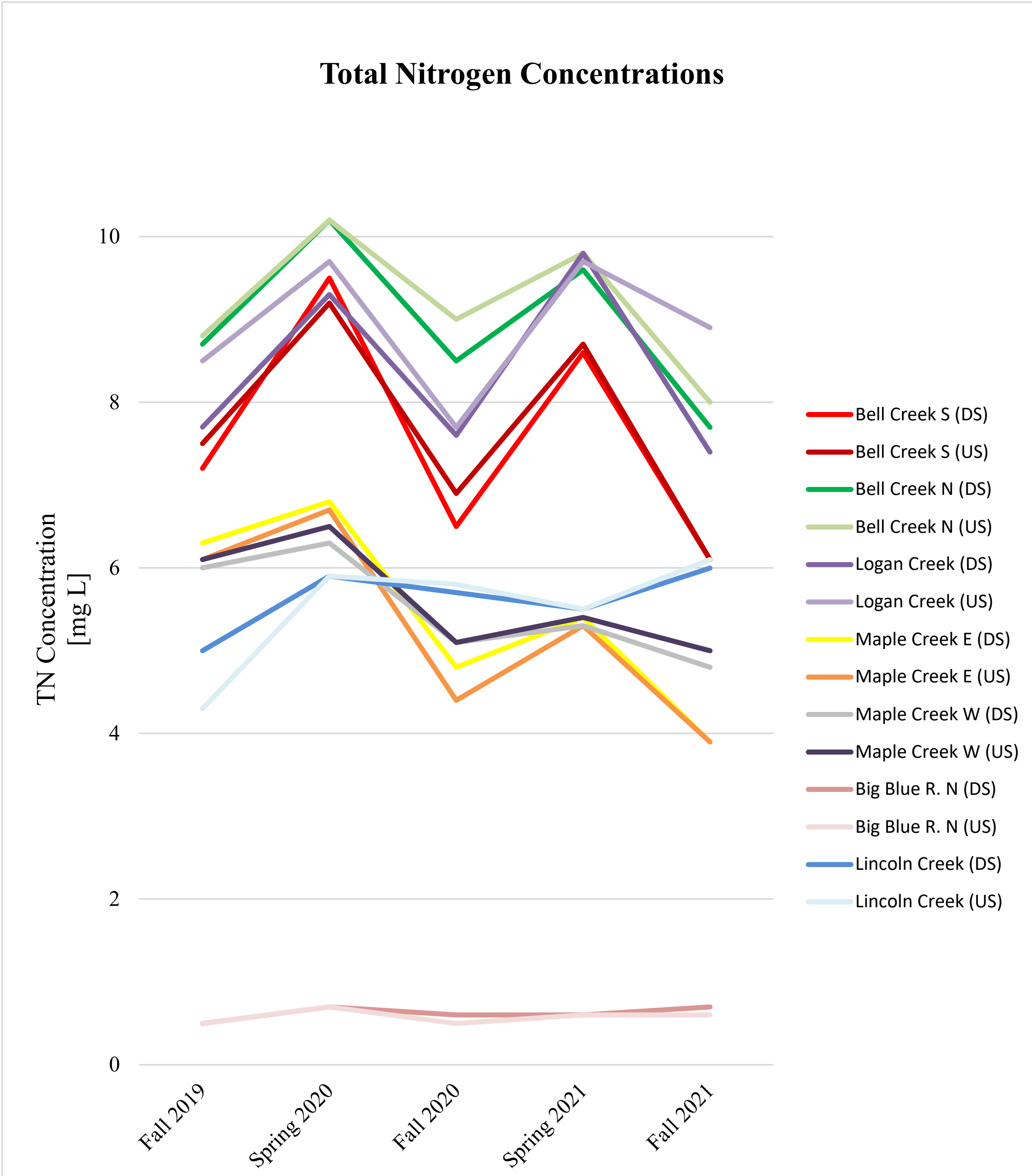


Figure 3: TN concentrations for individual sites by season.

(DS = Downstream, US = Upstream)

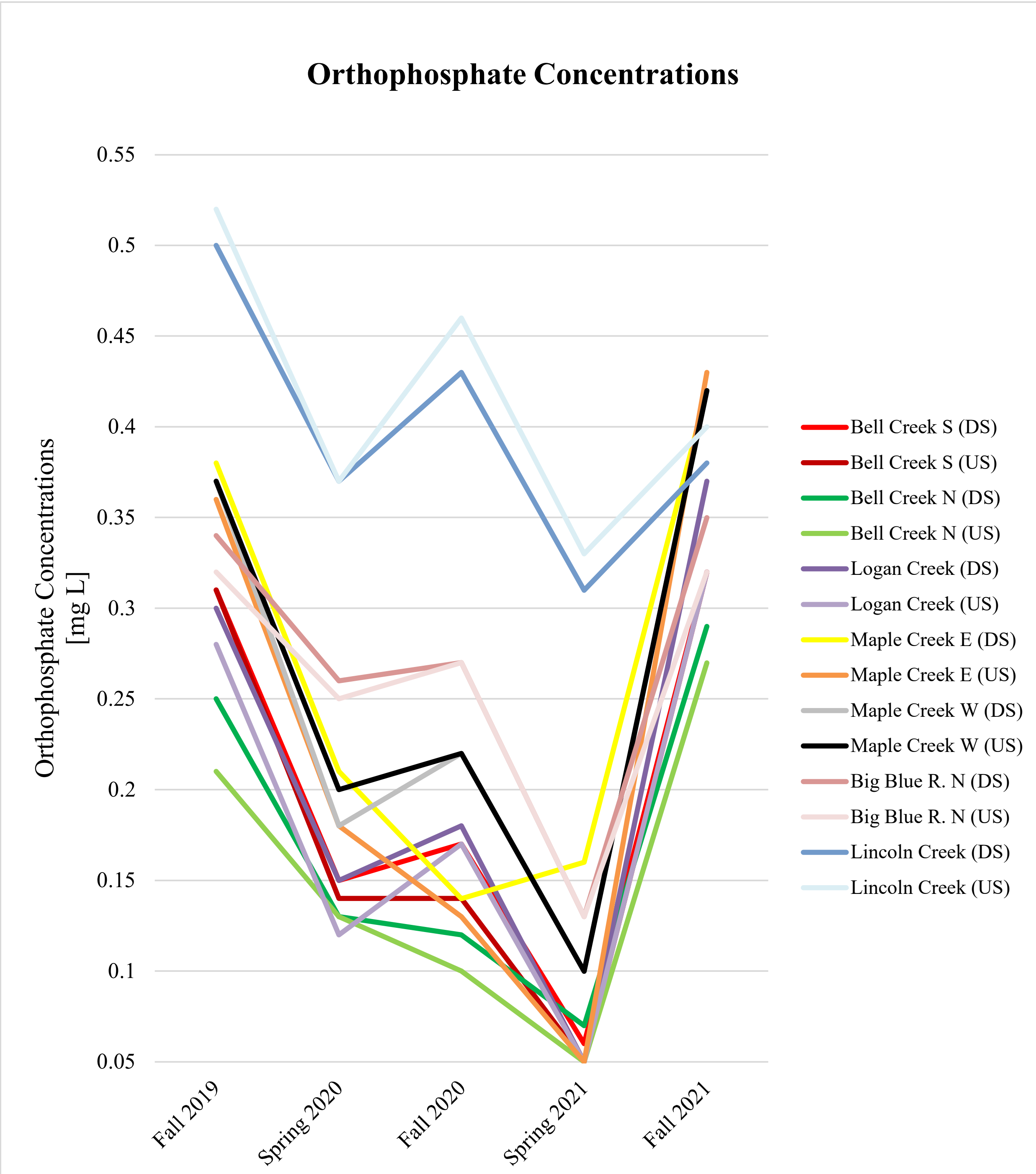


Figure 4: Orthophosphate (dissolved) concentrations for individual sites by season. (DS = Downstream, US = Upstream)

The rise in orthophosphate in fall 2021 is especially notable because the concentrations tended to exceed those recorded in fall 2019, which was a year of major flooding. Since phosphorous binds more tightly to the soil than nitrogen, and doesn't migrate as easily into groundwater, it is primarily transported into streams through erosion. It is therefore reasonable to conclude that higher rates of erosion during flooding would lead to higher contributions of phosphorous to waterways. What is alarming about the results from fall 2021 is that, despite being a non-flood year, orthophosphate levels marked the peak of the whole study period for six of the seven locations (only Lincoln Creek in Seward County did not spike to a maximum level). While the reasoning behind this peak is unclear, a couple of options are worth considering: 1) inputs of phosphorous increased surficially (e.g., through fertilizer application), derived from poultry litter or otherwise; or, 2) dry weather and soil conditions allowed for the transport of more soil (and thereby phosphorous) into stream systems. A third option is a combination of the two.

Pathogens

For the entirety of the study, almost 75% of the samples exceeded the recommendations for E. coli, often substantially, and nearly 80% were above limits for enterococci (see Figure 5). Of those samples which met the United States Environmental Protection Agency acceptability criteria, at least two-thirds were obtained during a single season (spring 2021), a seemingly anomalous occurrence among otherwise persistent contamination. All streams during most seasons were found to violate the limits set by the U.S. EPA for both E. coli and enterococci.

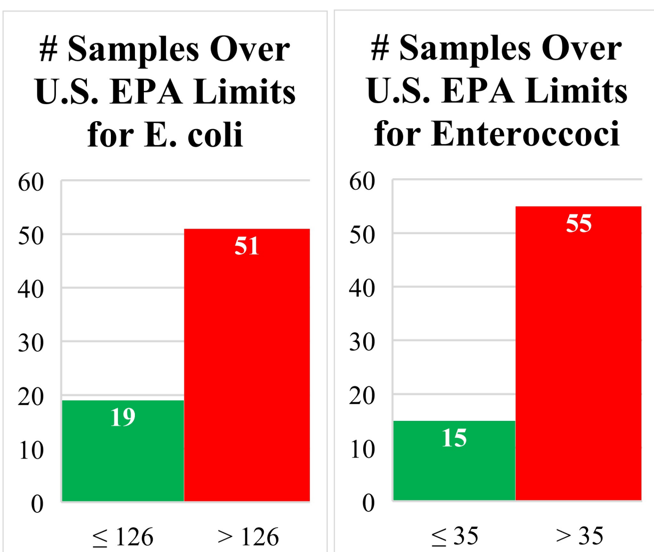


Figure 5: Number of samples throughout study period that exceeded U.S. EPA recommended limits for indicator bacteria. E. coli results less than or equal to 126 CFU per 100 mL and enterococci measuring 35 CFU per 100 mL or less indicate acceptable levels. n = 70

In most locations during the first session in fall 2019, E. coli were present in numbers beyond the limits of measurability (2,420 CFU per 100 mL). In the most recent testing session (fall 2021), over one-third of sites were higher than test maximums. For those sites which exceeded E. coli test limits, samples examined for enterococci provide higher resolution, ranging in number from 490 – 10,300 CFU per 100 mL in fall 2019 and 580 – 1583 CFU per 100 mL in fall 2021. This upper limit represents a factor of nearly 300 above the U.S. EPA recommendation for enterococci.

The dynamic nature of stream systems is exemplified by this irregular distribution of bacterial quantity between locations, and specific findings should not be extrapolated to the wider area. General conclusions can still be drawn, particularly that most area streams in like environments exceed U.S. EPA recommended bacteria limits.

Campylobacter was identified in seven samples throughout the study period. In four cases, the bacteria were found at upstream test sites but not downstream. Most positive occurrences were during the fall. Salmonella appeared with lower frequency than campylobacter. Like the campylobacter results, detection of salmonella shows the dynamicity of local waterways. The ability to recover after evading detection is unclear, and further understanding requires additional test points in the vicinity of individual locations. Nearly half of the positive results for the entirety of the whole study period were registered in the most recent fall 2021 testing season.

The most remarkable change in pathogen levels was at the Big Blue River North location in fall 2020. There, enterococci were present downstream at levels five times higher than the upstream site. Simultaneously, a near halving of the number of E. coli occurred. One possible cause is a change in the environment more suitable to enterococci reproduction caused its proliferation to an extent that E. coli became overwhelmed. A more likely explanation, given the substantial expansion in the total bacterial load, is a significant input source of enterococci was discovered.

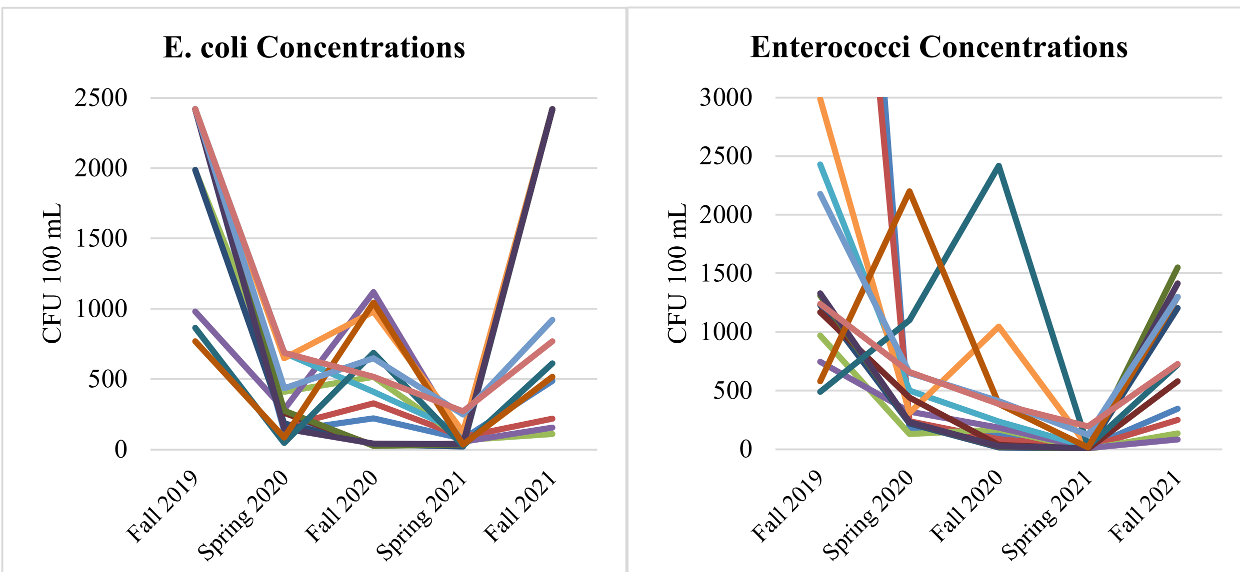


Figure 6: Seasonal concentrations of E. coli and enterococci quantities.

Interpretations

When deviations between upstream and downstream nutrient loads at a location are identified, it is generally observed that a drop in nitrogen values corresponds with a rise in phosphorous values. Comparing the graphical representations of bacterial loads (Figure 6) and orthophosphate (Figure 4) indicate related seasonal spikes between the two variables. This pattern is more pronounced with E. coli. Phosphorous is known to be the limiting factor for cellular growth and a positive correlation is suggested here, whereby availability of orthophosphate is linked to bacterial colony formation.[8] A similar comparison with nitrogen amounts makes it clear that heightened nitrogen levels do not correspond with bacterial loads. This phenomenon is observed most clearly in the spring of 2021, the single skewed season during which orthophosphate concentrations coincided with background levels in half of samples and when indicator bacteria tended to rest below recommended limits set by the U.S. EPA.

The significant rise in orthophosphate levels revealed in the fall 2021 testing season also corresponds with the highest detection levels of poultry-related bacteria throughout the course of the study. This suggests that poultry litter was applied in a widespread manner throughout the area prior to the fall testing season, at such a time that local waterways were not impacted in the previous spring. This occurs approximately two years after the beginning of litter accumulation and could be useful in better understanding the litter application schedule, particularly through continued observation during which a trend can emerge.

Reliability

The covered properties represent only a small fraction of the overall number of the known fields on which poultry litter will be applied. These sites were identified through nutrient management plans submitted to the Nebraska Department of Environment and Energy (NDEE). Since it was compiled prior to full operational capacity, this is an incomplete list, and it should also be understood as tentative since poultry suppliers may lose contracts and new growers may be added. More location data will allow for a testing approach that identifies the most at-risk areas. This study focused on areas able to represent that risk rather than to identify its extreme ends.

Testing locations were chosen where poultry litter will be applied on each side of a stream. By testing upstream and downstream at the edges of these properties, differences in contaminant levels could be specifically attributed to the fields in question. Other sites of application, which were not observed, may run between fields where an opposing side will not receive litter. In cases where land management practices are not known for all fields bordering a section of stream, more detailed study is required to determine responsibility of increased contaminant loads. Further, unexplored interactions from differing inputs may occur.

Consistency in data patterns between location pairs (Bell Creek North and South and Maple Creek West and East, representing four of the seven locations) indicate that collected samples accurately reflect local stream conditions and are thus useful in decision-making. In most cases, and consistently, pathogen results exceeded U.S. EPA recommendations. Contaminant loads are well above desired levels which should reinforce the need for efforts to maintain safe levels. Unsurprisingly, relatable upstream and downstream contaminant loads indicate sources of contribution begin upstream from tested sections. Streams should be evaluated beyond the fields of interest to gauge where contaminant levels rise and fall, raising the resolution of overall stream conditions and narrowing down source areas.

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[8] Schindler, D. W., Hecky, R. E., and Findlay, D. L. (2008). Eutrophication of lakes cannot be controlled by reducing nitrogen input: Results of a 37-year whole-ecosystem experiment. *Proceedings of the National Academy of Sciences, 105*, 32, 11254 – 11258. The Experimental Lakes Area in Ontario, Canada has shown that even in nitrogen-restricted conditions, eutrophication will not cease until phosphorous is exhausted from the ecosystem.

The extent to which these figures represent the wider area is unclear. While stream locations were largely isolated from each other, the sections tested all crossed through relatively similar terrain and soil type. Descriptive statistics indicate that some results are more predictive than others. Regarding pathogen activity, there was wide variation between both locations and seasons. Analysis inclusive of all seasons and locations show a mean TN of 6.05 (+/-) 2.785 mg L (with a 95% confidence that the mean would fall within 0.66 mg L) and mean dissolved orthophosphate of 0.25 (+/-) 0.125 mg L (95% confidence interval of 0.03 mg L). Given this order, it seems reasonable to expect that other streams within agricultural settings in the area carry similar quantities of these nutrients. In this way, these streams may be seen as representative of other stream sections running through similar environments in nearby Nebraska watersheds.

RECOMMENDATIONS

These recommendations provide a framework for increasing the accuracy and meaningfulness of results. Compartmentalizing recommendations allows for targeted goal management. The list is broken up into recommendations for continued study and suggestions for policy. It is advised that these recommendations be followed in conjunction as many are interdependent, e.g., more tools and data can culminate in building partnerships, which can in turn lead to more tools and data, thereby creating a feedback loop toward project expansion. Altogether, these recommendations are intended to inspire collaborative work and improve data reliability toward combined efforts of reducing contaminant inputs over time.

An overview of recommended goals is as follows:

Study Recommendations

- Establish molecular DNA testing of bacteria to identify contamination source.
- Maintain litter storage and application location and rate data.
- Identify other areas and sources of potential impact.
- Develop grower partnerships and designate test farms.
- Engage citizen scientists and increase public transparency of water quality issues.

Policy Recommendations

- Develop a working erosion and runoff model and update livestock operation matrix.
- Require nutrient management plans to include mitigation of litter impacts to soil health.
- Buffer running waterways to reduce soil loss and contaminant runoff due to erosion.

Study Recommendations

- ***Establish molecular DNA testing of bacteria to identify contamination source.***

Data forms the bedrock of scientific study. Evidence from this study has shown that there is widespread contamination of waterways around farms designated to receive Costco poultry litter. The most recent testing season has indicated, through substantially increased phosphorus loads coupled with heightened salmonella presence, that this litter is increasing the number and level of contaminants. Continued study should incorporate DNA sequencing of bacteria to determine their origin, which allows for a direct link to be made to the supply source. Since most testing seasons did not reveal contamination of the type normally associated with poultry litter, it may be possible to selectively perform this analysis during periods when conditions warrant it.

This sort of analysis is important because it creates a pathway to accountability and limits the potential for Costco or other industrial operators to deny their contributions to degraded stream systems. While this present study has implicated the poultry operation for a rise in nutrient and bacterial loads, DNA testing would provide the causal link to definitively tie the source of contamination from an industrial agricultural operation to worsened stream health.

- ***Maintain litter storage and application location and rate data.***

Reliable data about storage and application of poultry litter is needed to identify at-risk areas so that resources can be efficiently distributed for tracking and responding to violations of environmental regulations or recommendations. In order to aid public officials and other interested parties in evaluating impacts to public health and recreational water bodies, this information should be easily and permanently accessible, with updates as plan changes occur. As it currently stands, nutrient management plan records are only listed during an initial public review process. Accessibility after the review window closes depends on knowing criteria specific to each operation. Making these permits easier to track is paramount for transparency. More specific nutrient management plans should also be required to include application rates and schedules, a key part of assessing the big picture. Without knowing the quantity and frequency with which poultry litter is being applied to a field, information now absent from the permitting process, contaminant fluctuations cannot be meaningfully estimated. Data would ideally be combined with that for soil nutrient availability, when available, with consideration for crop removal rates, so that it can be determined if there is sufficient demand for the produced waste.

Without publicly available application rates, direct contact with farmers and property owners should be encouraged in order to better understand how to minimize runoff and to promote conservation practices. Actual application rate data would prove to be the most reliable for modeling contamination cycles. If data can be obtained from farmer participants, it would be assumed that best practices within the industry will result in relatively consistent application rates between operators on a per-acre basis, allowing for development of a generic model.

- ***Identify other areas and sources of potential impact.***

Current levels of observation, including those beyond the scope of this current study, limit the potential for an effective response against improper waste management and regulatory violations. Geographic expansion of the study area through an increase in the number of testing sites along waterways, to include additional farms and locations situated near meat processors and wastewater treatment facilities, will allow for more targeted conservation-based solutions which can be applied to more sensitive areas.

While pathogen levels varied widely between different streams, connected upstream and downstream sites shared a remarkable consistency. This consistency is indicative of a localized equilibrium within individual streams. Where spikes are revealed, a source of pollution can be more easily identified. There is also the possibility that tiling is concentrating inputs from a field to a point beyond where a test is carried out, meaning that spikes would be missed in such instances. Local conditions should be noted and incorporated into sampling strategies. Qualitative observations aimed at identifying agricultural practices, such as riparian filtration mechanisms, cropping and livestock management, and erosion prevention strategies, provide insight that numbered data alone cannot provide.

Additionally, excessive nutrients and pathogens are not the only issues related to poultry litter application. Estrogens, antibiotics, and metals are present at the operational scale in significant quantities (see Appendix B). Expanding the scope of the study to examine concentrations would reveal the extent of their distribution. Due to a passive sampling requirement, as opposed to the grab sampling used in this study, evaluating hormone and antibiotic loads depends on a more intensive testing schedule that requires two visits per sample, first for deployment and second for retrieval.

Further, contaminated water associated with the poultry operation is not only limited to streams. Flows from wastewater treatment plants, both public and private, should be evaluated to ensure that concentrations are acceptable upon exit into streams. Any increase of industrial livestock activity may compromise the ability of such treatment plants to sufficiently process these wastes.

Finally, it is unlikely that the market for poultry litter is agronomically and environmentally viable. How the waste will be stored when awaiting use is unclear. If the poultry litter is not used in full, then it will have to be stored onsite where it is produced. When vicinity to a stream can be distinguished, then it would be valuable to monitor relevant parameters of nearby waterways to assess any significant deviations in stream quality, especially after heavy precipitation events when contaminant leaching is most common.

- ***Develop grower partnerships and designate test farms.***

With increased farmer participation it will become easier to estimate healthy fertilizer application rates by combining agronomic, soil, and vegetation data. The field locations where poultry litter related to the Costco project is proposed for application are included in the public domain through initial nutrient management plans, though these are subject to change without notice, and, as mentioned, updates are not adequately maintained by the NDEE. If initial data sets for soil nutrient quantities can be determined or estimated for the fields intended to receive poultry litter, then a projected fertilization schedule and loss to streams can be predicted based on crop species removal rates, soil type, climate, slope, and erosion factor. Much of this land use information is already included in nutrient management plans. The average values for various litter constituents, i.e., nutrients, metals, and hormones, is also shared in these plans. Combining these variables allows leaching and runoff rates to be modeled when application amount and frequency is determined.

Test farms allow for models to be updated to better reflect conditions found in natural settings, increasing data availability and extent which expands insight into the contaminant pathways.

Building these relationships also provides opportunities for better understanding practical solutions that farmers can reasonably adopt. By implementing a variety of experimentally designed methods and practices related to both poultry litter application and soil stabilization, strategies for mitigating contamination can be evaluated and the most effective solutions can be determined. The ecological benefits of different operational styles, e.g., cover cropping and pasture grazing, can be quantified. This contributes to knowledge of best practices and can be used as reference models for others involved in poultry litter dispersion.

- ***Engage citizen scientists and increase public transparency of water quality issues.***

Citizen efforts, lacking influence by special interests, empower the public to have a greater understanding of stream health and, by proxy, their own health. Health issues and disparities associated with the use and consumption of contaminated water can be mitigated by public awareness, involvement, and transparency. A volunteer force willing to sample at pre-determined locations at specified time intervals will provide valuable data in a relatively inexpensive manner. Executive level planning should be used to select potential sites of interest. Following selection, a recruitment campaign can identify willing persons committed to a regular sampling schedule. Digital or in-person training sessions and workshops will be necessary to ensure proper collection. Following effective planning and training, individuals would ideally receive a test kit good for many uses, with the added benefit of testing for a wider variety of substances.

High school and collegiate classrooms traditionally make for enthusiastic citizen scientists. Local FFA chapters, non-profit organizations, and community groups are other examples of constituencies with a propensity to participate in citizen science programs. Leveraging such networks will heighten the ability to carry out more widespread testing initiatives which will manifest in more robust data sets and targeted collections.

Policy Recommendations

- ***Develop a working erosion and runoff model and update the livestock operation matrix.***

A review of all permit applications submitted by Costco poultry growers to the NDEE prior to the beginning of this current study was completed by the University of Nebraska Department of Civil Engineering. Specific data was gathered about the properties marked to receive the poultry litter, including usable acres, dominant soil type, slope, flood risk, erosion risk, phosphorus risk, and miscellaneous setbacks. By coupling this information with litter distribution data and crop removal rates, an impact assessment can be conducted.

The fourteen (14) operators reviewed prior to this study obtained permits for at least sixty-nine (69) barns (out of an estimated final operational total of 432). The litter from known barns will be applied to 102 fields. Based on the nutrient management plans, and assuming uniform distribution, early analysis shows that half of the poultry grow operations will produce litter with phosphorus quantities in excess of the crop removal rate. On average, phosphorus contained within the poultry will provide 85% of yield demand, capping at 137%; nitrogen is projected to be present at a much lower factor in relation to total crop needs, averaging 14% and ranging from 6% to 22% of crop requirements.[9] From the current sample of operators, six (6) are projected to accumulate phosphorus at a rate faster than the designated application sites need replenished. Either the excess litter will be stored onsite at the point of origin or it will be distributed in quantities higher than the fields outlined in the nutrient management plan are capable of utilizing. In either case, eutrophication is the inevitable outcome.

Quantity and frequency estimates will make it possible to determine on which fields overapplication is likely to occur, allowing for targeted sampling campaigns. Of the 102 known field locations, one-third experience flooding, most regularly. One-third also have slopes greater than 10% and almost half border a stream. Resources can be better appropriated by determining not only which properties will face the most pressure for accepting litter in excess, but also those which pose the greatest risk to stream systems as a result of topography.

Currently, a matrix point system is used for permit approval of livestock operations, and it is possible to accumulate a sufficient number of points without any consideration for environmental damage. This livestock operation matrix point system should be updated so that concentrated animal feeding operations (CAFOs) are required by law to consider, prior to the approval of development of livestock barns, predicted runoff as determined by such a model as the one suggested above.

- ***Require nutrient management plans to include mitigation of litter impacts to soil health.***

In addition to updating the matrix application process for approving CAFOs, nutrient management plans should be updated to proactively address runoff concerns. A requirement for all companies proposing the development of CAFOs should include proven soil health practices such as cover cropping for all farms outlined to receive litter, and the introduction of buffer strips along all running waterways adjacent to those properties. An "Environmental Impact Review" as part of a nutrient management plan submitted by CAFOs should be included prior to county processing and public hearings. This, along with cooperative support of local, state, and federal agencies, can start to shift farmers into a more proactive role designed to reduce threats of contamination.

With the emergence of more bio-diverse farm operations that utilize cover crops and expanded pastures, adaptive farms will produce more diversified feed sources for livestock and more efficiently apply waste with consideration for individual field requirements. This will allow for animals to spend less time in CAFOs and more time in newly established grazing systems. Not only will this approach minimize negative impacts from excess runoff, but it will also help farmers lower their dependence on synthetically produced nutrients while diversifying livestock feed sources. This increases farm business profits and makes farms more resilient against extreme weather events.

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[9] Ward, R. C. (2019). *Ward guide: Guiding producers today to feed the world tomorrow.* Ward Laboratories. Corn and soybean phosphorus requirements are 0.33 lbs. per bushel and 0.77 lbs. per bushel, respectively. Nitrogen demands for corn and soybeans equal 0.75 lbs. per bushel and 3.7 lbs. per bushel, respectively.

❖ ***Buffer running waterways to reduce soil loss and contaminant runoff due to erosion.***

According to the U.S. Department of Agriculture Natural Resources Conservation Service, agricultural land in Nebraska loses annually about three tons of soil per acre due to erosion.[10] This study also highlights that agricultural runoff is increasing in the State of Nebraska. At the state level, priorities should include buffering all running waterways, e.g., filter strips and riparian buffers, to reduce the transmission of soil and contaminants into area and downstream watersheds. Federal conservation programs already aid in the development of buffer zones in sensitive areas. Matching funds through local, state, and federal programs is critical for making more resources available to producers who farm near waterways. Nebraska Natural Resource Districts should work in conjunction with state and federal agencies to strategically appropriate funds toward reducing soil loss to streams.

CONCLUSION

This document has laid out suggestions for ways in which community stakeholders can make informed environmental and public health decisions regarding the management of waste derived from the Costco poultry project and operations of similar scales. This initial analysis builds on previous efforts to quantify the impact of livestock waste on waterways surrounding properties outlined as recipients in state nutrient management plans. The results herein will be most meaningful in conjunction with continued study. Detection of poultry-related pathogens did not occur throughout most of the study period, however, there was an observed spike in the most recent testing season. In this case, five sites returned a positive indication for either campylobacter or salmonella (out of a total of eleven positives throughout the entire study period). This occurs simultaneously with a substantial rise in phosphorus levels in all observed systems. Together, this appears to be an indication that the application of poultry litter corresponds with the most recent testing season. The present study is known to have begun prior to livestock waste application and most samples during its course did not contain obvious poultry contamination. Therefore, the combination of outcomes appears to implicate Costco poultry litter as the source of increased nutrients and pathogens. Given emerging patterns identified in this study, particularly as exposed in the most recent testing season, more investment in stream analysis related to livestock waste application is highly recommended. More reliable and insightful results can be obtained by investing in advanced testing protocols, enlarging the number of study locations and sampling points, and through expanded use of public stream gauge stations. Leveraging organizational networks and furthering private and public partnerships, alongside heightened farmer participation, will be the most effective approach in developing a better understanding and improved oversight for industrial agriculture operations of this magnitude. Combined with proper governmental oversight and guidance, which is currently lacking, restoration of damaged waterways can begin.

[10] U.S. Department of Agriculture (2017). *National Resources Inventory*. Natural Resources Conservation Service.

APPENDIX A: INDIVIDUAL SITE DATA

Location 1

Bell Creek South

Site:	County:
Bell Creek S (US)	Washington

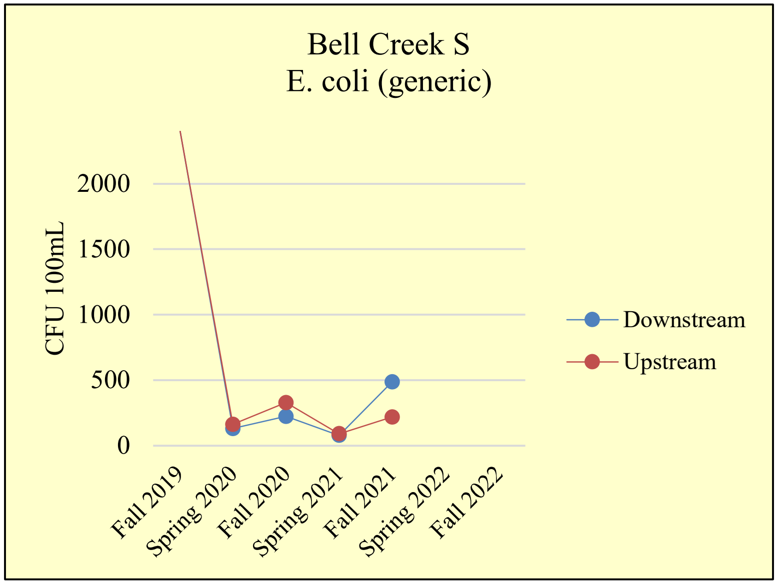
Season	Date	Total Coliforms [CFU 100mL]*	E. coli (generic) [CFU 100mL]**	Enterococci [CFU 100mL]	Campylobacter	Salmonella	TN [mg L]	Orthophosphate [mg L]
Fall 2019	9/23/2019	2420	2420	8600	Positive	Negative	7.5	0.31
Spring 2020	5/21/2020	2420	162	240	Negative	Negative	9.2	0.14
Fall 2020	9/28/2020	2420	328	86.2	Negative	Negative	6.9	0.14
Spring 2021	5/2/2021	2420	90	18.5	Negative	Negative	8.7	0.05
Fall 2021	10/3/2021	2420	219	249.5	Negative	Negative	6.1	0.32

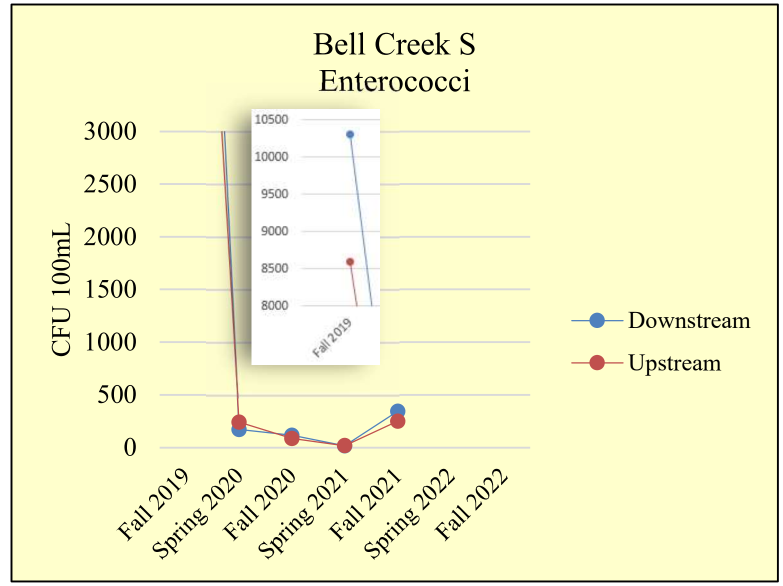
Site:	County:
Bell Creek S (DS)	Washington

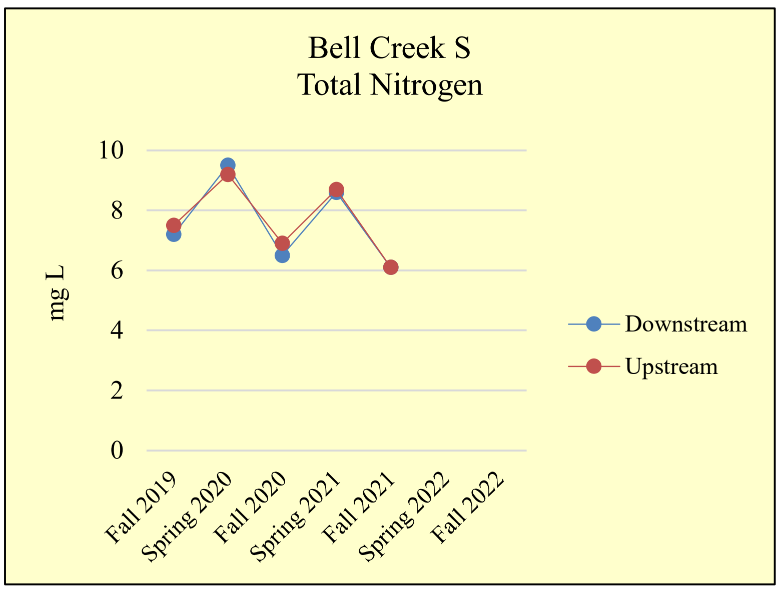
Season	Date	Total Coliforms [CFU 100mL]	E. coli (generic) [CFU 100mL]	Enterococci [CFU 100mL]	Campylobacter	Salmonella	TN [mg L]	Orthophosphate [mg L]
Fall 2019	9/23/2019	2420	2420	10300	Negative	Negative	7.2	0.31
Spring 2020	5/21/2020	2420	131	170	Negative	Negative	9.5	0.15
Fall 2020	9/28/2020	2420	222	116.9	Negative	Negative	6.5	0.17
Spring 2021	5/2/2021	2420	78	16.1	Negative	Negative	8.6	0.06
Fall 2021	10/3/2021	2420	488	344.8	Negative	Negative	6.1	0.32

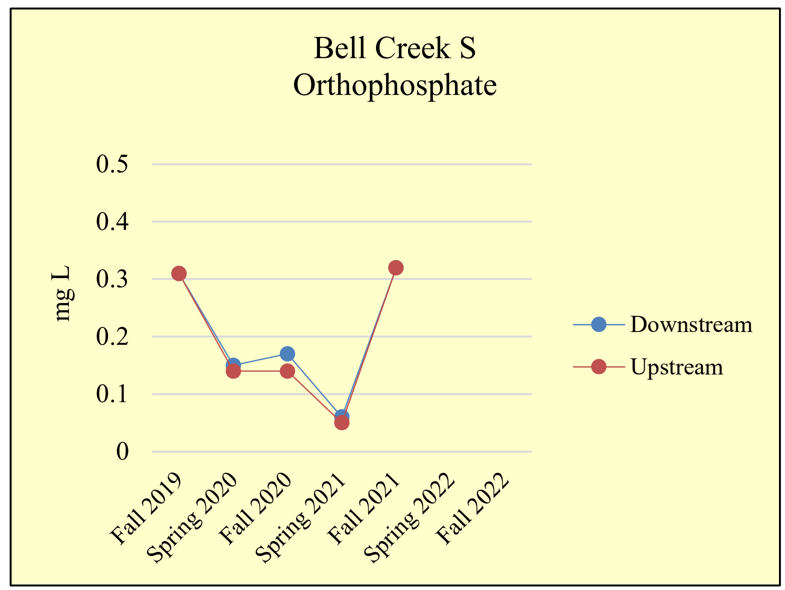
*   Maximum test threshold of 2,420 CFU per 100mL.

** Maximum test threshold of 2,420 CFU per 100mL.


Bell Creek S
E. coli (generic)
CFU 100mL
2000
1500
1000
500
0
Fall 2019
Spring 2020
Fall 2020
Spring 2021
Fall 2021
Spring 2022
Fall 2022
Downstream
Upstream


Bell Creek S
Enterococci
CFU 100mL
3000
2500
2000
1500
1000
500
0
10500
10000
9500
9000
8500
8000
Fall 2019
Fall 2019
Spring 2020
Fall 2020
Spring 2021
Fall 2021
Spring 2022
Fall 2022
Downstream
Upstream


Bell Creek S
Total Nitrogen
mg L
10
8
6
4
2
0
Fall 2019
Spring 2020
Fall 2020
Spring 2021
Fall 2021
Spring 2022
Fall 2022
Downstream
Upstream


Bell Creek S
Orthophosphate
mg L
0.5
0.4
0.3
0.2
0.1
0
Fall 2019
Spring 2020
Fall 2020
Spring 2021
Fall 2021
Spring 2022
Fall 2022
Downstream
Upstream

Location 2

Bell Creek North

Site:	County:
Bell Creek N (US)	Burt

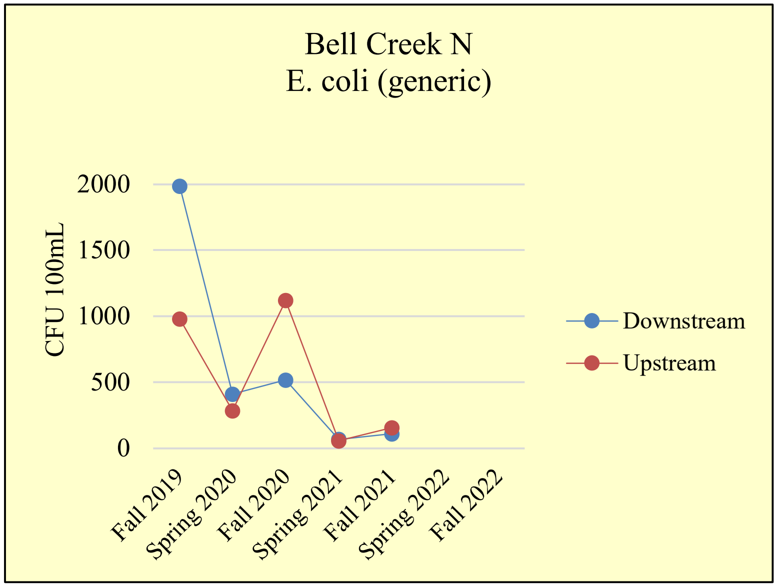
[redacted]

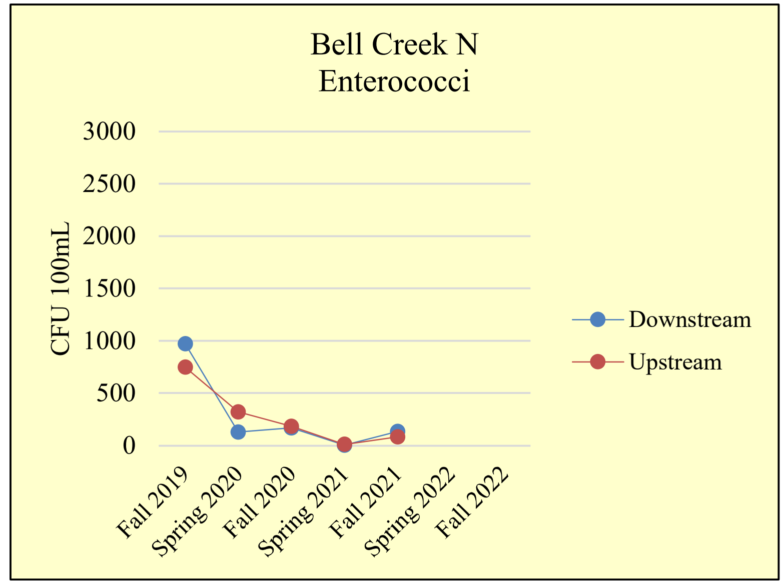
Season	Date	Total Coliforms [CFU 100mL]	E. coli (generic) [CFU 100mL]	Enterococci [CFU 100mL]	Campylobacter	Salmonella	TN [mg L]	Orthophosphate [mg L]
Fall 2019	9/23/2019	2420	980	748	Negative	Negative	8.8	0.21
Spring 2020	5/21/2020	2420	285	320	Negative	Negative	10.2	0.13
Fall 2020	9/28/2020	2420	1120	185	Negative	Negative	9	0.1
Spring 2021	5/2/2021	2420	57	10.9	Negative	Negative	9.8	0.05
Fall 2021	10/3/2021	2420	156	83.6	Negative	Negative	8	0.27

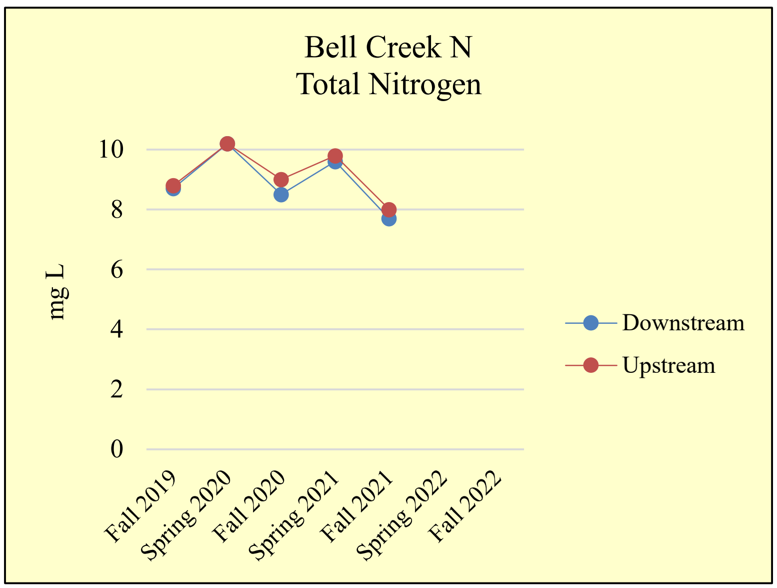
Site:	County:
Bell Creek N (DS)	Burt

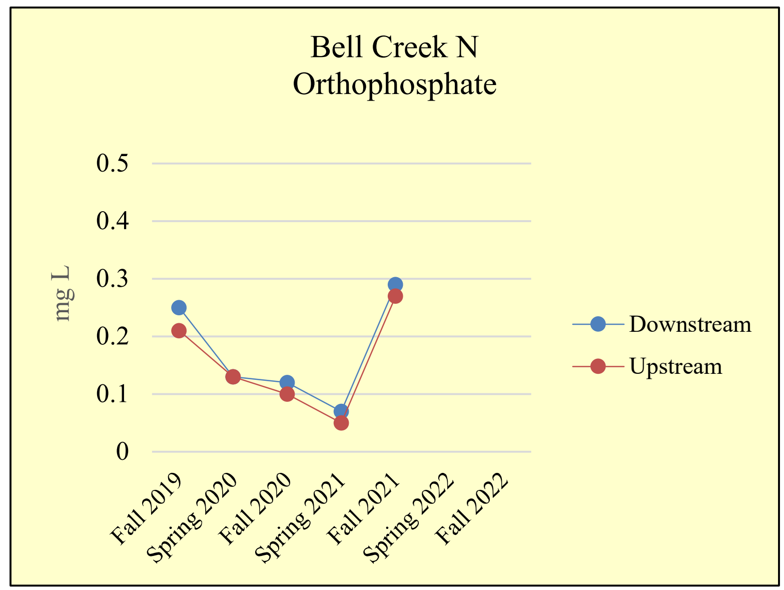
[redacted]

Season	Date	Total Coliforms [CFU 100mL]	E. coli (generic) [CFU 100mL]	Enterococci [CFU 100mL]	Campylobacter	Salmonella	TN [mg L]	Orthophosphate [mg L]
Fall 2019	9/23/2019	2420	1986	972	Negative	Negative	8.7	0.25
Spring 2020	5/21/2020	2420	411	130	Negative	Negative	10.2	0.13
Fall 2020	9/28/2020	2420	517	167.4	Negative	Negative	8.5	0.12
Spring 2021	5/2/2021	2420	68	4.1	Negative	Negative	9.6	0.07
Fall 2021	10/3/2021	2420	110	135.4	Negative	Negative	7.7	0.29


Bell Creek N
E. coli (generic)
CFU 100mL
2000
1500
1000
500
0
Fall 2019
Spring 2020
Fall 2020
Spring 2021
Fall 2021
Spring 2022
Fall 2022
Downstream
Upstream


Bell Creek N
Enterococci
CFU 100mL
3000
2500
2000
1500
1000
500
0
Fall 2019
Spring 2020
Fall 2020
Spring 2021
Fall 2021
Spring 2022
Fall 2022
Downstream
Upstream


Bell Creek N
Total Nitrogen
mg L
10
8
6
4
2
0
Fall 2019
Spring 2020
Fall 2020
Spring 2021
Fall 2021
Spring 2022
Fall 2022
Downstream
Upstream


Bell Creek N
Orthophosphate
mg L
0.5
0.4
0.3
0.2
0.1
0
Fall 2019
Spring 2020
Fall 2020
Spring 2021
Fall 2021
Spring 2022
Fall 2022
Downstream
Upstream

Location 3

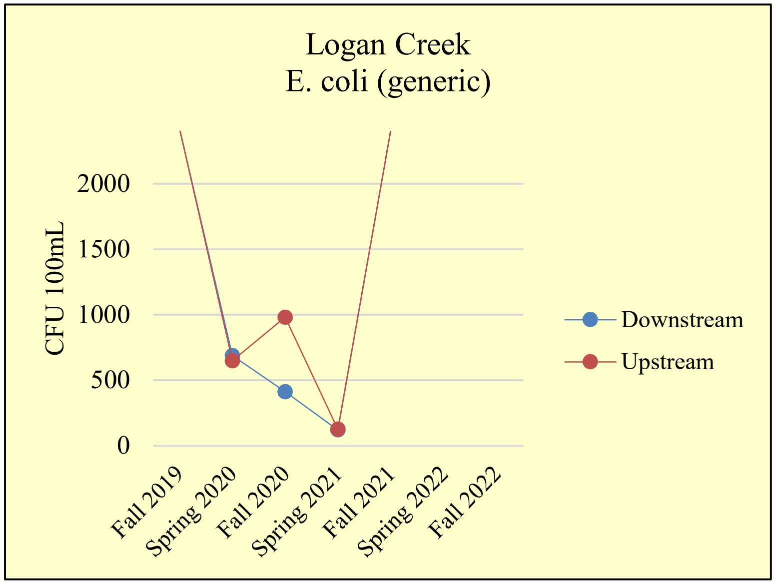
Logan Creek

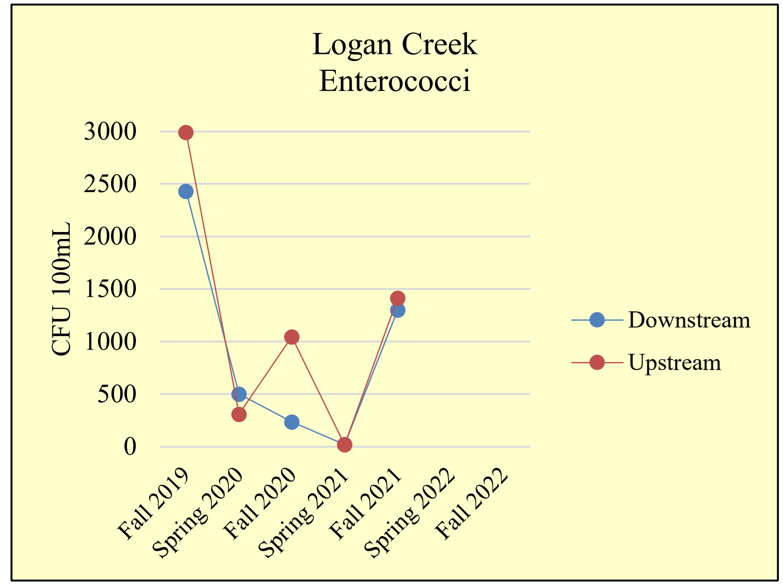
Site:	County:
Logan Creek (US)	Burt

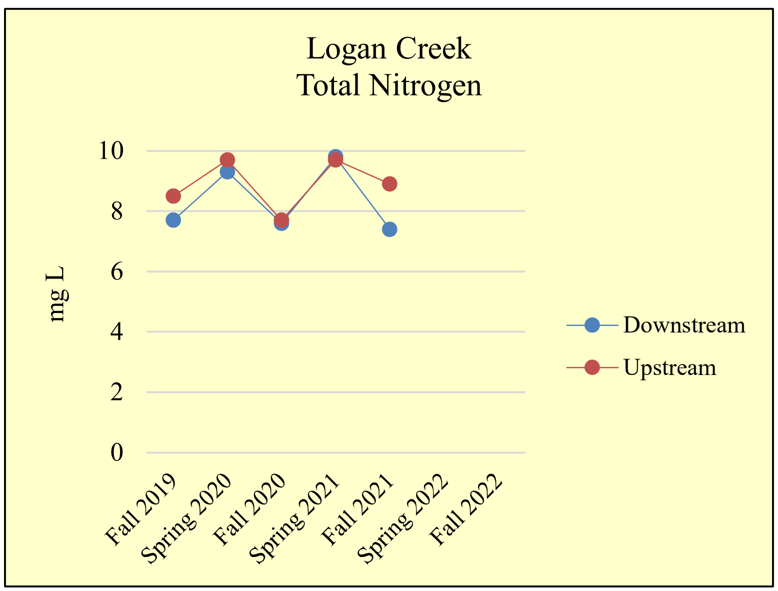
Season	Date	Total Coliforms [CFU 100mL]	E. coli (generic) [CFU 100mL]	Enterococci [CFU 100mL]	Campylobacter	Salmonella	TN [mg L]	Orthophosphate [mg L]
Fall 2019	9/23/2019	2420	2420	2990	Negative	Negative	8.5	0.28
Spring 2020	5/21/2020	2420	649	310	Positive	Negative	9.7	0.12
Fall 2020	9/28/2020	2420	980	1046	Negative	Negative	7.7	0.17
Spring 2021	5/2/2021	2420	125	18.1	Negative	Negative	9.7	0.05
Fall 2021	10/3/2021	2420	2420	1414	Negative	Negative	8.9	0.32

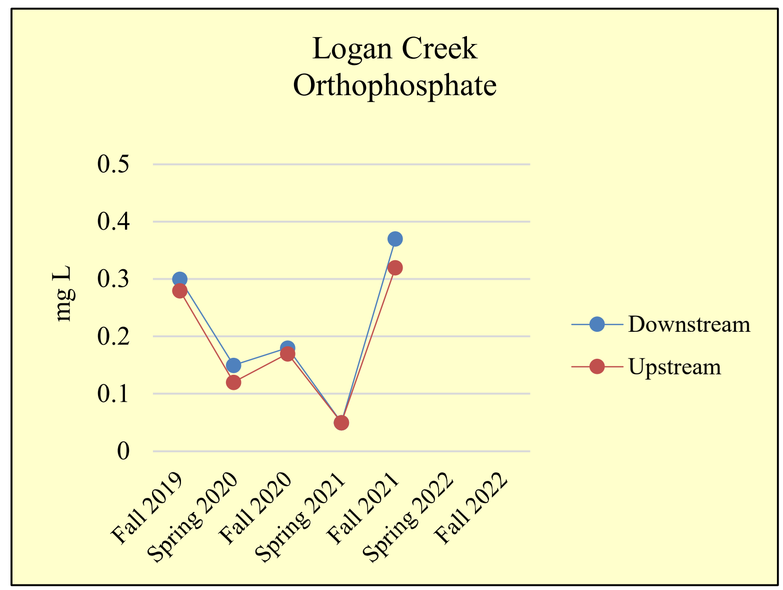
Site:	County:
Logan Creek (DS)	Burt

Season	Date	Total Coliforms [CFU 100mL]	E. coli (generic) [CFU 100mL]	Enterococci [CFU 100mL]	Campylobacter	Salmonella	TN [mg L]	Orthophosphate [mg L]
Fall 2019	9/23/2019	2420	2420	2430	Negative	Negative	7.7	0.3
Spring 2020	5/21/2020	2420	687	500	Negative	Negative	9.3	0.15
Fall 2020	9/28/2020	2420	411	235.9	Negative	Negative	7.6	0.18
Spring 2021	5/2/2021	2420	120	21.6	Negative	Negative	9.8	0.05
Fall 2021	10/3/2021	2420	2420	1300	Negative	Negative	7.4	0.37


Logan Creek
E. coli (generic)
CFU 100mL
2000
1500
1000
500
0
Fall 2019
Spring 2020
Fall 2020
Spring 2021
Fall 2021
Spring 2022
Fall 2022
Downstream
Upstream


Logan Creek
Enterococci
CFU 100mL
3000
2500
2000
1500
1000
500
0
Fall 2019
Spring 2020
Fall 2020
Spring 2021
Fall 2021
Spring 2022
Fall 2022
Downstream
Upstream


Logan Creek
Total Nitrogen
mg L
10
8
6
4
2
0
Fall 2019
Spring 2020
Fall 2020
Spring 2021
Fall 2021
Spring 2022
Fall 2022
Downstream
Upstream


Logan Creek
Orthophosphate
mg L
0.5
0.4
0.3
0.2
0.1
0
Fall 2019
Spring 2020
Fall 2020
Spring 2021
Fall 2021
Spring 2022
Fall 2022
Downstream
Upstream

Location 4

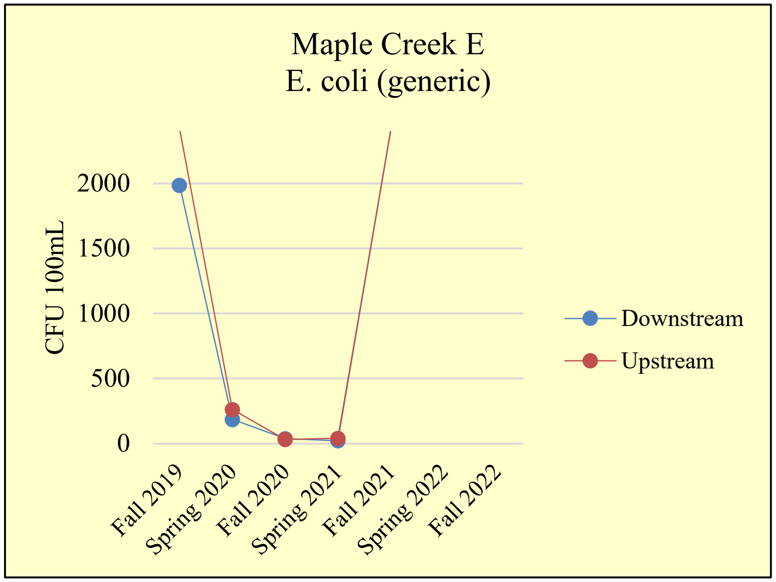
Maple Creek East

Site:	County:
Maple Creek E (US)	Dodge

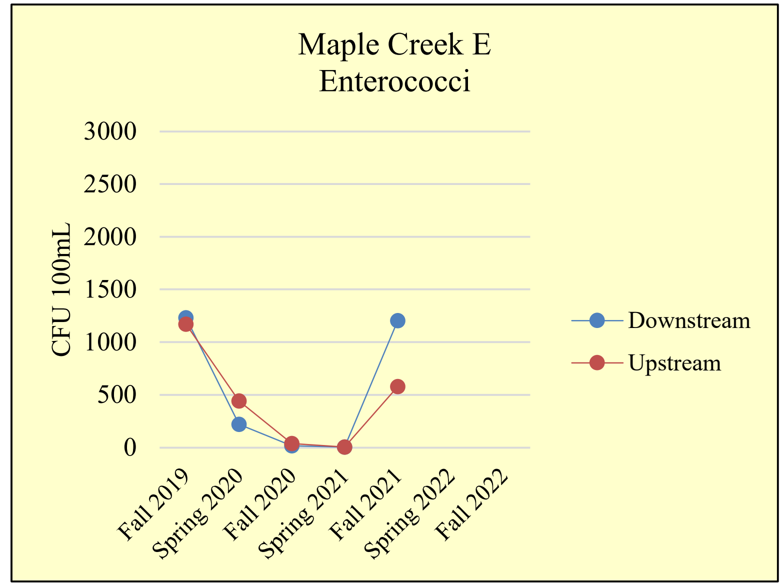
Season	Date	Total Coliforms [CFU 100mL]	E. coli (generic) [CFU 100mL]	Enterococci [CFU 100mL]	Campylobacter	Salmonella	TN [mg L]	Orthophosphate [mg L]
Fall 2019	9/23/2019	2420	2420	1170	Negative	Negative	6.1	0.36
Spring 2020	5/21/2020	2420	261	440	Negative	Negative	6.7	0.18
Fall 2020	9/28/2020	2420	32	36.4	Negative	Negative	4.4	0.13
Spring 2021	5/2/2021	1203	41	5.2	Negative	Negative	5.3	0.05
Fall 2021	10/3/2021	2420	2420	579.4	Positive	Positive	3.9	0.43

Site:	County:
Maple Creek E (DS)	Dodge

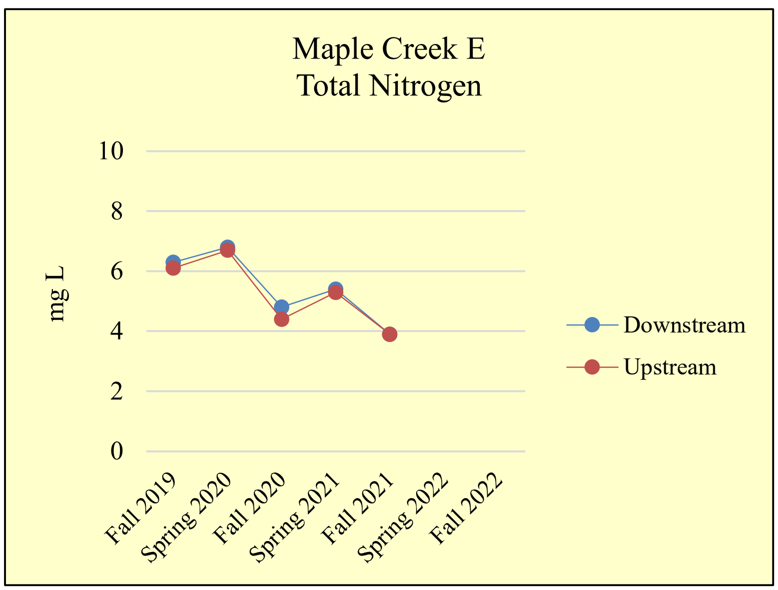
Season	Date	Total Coliforms [CFU 100mL]	E. coli (generic) [CFU 100mL]	Enterococci [CFU 100mL]	Campylobacter	Salmonella	TN [mg L]	Orthophosphate [mg L]
Fall 2019	9/23/2019	2420	1986	1230	Negative	Negative	6.3	0.38
Spring 2020	5/21/2020	2420	185	220	Negative	Negative	6.8	0.21
Fall 2020	9/28/2020	2420	37	16.4	Negative	Negative	4.8	0.14
Spring 2021	5/2/2021	1986	22	5.2	Negative	Negative	5.4	0.16
Fall 2021	10/3/2021	2420	2420	1203	Negative	Negative	3.9	0.42



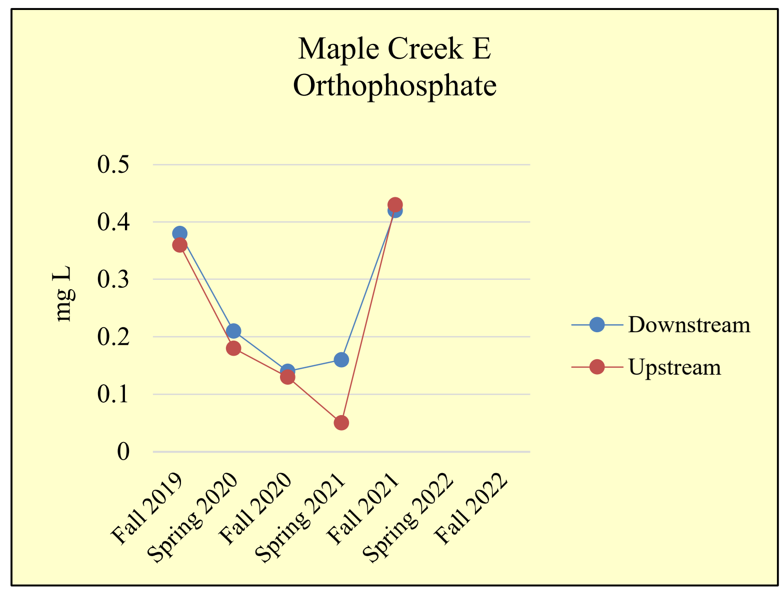
Maple Creek E
E. coli (generic)
CFU 100mL
2000
1500
1000
500
0
Fall 2019
Spring 2020
Fall 2020
Spring 2021
Fall 2021
Spring 2022
Fall 2022
Downstream
Upstream



Maple Creek E
Enterococci
CFU 100mL
3000
2500
2000
1500
1000
500
0
Fall 2019
Spring 2020
Fall 2020
Spring 2021
Fall 2021
Spring 2022
Fall 2022
Downstream
Upstream



Maple Creek E
Total Nitrogen
mg L
10
8
6
4
2
0
Fall 2019
Spring 2020
Fall 2020
Spring 2021
Fall 2021
Spring 2022
Fall 2022
Downstream
Upstream



Maple Creek E
Orthophosphate
mg L
0.5
0.4
0.3
0.2
0.1
0
Fall 2019
Spring 2020
Fall 2020
Spring 2021
Fall 2021
Spring 2022
Fall 2022
Downstream
Upstream

Location 5

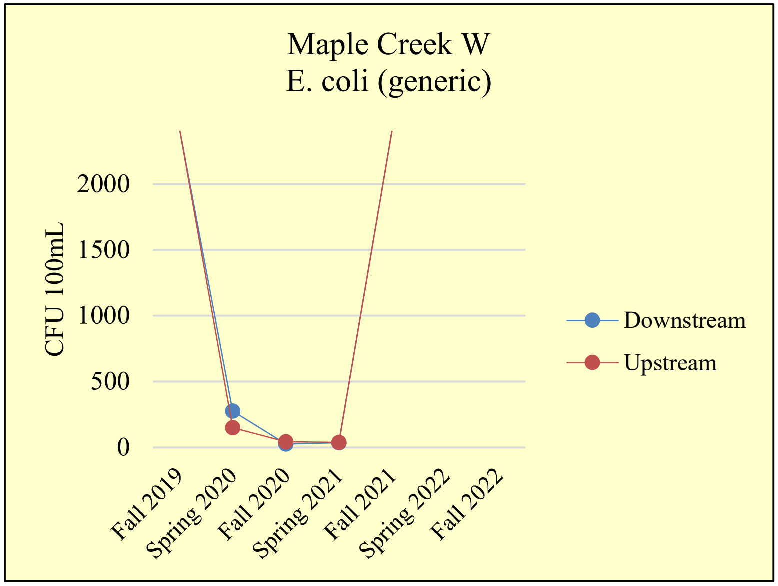
Maple Creek West

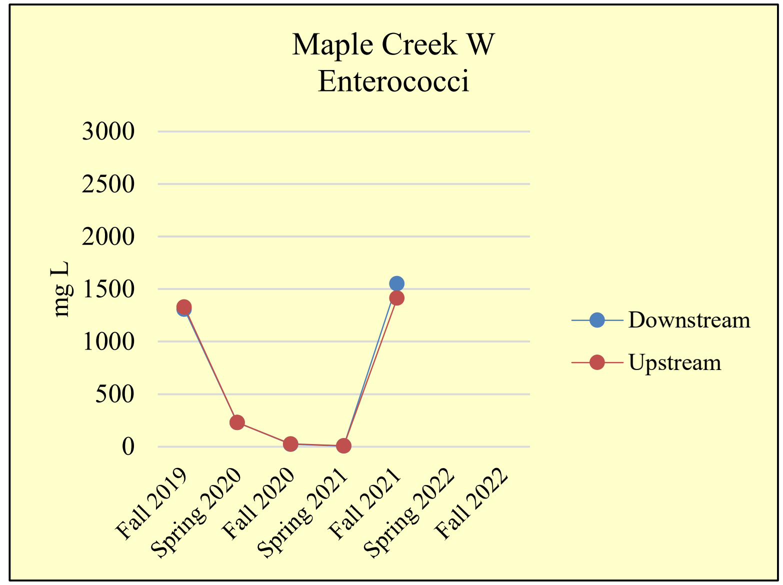
Site:	County:
Maple Creek W (US)	Dodge

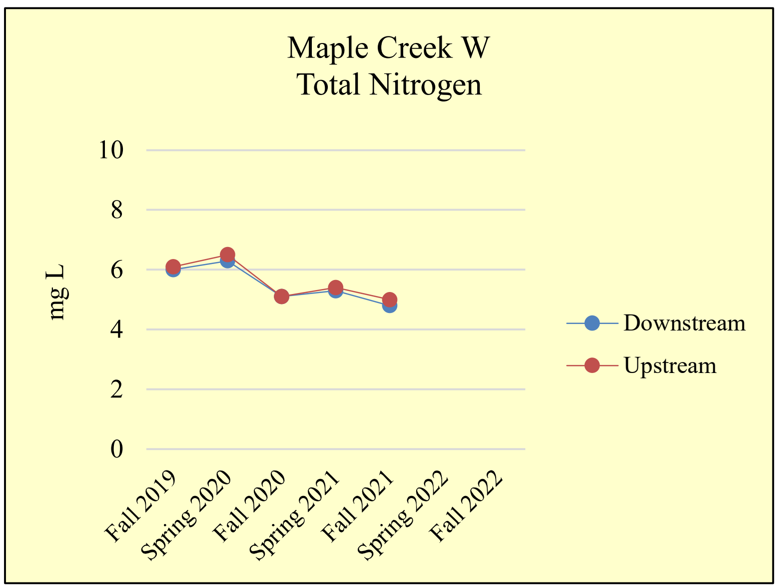
Season	Date	Total Coliforms [CFU 100mL]	E. coli (generic) [CFU 100mL]	Enterococci [CFU 100mL]	Campylobacter	Salmonella	TN [mg L]	Orthophosphate [mg L]
Fall 2019	9/23/2019	2420	2420	1330	Negative	Negative	6.1	0.37
Spring 2020	5/21/2020	2420	148	230	Negative	Negative	6.5	0.2
Fall 2020	9/28/2020	2420	41	26.2	Negative	Negative	5.1	0.22
Spring 2021	5/2/2021	1733	38	9.7	Negative	Negative	5.4	0.1
Fall 2021	10/3/2021	2420	2420	1414	Negative	Negative	5	0.42

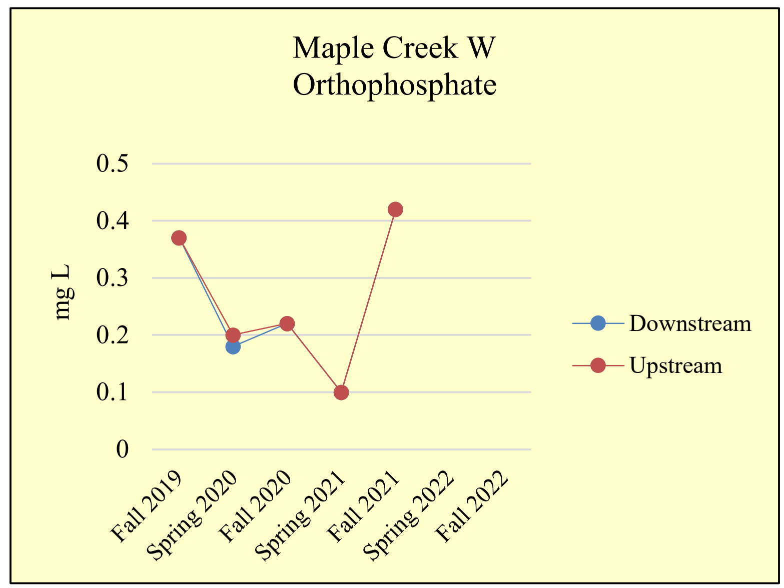
Site:	County:
Maple Creek W (DS)	Dodge

Season	Date	Total Coliforms [CFU 100mL]	E. coli (generic) [CFU 100mL]	Enterococci [CFU 100mL]	Campylobacter	Salmonella	TN [mg L]	Orthophosphate [mg L]
Fall 2019	9/23/2019	2420	2420	1310	Negative	Negative	6	0.37
Spring 2020	5/21/2020	2420	276	230	Negative	Negative	6.3	0.18
Fall 2020	9/28/2020	2420	26	22.8	Negative	Negative	5.1	0.22
Spring 2021	5/2/2021	1553	34	7.2	Negative	Negative	5.3	0.1
Fall 2021	10/3/2021	2420	2420	1553	Positive	Negative	4.8	0.42


Maple Creek W
E. coli (generic)
CFU 100mL
2000
1500
1000
500
0
Fall 2019
Spring 2020
Fall 2020
Spring 2021
Fall 2021
Spring 2022
Fall 2022
Downstream
Upstream


Maple Creek W
Enterococci
mg L
3000
2500
2000
1500
1000
500
0
Fall 2019
Spring 2020
Fall 2020
Spring 2021
Fall 2021
Spring 2022
Fall 2022
Downstream
Upstream


Maple Creek W
Total Nitrogen
mg L
10
8
6
4
2
0
Fall 2019
Spring 2020
Fall 2020
Spring 2021
Fall 2021
Spring 2022
Fall 2022
Downstream
Upstream


Maple Creek W
Orthophosphate
mg L
0.5
0.4
0.3
0.2
0.1
0
Fall 2019
Spring 2020
Fall 2020
Spring 2021
Fall 2021
Spring 2022
Fall 2022
Downstream
Upstream

Location 6

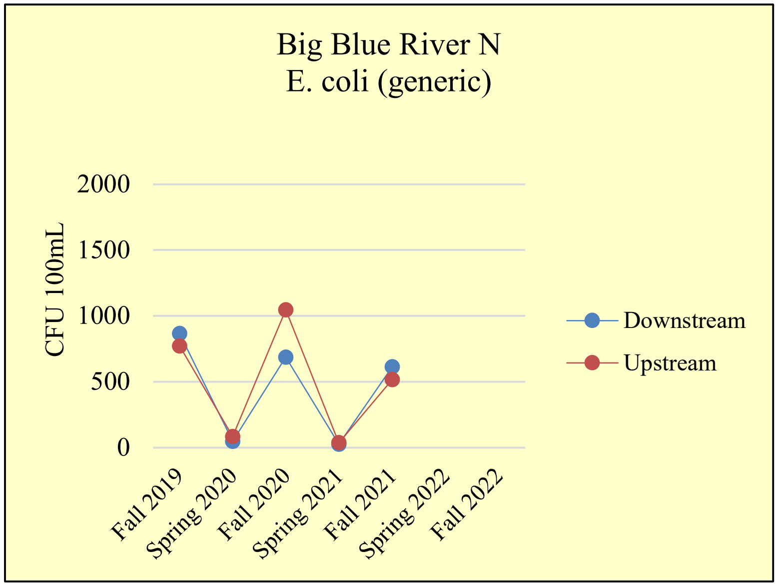
Big Blue River North

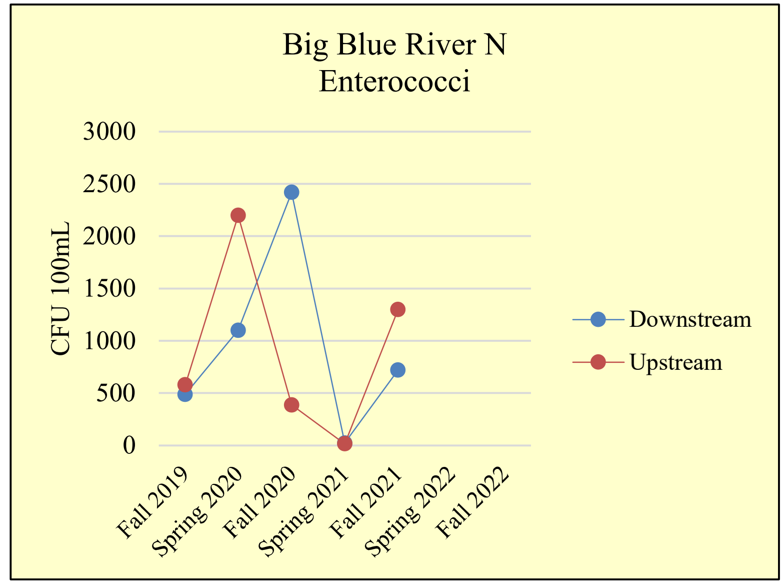
Site:	County:
Big Blue River N (US)	Butler

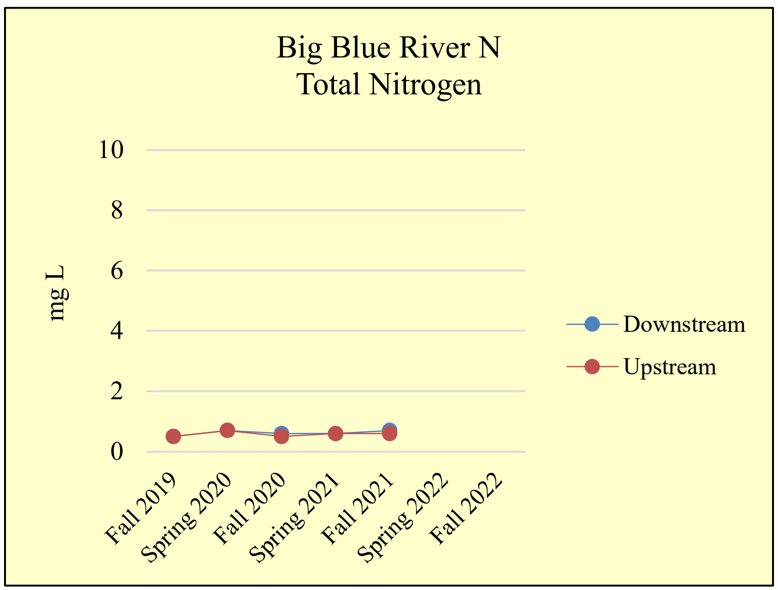
Season	Date	Total Coliforms [CFU 100mL]	E. coli (generic) [CFU 100mL]	Enterococci [CFU 100mL]	Campylobacter	Salmonella	TN [mg L]	Orthophosphate [mg L]
Fall 2019	9/23/2019	2420	770	580	Negative	Negative	0.5	0.32
Spring 2020	5/21/2020	980	84	2200	Negative	Negative	0.7	0.25
Fall 2020	9/28/2020	2420	1046	387.3	Negative	Negative	0.5	0.27
Spring 2021	5/2/2021	1300	37	16.8	Negative	Negative	0.6	0.13
Fall 2021	10/3/2021	2420	517	1300	Negative	Negative	0.6	0.32

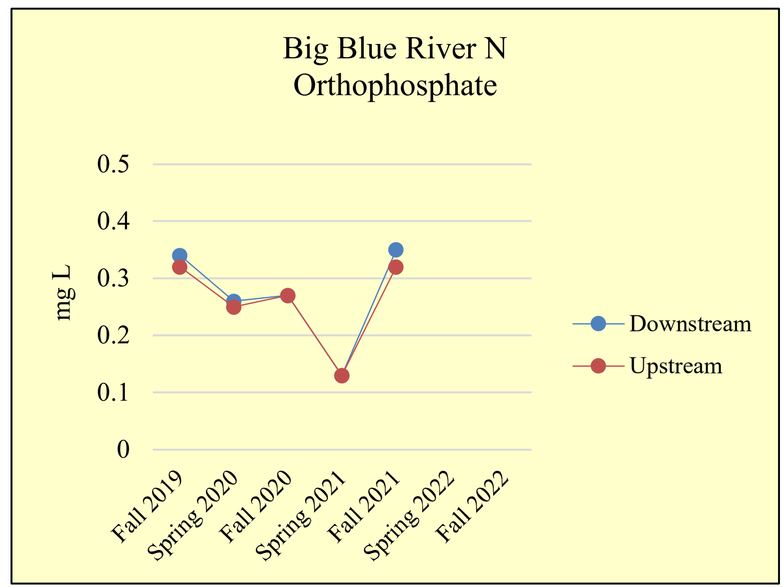
Site:	County:
Big Blue River N (DS)	Butler

Season	Date	Total Coliforms [CFU 100mL]	E. coli (generic) [CFU 100mL]	Enterococci [CFU 100mL]	Campylobacter	Salmonella	TN [mg L]	Orthophosphate [mg L]
Fall 2019	9/23/2019	2420	866	490	Negative	Negative	0.5	0.34
Spring 2020	5/21/2020	517	46	1100	Negative	Negative	0.7	0.26
Fall 2020	9/28/2020	2420	687	2420	Negative	Positive	0.6	0.27
Spring 2021	5/2/2021	1046	26	25.3	Negative	Negative	0.6	0.13
Fall 2021	10/3/2021	2420	613	721.5	Negative	Negative	0.7	0.35


Big Blue River N
E. coli (generic)
CFU 100mL
2000
1500
1000
500
0
Fall 2019
Spring 2020
Fall 2020
Spring 2021
Fall 2021
Spring 2022
Fall 2022
Downstream
Upstream


Big Blue River N
Enterococci
CFU 100mL
3000
2500
2000
1500
1000
500
0
Fall 2019
Spring 2020
Fall 2020
Spring 2021
Fall 2021
Spring 2022
Fall 2022
Downstream
Upstream


Big Blue River N
Total Nitrogen
mg L
10
8
6
4
2
0
Fall 2019
Spring 2020
Fall 2020
Spring 2021
Fall 2021
Spring 2022
Fall 2022
Downstream
Upstream


Big Blue River N
Orthophosphate
mg L
0.5
0.4
0.3
0.2
0.1
0
Fall 2019
Spring 2020
Fall 2020
Spring 2021
Fall 2021
Spring 2022
Fall 2022
Downstream
Upstream

Location 7

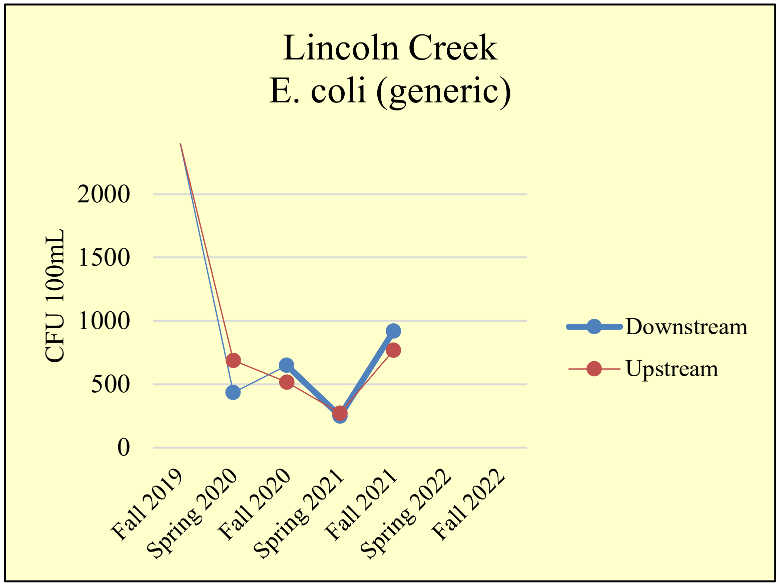
Lincoln Creek

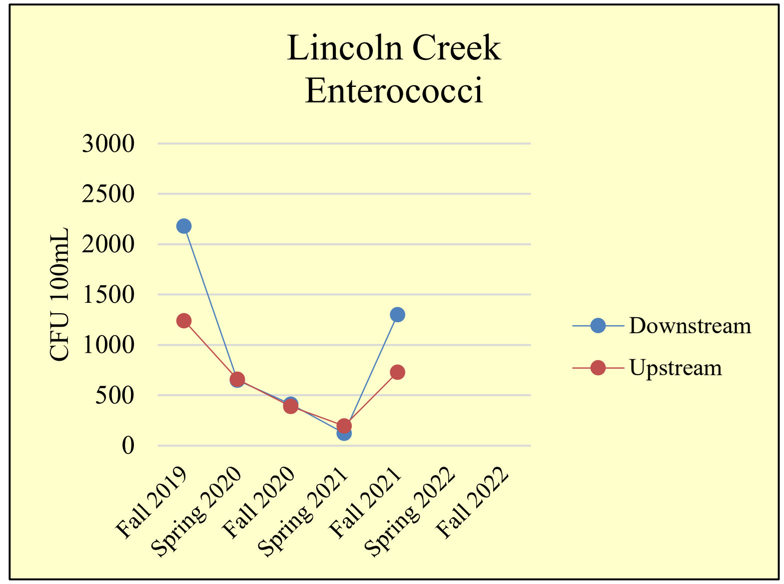
Site:	County:
Lincoln Creek (US)	Seward

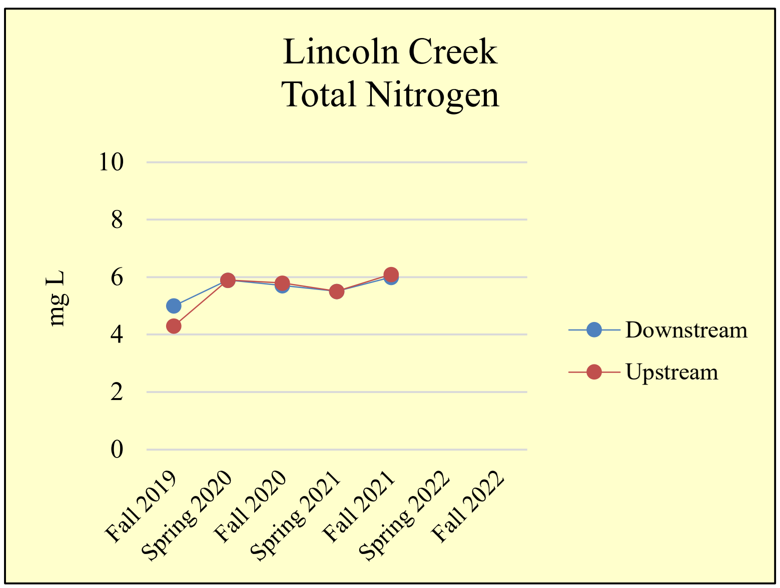
Season	Date	Total Coliforms [CFU 100mL]	E. coli (generic) [CFU 100mL]	Enterococci [CFU 100mL]	Campylobacter	Salmonella	TN [mg L]	Orthophosphate [mg L]
Fall 2019	9/23/2019	2420	2420	1240	Positive	Negative	4.3	0.52
Spring 2020	5/21/2020	2420	687	660	Negative	Negative	5.9	0.37
Fall 2020	9/28/2020	2420	517	387.3	Negative	Positive	5.8	0.46
Spring 2021	5/2/2021	2420	272	195.6	Negative	Negative	5.5	0.33
Fall 2021	10/3/2021	2420	770	727	Positive	Negative	6.1	0.4

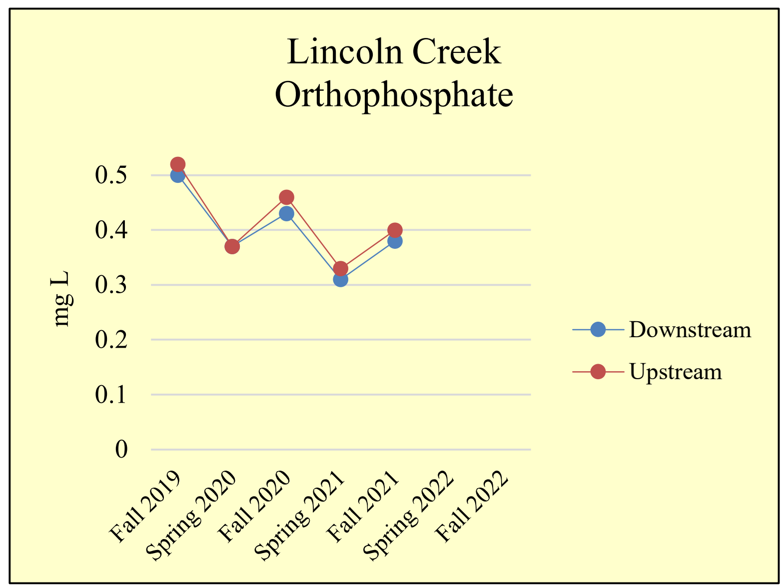
Site:	County:
Lincoln Creek (DS)	Seward

Season	Date	Total Coliforms [CFU 100mL]	E. coli (generic) [CFU 100mL]	Enterococci [CFU 100mL]	Campylobacter	Salmonella	TN [mg L]	Orthophosphate [mg L]
Fall 2019	9/23/2019	2420	2420	2180	Negative	Negative	5	0.5
Spring 2020	5/21/2020	2420	435	650	Negative	Negative	5.9	0.37
Fall 2020	9/28/2020	2420	649	410.6	Negative	Positive	5.7	0.43
Spring 2021	5/2/2021	2420	250	122.4	Negative	Negative	5.5	0.31
Fall 2021	10/3/2021	2420	921	1300	Positive	Negative	6	0.38


Lincoln Creek
E. coli (generic)
CFU 100mL
2000
1500
1000
500
0
Fall 2019
Spring 2020
Fall 2020
Spring 2021
Fall 2021
Spring 2022
Fall 2022
Downstream
Upstream


Lincoln Creek
Enterococci
CFU 100mL
3000
2500
2000
1500
1000
500
0
Fall 2019
Spring 2020
Fall 2020
Spring 2021
Fall 2021
Spring 2022
Fall 2022
Downstream
Upstream


Lincoln Creek
Total Nitrogen
mg L
10
8
6
4
2
0
Fall 2019
Spring 2020
Fall 2020
Spring 2021
Fall 2021
Spring 2022
Fall 2022
Downstream
Upstream


Lincoln Creek
Orthophosphate
mg L
0.5
0.4
0.3
0.2
0.1
0
Fall 2019
Spring 2020
Fall 2020
Spring 2021
Fall 2021
Spring 2022
Fall 2022
Downstream
Upstream

APPENDIX B: LITTER CONSTITUENT ESTIMATES

Birds per barn: 47,500	Litter Constituents		
Barns: 432			
Annual flocks: 6	*Per Bird*	*Per Flock*	*Annually*
Litter [lbs.] - As Rec.	2.4	114,000	295,488,000
Litter [lbs.] - Dry	1.8	84,269	218,424,730
Ammonium-N [lbs.] - Dry	0.01	498	1,290,890
Organic-N [lbs.] - Dry	0.07	3,118	8,081,715
Total-N [lbs.] - Dry	0.08	3,616	9,372,605
Phosphorus [lbs.] - Dry	0.06	2,899	7,513,811
Potassium [lbs.] - Dry	0.08	3,750	9,719,900
Sulfur [lbs.] - Dry	0.03	1,306	3,385,583
Calcium [lbs.] - Dry	0.04	1,829	4,739,817
Magnesium [lbs.] - Dry	0.01	683	1,769,240
Sodium [lbs.] - Dry	0.01	649	1,681,870
Zinc [lbs.] - Dry	7.31E-04	35	90,035
Iron [lbs.] - Dry	4.72E-03	224	580,879
Manganese [lbs.] - Dry	9.14E-04	43	112,532
Copper [lbs.] - Dry	1.00E-03	48	123,585
Estradiol [lbs.] - Dry	4.20E-07	2.00E-02	52
Estrone [lbs.] - Dry	7.10E-08	3.37E-03	9

Site specific and annual total accumulations of various constituents are shown. Litter production estimates are standardized numbers from similar operations. All constituents except for estradiol and estrone are based on percentages provided in nutrient management plans submitted as part of the NDEE permitting process (estradiol and estrone quantities are drawn from literature). All constituent amounts are calculated from dry quantities and are presented in pounds [lbs.]. Annual operational numbers depend on the actual number of birds raised for production.

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