Taste and Odor Problems in Clinton Lake Reservoir's Drinking Water

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INTRODUCTION

Water is a requirement for human health and welfare; however, an exceedingly large number of people around the world lack reliable sources of drinking water[1]. According to the World Health Organization, approximately 3.5 million people die every year, generally in developing countries, from diseases linked to poor water supplies[2]. The United States of America has one of the best drinking water supply systems in the world. According to the United States Geological Service (USGS), an average person in the U.S. uses 80-100 gallons per day[3]. Americans often take for granted the availability of water, and seldom do they question its quality. However, humans' keen senses are able to detect minute levels of chemicals causing taste and odor in water, and when this happens, institutions treating drinking water are often the first to be blamed. Great efforts are being made, however, to build public awareness that every person plays a major role in reducing pollution that leads to taste and odor problems, and that water treatment facilities alone may be inadequate to provide high quality drinking water to our communities.

BACKGROUND

More than 100,000 people in northeast Kansas get their drinking water from Clinton Lake reservoir. The Army Corp of Engineers built Clinton Lake reservoir in 1977 for flood control; however, it serves multiple purposes, such as swimming, boating, fishing, municipal water supplies, etc.[4,5]. The reservoir covers an area of 30.81 km^2 with an average depth of 5.1m. Clinton reservoir is located in the Wakarusa River watershed[6,7], which encompasses 95,320 ha, including Deer Creek and Rock Creek which are major tributaries [4,5,8]. According to KDHE, the watershed is primarily used for agriculture (Table 1)[9]. Most of the runoff that drains into the tributaries, therefore, comes from agricultural land, which generally contains elevated amounts of fertilizers, pesticides, manure, etc. Yearly weighted input of non-point fertilizer ranges from 1,604 to 2,312 metric tons for nitrogen (N) and from 269 to 325 metric tons for phosphorous (P) [8]. Local water-treatment plants have difficulty adequately treating this non-point pollutant runoff, and currently it is not adequately regulated by the Kansas Department of Health and Environment or the U.S. Environmental Protection Agency. In the US, non-point pollutants are the most challenging to control and the most significant cause of water pollution in the Kansas River [7].

In contrast, point source pollutants are those that drain into a river via an identifiable location such as a pipe or a conduit and are carefully regulated by EPA and KDHE. The types of pollutants and their amounts are regulated by the National Pollutant Discharge Elimination

System (NPDES) with the Clean Water Act permit program[7]. Although point source pollutants are regulated, immense amounts are discharged into the Wakarusa watershed; two wastewater treatment plants release up to 1.12 million liters per day into tributaries of the Wakarusa River, and there is an NPDES permitted hog feed yard situated in the Deer Creek arm [8], which is one of the main tributaries of Clinton Lake reservoir. These point source pollutants, together with non-point pollutants greatly affect the water quality of the reservoir.

Nutrients such as nitrogen and phosphorous are found naturally in water bodies and are needed by all aquatic organisms in low levels. When these nutrients rise to abnormally high quantities, however, the balance of the water ecosystem is disturbed [7]. Clinton reservoir is eutrophic (Table 2), which results from excess nutrients increasing the unwanted growth of blue-green algae (cyanobacteria) [4]. When conditions are optimal, these cyanobacteria are able to create large biomasses or algal blooms. When this large amount of organic material decays, it uses dissolved oxygen (DO), and if the DO level falls below a certain threshold, fish kills can happen readily[7]. Cyanobacteria biomasses are said to be responsible for taste and odor problems in drinking water and in addition, it also decreases recreational value[7]. Cyanobacteria produce an organic chemical called geosmin that dissolves in water. This is responsible for the earthy/musty taste and odor residents perceive during certain times of the year[8], especially during the fall and winter months [5]. Unfortunately, the water treatment method used today has not been able to completely remove geosmin from drinking water. In December of 1995, the level of geosmin rose to such high levels that the City of Lawrence Clinton Lake Water Treatment Plant was shut down due to the high number of customer complaints[8].

There are three dominant taxa of cyanobacteria residing in Clinton reservoir: *Microcystis* sp., *Aphanizomenon* sp., and *Anabaena* sp. *Aphanizomenon* sp. was found to be most common during late spring (May-June) and *Anabaena* sp. accounted for over 90% of biomass during the summer and early fall (June-October) [5,10]. Cyanobacteria and algal blooms affect the aesthetics and, therefore, the recreational value of the reservoir. Clinton reservoir has a large economic impact on the City of Lawrence[11]. In 2007, this reservoir was the most visited out of 17 reservoirs around the area with 2,008,108 visits in a year. According to Smith et al. visitor spending generated $30.4 million and 423 jobs in the region[11]. It is in the residents' and authorities' best interest to successfully manage the state of cyanobacteria at this reservoir due to the multipurpose nature of the reservoir and the many impacts caused by the presence of blue-green algae.

The Army Corp of Engineers controls the public land surrounding Clinton Lake reservoir, which includes the lacustrine and transitional zones of the reservoir; however, riverine zones are mostly privately owned, and the local authorities are unable to monitor the pollutant input resulting from this land (Fig 1). Deer Creek, the Wakarusa River, and Rock Creek are the main tributaries of Clinton reservoir. The smaller streams feeding these tributaries are commonly located in private land and much of the pollutants coming from these are thought to directly affect the reservoir.

METHODS

The study was carried out during the summer of 2010. Sites were chosen in places that seemed to account for input from all small streams that drained into Rock Creek (1,2,3,5); one (4) site was chosen to be in a larger stream that drains into the creek of interest (Fig 1). Sample site 1 was designated as the reservoir site, sample sites 2 and 3 were midstream sites, and sample sites 4 and 5 were headwaters sites.

Field Measurements of WATER QUALITY

Turbidity

A turbidity tube, which consists of a clear Plexiglass tube with a small Secchi disk at one end, was used. The tube was filled with water from the stream, the water level was slowly lowered through a release valve and when the disk became visible, the depth of the water was measured in centimeters. This provides a measure of suspended solids (such as sediment or algae) in the water column[12].

Phosphorous

Phosphorous (P) is one of the limiting factors for aquatic plant growth. This element enters a stream in several ways including: industrial waste, treatment plant wastewater, stormwater runoff, runoff from agricultural land, livestock waste, and others. According to the Citizen Science Fact Sheet W-5, a major phosphorous input comes from soil runoff from erosion of areas that have been recently treated with fertilizer[13].

Phosphorous was measured by taking sample water from the sampling sites and was processed using a CHEMets orthophosphate test kit. Phosphorous is rarely detected in surface water unless it was recently added; therefore, any P detected with this kit was added shortly before testing took place. According to the Kansas Department of Health and Environment, 0.1ppm of phosphorous can have detrimental effects on aquatic life. The kit test used for this experiment tests for phosphorous in its PO_4 form which presents a chronic criteria level of 0.3ppm which is three times greater than the equivalent phosphorous value of 0.1ppm[13].

Nitrogen

Decomposing plants become organic debris and release ammonia (NH_3), followed by bacteria which converts it to nitrite (NO_2). Next, bacteria carry out the conversion of NO_2 to nitrate (NO_3), which is then used by plants such as algae for growth. Consuming excessive nitrate in drinking water (>10ppm) is not only dangerous to wildlife but to pregnant women who can develop serious health concerns such as blue baby syndrome[12].

Hach test strips were used for this experiment; nitrate is tested on a 1-50ppm range, nitrite on a 0.15-3.0ppm range on the same strip and ammonia on a 0.25-6.0ppm. According to the Citizen Science Fact Sheet W-4, there are no quantitative national or state standards established for nitrate/nitrite.

Velocity

Streams have characteristic higher velocities when compared to lakes, a factor that is important to this study given that the sampling sites vary in velocities depending on their location from the headwaters to the reservoir. In this study, velocity was measured along a 100 ft stretch at the sampling site using an ice cold orange, which used as a float, and a timer[14].

Chlorophyll a Concentrations

Samples were processed at the Kansas Biological Survey the same day they were collected using a five-sample vacuum by filtering approximately 200ml of sample with Gelman A/E filters, Daigger Catalog Number EF8583K, these filters were folded in half and placed inside a labeled Fisher Qualitative P8 filters, Fisher Scientific 09-795C. The corners were stapled and the samples placed in silica desiccant inside a black box and frozen to prevent disruption of the cells.

USGS (Lawrence, Kansas) helped with the *Chlorophyll a* sample analysis by providing a fluorometer. The USGS summer 2007 protocol was used to analyze the samples. *Chlorophyll a* levels are thought to be one of the best indicators of eutrophication and recreational interest since it is strongly related to algal biomass concentrations[4, 5, 8]. The Trophic State Index (TSI) used by the KDHE to classify trophic states for reservoirs and lakes served as a reference point for this study[8].

Data Analysis and Quality Control of Historic Data Sets

Unanalyzed data sets containing information on geosmin, Chlorophyll a and nutrient input to Rock Creek and Clinton Lake reservoir were obtained for the months of June, July and August of 2010. The Army Corp of Engineers (ACOE) provided data on nutrient levels in Rock Creek, Kansas Department of Health and Environment (KDHE) provided data on Chlorophyll a and nutrient levels in Clinton Lake reservoir, and the City of Lawrence Department of Utilities provided data on geosmin levels. We subjected these complex data sets to quality control procedures and analyzed the data. This helped to put our results from our 2010 field season in context, and provided insights into possible relationships between the parameters.

Historical weather data were obtained using the Weather Underground web site at http://www.wunderground.com to carry out quality control based on rain/storm events during the dates chosen for analysis. Data providers were also contacted to obtain detailed information regarding methodology used in sampling, including whether samples were collected during rain/storm events. Dates and years with adequate and comparable data were chosen to investigate important phenomena over a long period of time i.e., Chlorophyll a and geosmin levels.

Spatial Visualization

Google Earth Pro was used as a Geographic Information System (GIS) to display and analyze possible patterns in complex data sets related to a physical location that may otherwise not be detected through other analytical methods[15]. Google

Earth Pro was used to record a tour as an interactive and easily retrievable spatial visualization. The tour illustrated the global and regional location of the Upper Wakarusa watershed and emphasizes the importance of Clinton Lake reservoir as the water source for important establishments. Rock Creek's watershed location and land usage was included as well as bar graphs and scatter plots of analyzed data sets. Colored polygons, pathways and photographs were placed in strategic geographical locations for better understanding of the material[16].

RESULTS

Field Measurements of WATER QUALITY

Velocity decreased at sites closer to the reservoir, allowing the sediment and other matter that is suspended on the water column to settle to the bottom. When this occurs, more sunlight is able to penetrate the water body and is available to plants and algae on the bottom and in the water column. Nutrients that runoff into Clinton Lake reservoir, in addition to extra sunlight, serves as the catalyst for overgrowth of plants, green algae, and cyanobacteria. Cyanobacteria is one of the organisms that forms blooms due to the excess nutrient supply in water bodies, creating multiple problems for the city of Lawrence. The excessive growth of cyanobacteria was observed in this study with the use of Chlorophyll a. A clear pattern of increasing Chlorophyll a while approaching the reservoir was seen, confirming the fact that upstream events greatly affect downstream water quality (Fig 2).

Visit https://sites.google.com/site/shawneecountynria/rock-creek-comprehensive to see photographs of sampling sites during the three sampling dates. Major factors influencing sampling sites and a detailed upstream series of photos can also be found on that web site.

Data Analysis and Quality Control

Acquiring data and its analysis was challenging since the relevant data have not been made accessible to the public online. Additionally, data sets were challenging to analyze due to the fact that the methodologies used by the various government agencies are not standardized. By creating scatter plots and bar graphs, we identified specific areas for improvement in sampling methods, effects of nutrient input, and confirmed previous findings regarding the movement of contaminants entering the water body. During the month of July during the years 1997 to 2010, nitrogen input to Rock Creek was higher during rainy weather and lower on days without rainfall. No indication of these weather conditions, however, was included in the data sets released by the state and federal agencies. Phosphorous displayed similar characteristics, however, the effect of weather was not as extreme (Fig 3).

During the months of June through August of the years 1979 to 2009, levels of nitrogen input to Clinton Lake Reservoir seemed to have increased. During the same time period, levels of phosphorous input to the reservoir did not show a specific pattern (Fig 4).

During the months of June through August of the years 1979 to 2009, more than half of the Chlorophyll a samples in Clinton Lake reservoir exceed the fully eutrophic levels, and samples for 1998 and 2003 exceed the hypereutrophic levels. Geosmin levels in tap water from the reservoir from 2006 to 2010 went over the human detection levels of 10 ng/L in more than half of the samples (2006, 2007 and 2009). The highest sample was that of August 2007 where geosmin levels was four times that of the human detection level (Fig 5).

Spatial Visualization

The Google Earth visualization allowed us to communicate the definition of the concept of a watershed, highlighting important geographical landmarks including Rock Creek as the site of interest (Fig 6). Although Clinton Lake reservoir is the draining point of the Upper Wakarusa watershed, the visualization highlighted the importance of this reservoir to institutions and businesses outside the watershed. Patterns were found through color-coded layers representing data set analysis, which were placed on appropriate geographic locations along Rock Creek coupled to bar charts/scattered plots (Fig 7,8). Photographic evidence of factors affecting the quality and quantity of Rock Creek's water supported previous findings of incoming pollutants to the water body, their trajectory to the public reservoir and the contribution made by anthropogenic activities along the creek to the degradation of the reservoir (Fig 9).

DISCUSSION

Nutrient inputs from the Upper Wakarusa watershed have shown to be problematic for the past decade in spite efforts to alleviate this issue. The effects of nutrient input at Rock Creek have been reflected in Clinton Lake reservoir with elevated levels of Chlorophyll a and geosmin concentrations surpassing the human detection levels of 10ng/L multiple times during the past four years[4, 5, 8, 10, 17].

According the Kansas Biological Survey (KBS), Clinton Lake reservoir surpassed human detection levels 86% of the time, second to Cheney reservoir with 89% during the length of the study in 2007, long after improvement attempts had been put in place[8, 17]. Their findings included a correlation between cyanobacteria and turbidity as a method to predict the appearance of geosmin, which is the same model used in this paper where, as turbidity decreases cyanobacteria increases leading to the emergence of geosmin and therefore taste and odor problems during the winter season for Clinton Lake reservoir[4, 5, 10, 17].

There are several monetary and health related consequences of non-point pollution to consider, such as; the decrease of incoming revenue with algae-filled unusable recreational areas, toxic effects to humans and pets from a variety of blue-green algae species blooming in the reservoir, lethality to water dwelling organisms such as fish due because of decreased dissolved oxygen, higher water treatment costs to diminish the effects of geosmin and the costs of dredging the reservoir as it fills with sediment from erosion [8,11,14].

The actual situation is often undetected due to inadequate methodologies used at the time of sampling. Weather conditions are often disregarded, resulting in a data set with a mixture of rain and non-rain event samples; sampling during dry periods minimizes the amount of nutrients in the sample and does not adequately detect nutrients in runoff. The effects of nutrient input during rain events can be seen in nitrogen levels in Clinton Lake reservoir from 1979 to 2009. Methodologies need to be revised to measure nutrients during runoff events, carry out quality control on data sets, and make them available to the public.

Further expansion and development of Rock Creek's subwatershed Natural Resource Inventory Assessment will serve as a basis for pilot projects related to city planning and development. Future work includes Natural Resource Inventory Assessments for Shawnee County and perhaps the remainder of the Upper Wakarusa in Douglas County (Fig 3).

ACKNOWLEDGEMENTS

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FIGURES

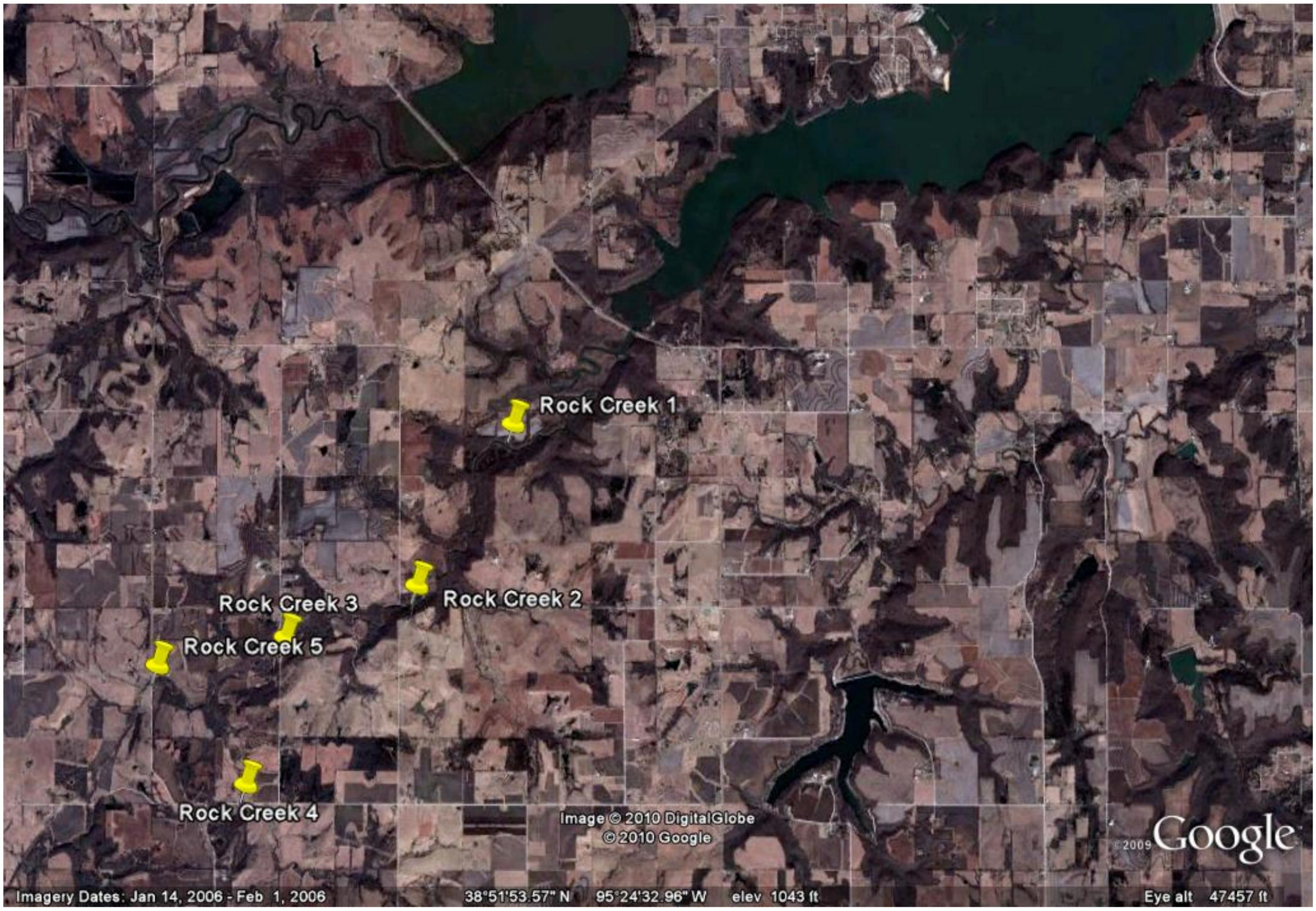
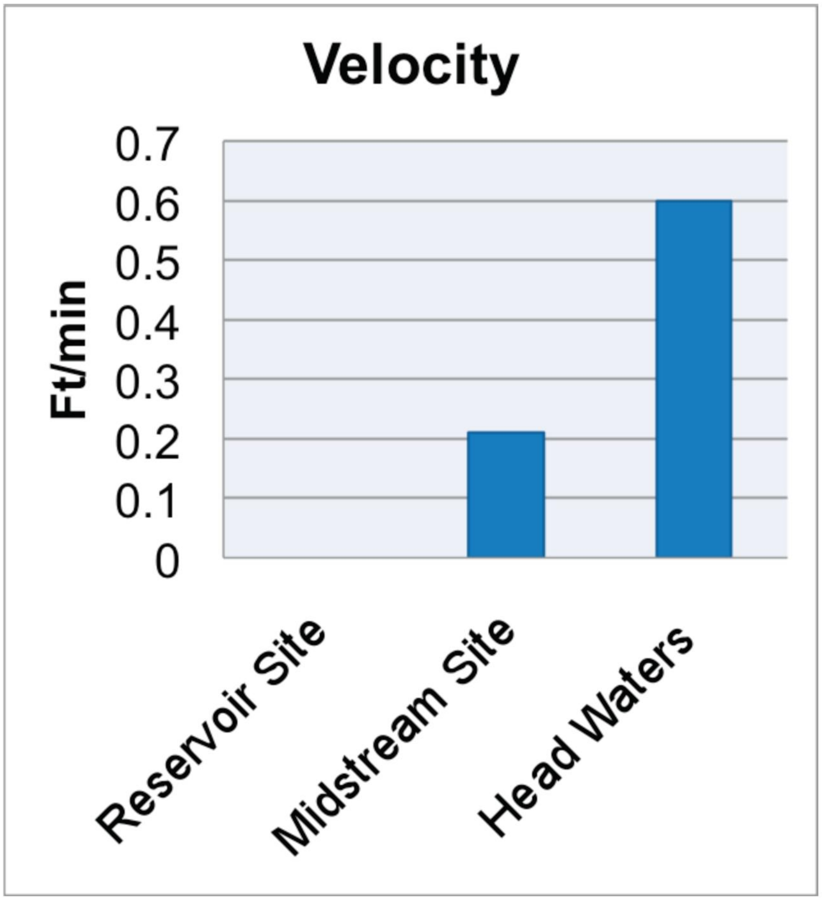
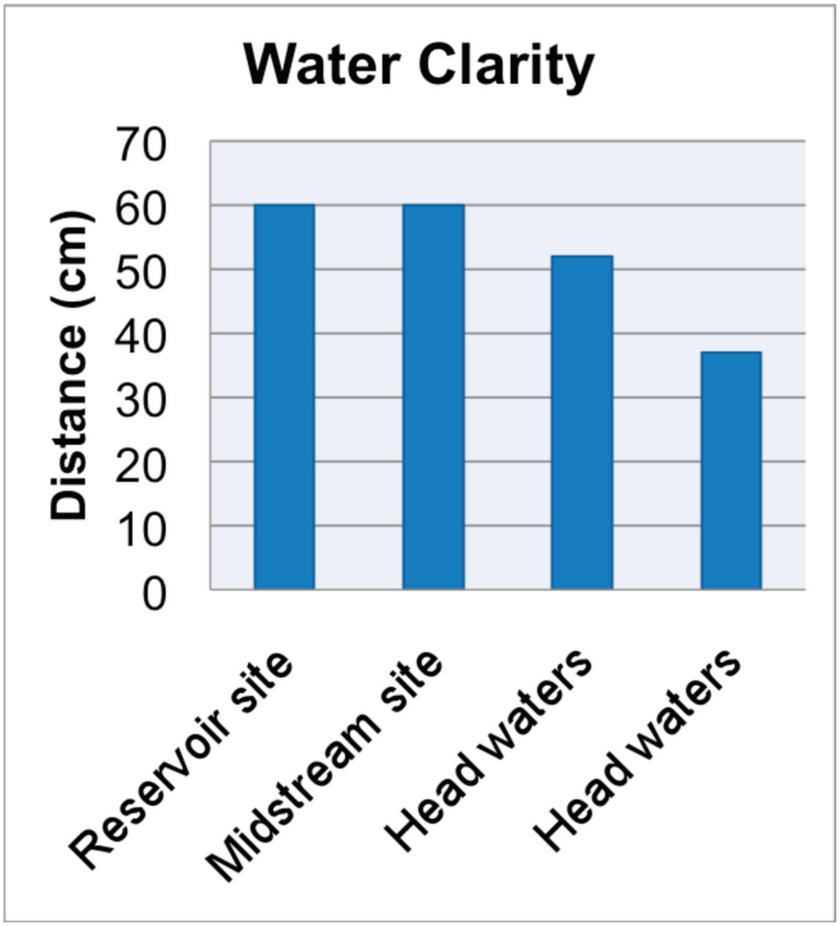


Figure 1. Rock Creek Sampling sites

Land Cover	Acres	Percentage
Water	10,391	4.48
Urban/Developed	1,762	0.76
Barren/Transitional	164	0.07
Forest/Woodland	29,593	12.75
Shrub land	832	0.36
Grassland/Herbaceous	65,628	28.27
Pasture/Hay	60,364	26.00
Cropland	59,075	25.44
Urban/Recreational Grasses	1,118	0.48
Wetlands	3,259	1.40
Total	**232,286**	**100.00**

Table 1. Land Cover Statistics for Entire Watershed (9)


Velocity
Ft/min
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Reservoir Site
Midstream Site
Head Waters


Water Clarity
Distance (cm)
70
60
50
40
30
20
10
0
Reservoir site
Midstream site
Head waters
Head waters

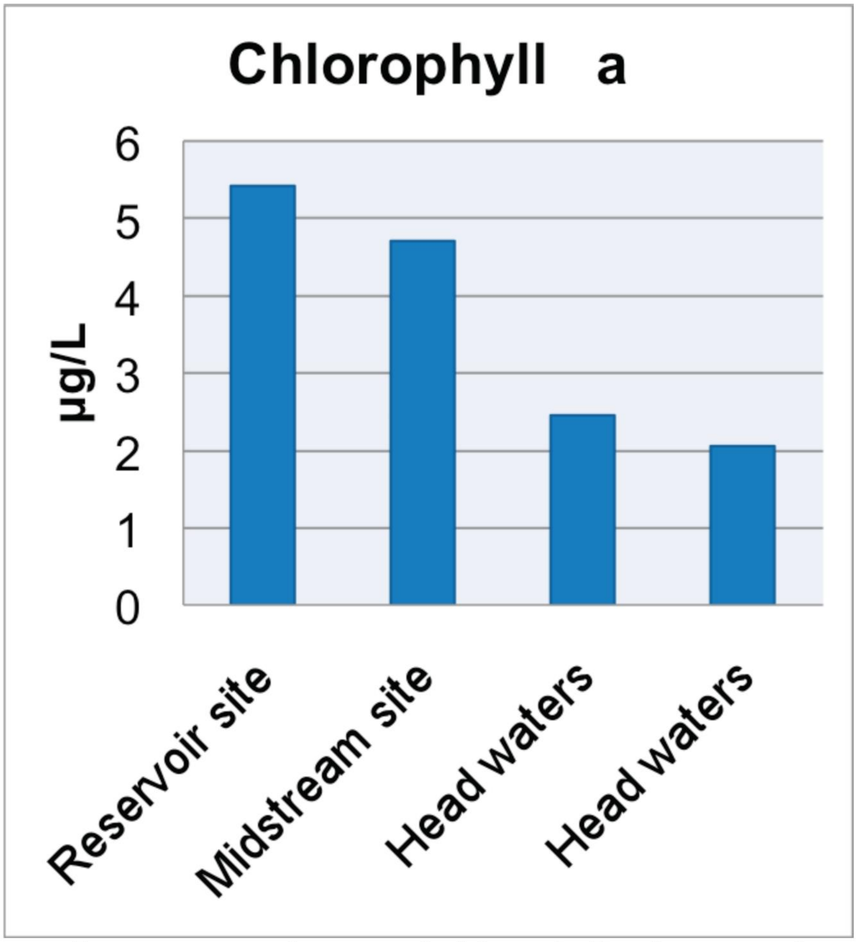


Figure 2. Velocity, Water Clarity and Chlorophyll a (2010 Study Results)

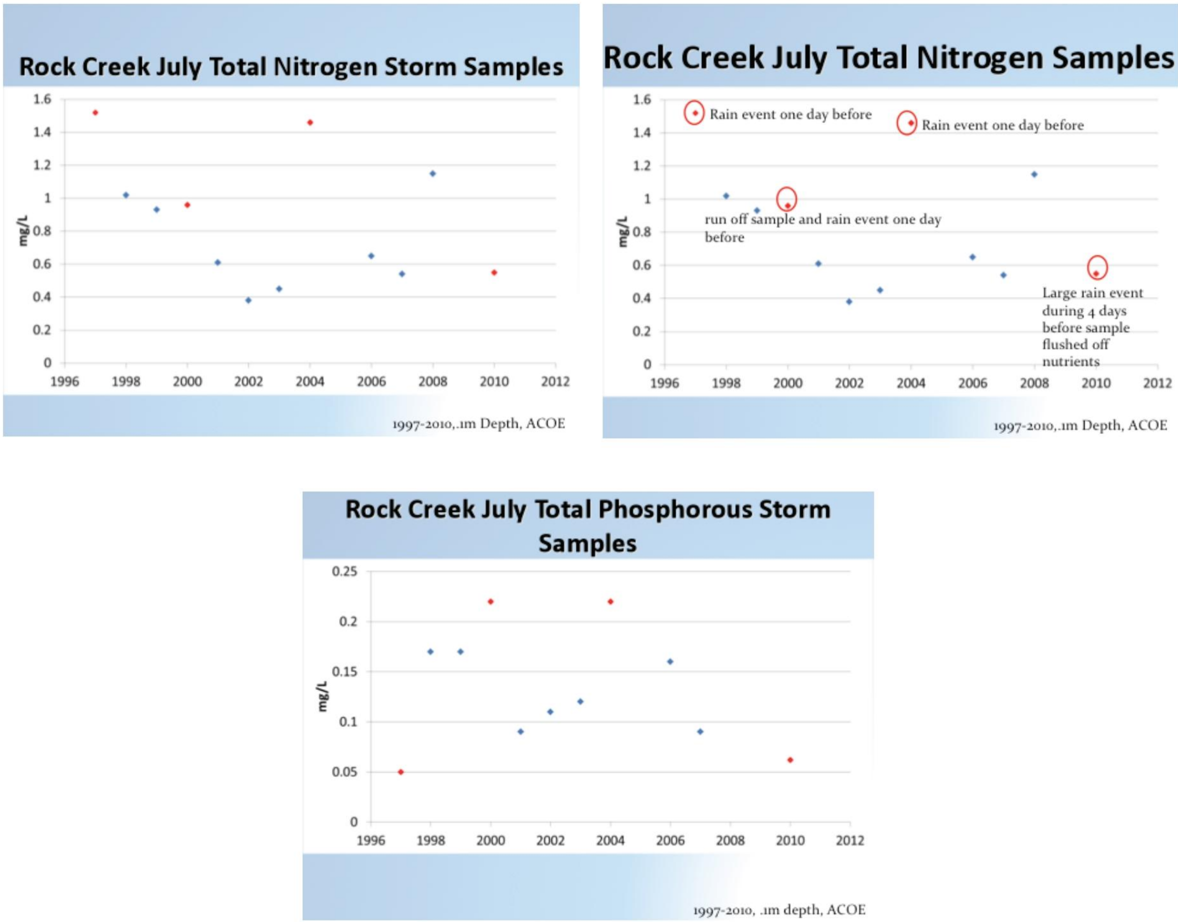


Figure 3. Rock Creek Data Analysis-Run off (N,P)-

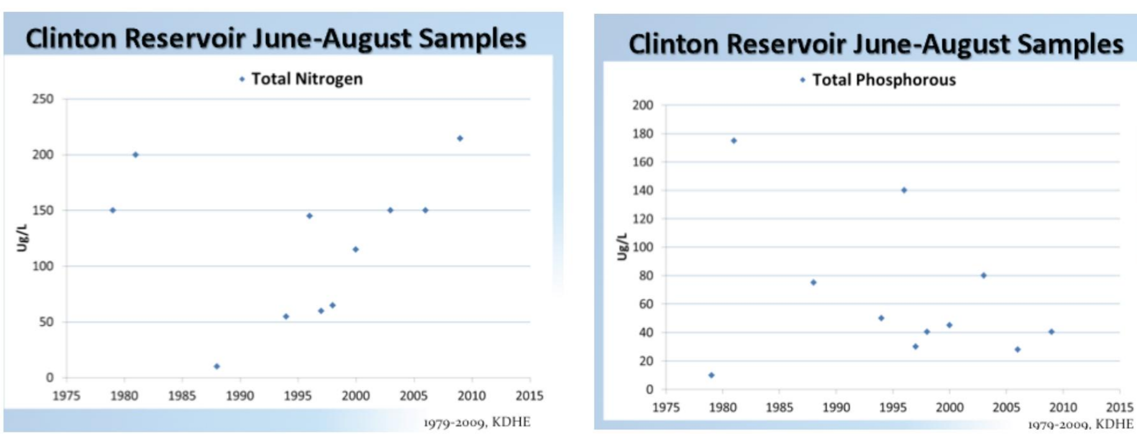
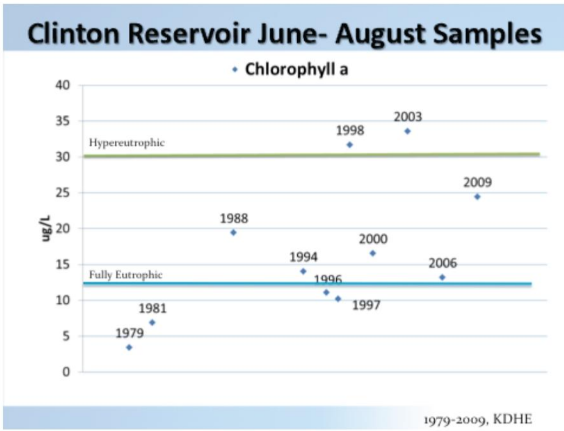


Figure 4. Clinton Reservoir Data Analysis- N, P-



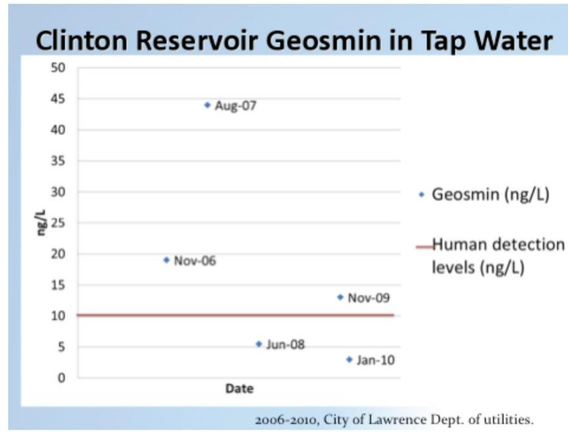


Figure 5. Clinton Reservoir Data Analysis Chlorophyll a and Geosmin

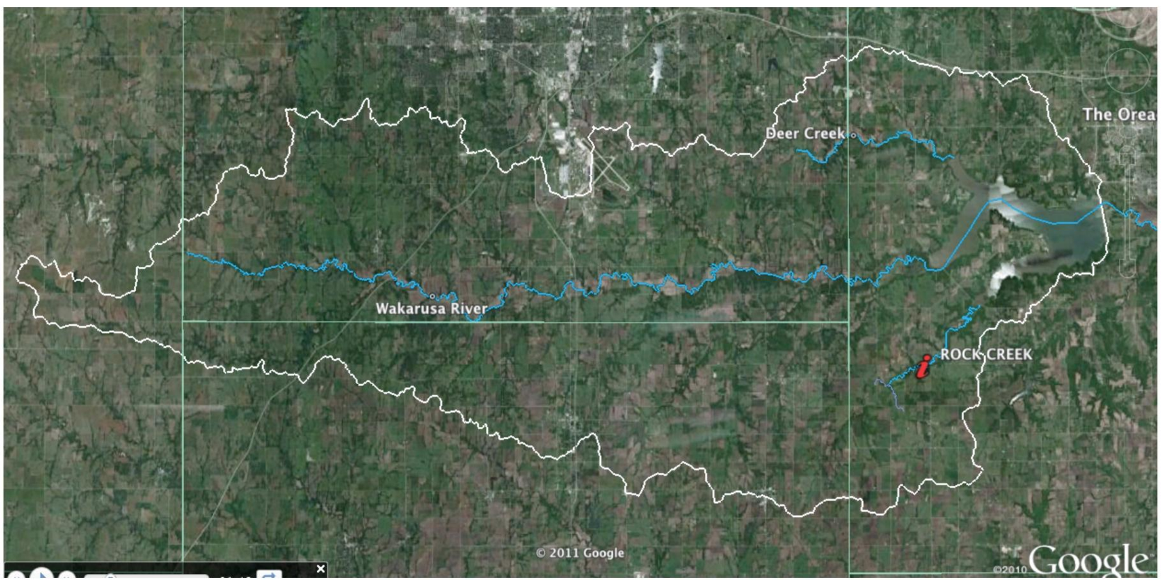


Figure 6. Upper Wakarusa Watershed and Major Tributaries

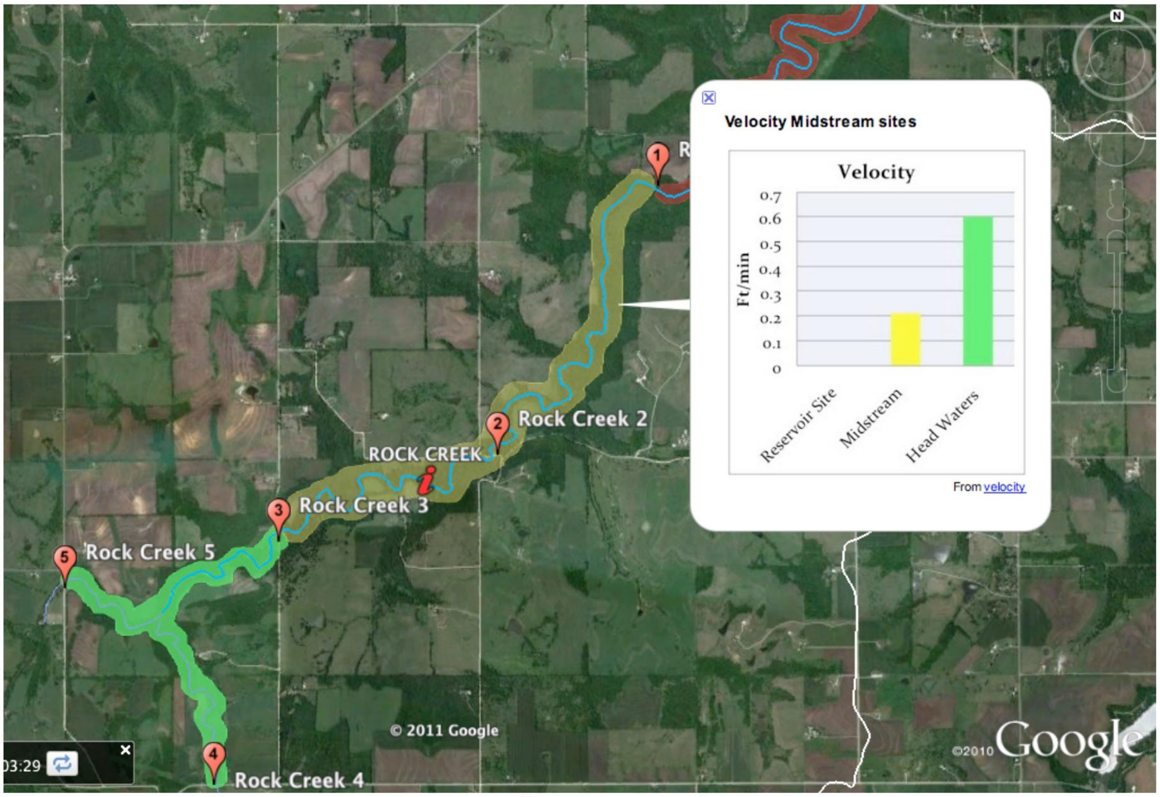


Figure 7. Velocity in Rock Creek

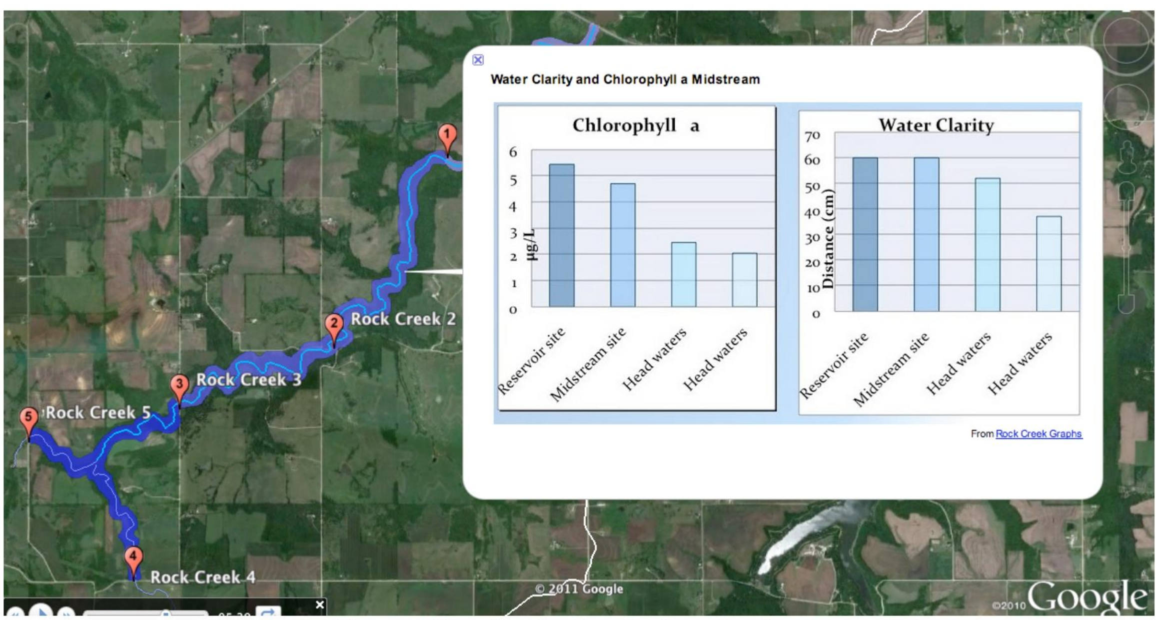


Figure 8. Water Clarity in Rock Creek- Summer 2010

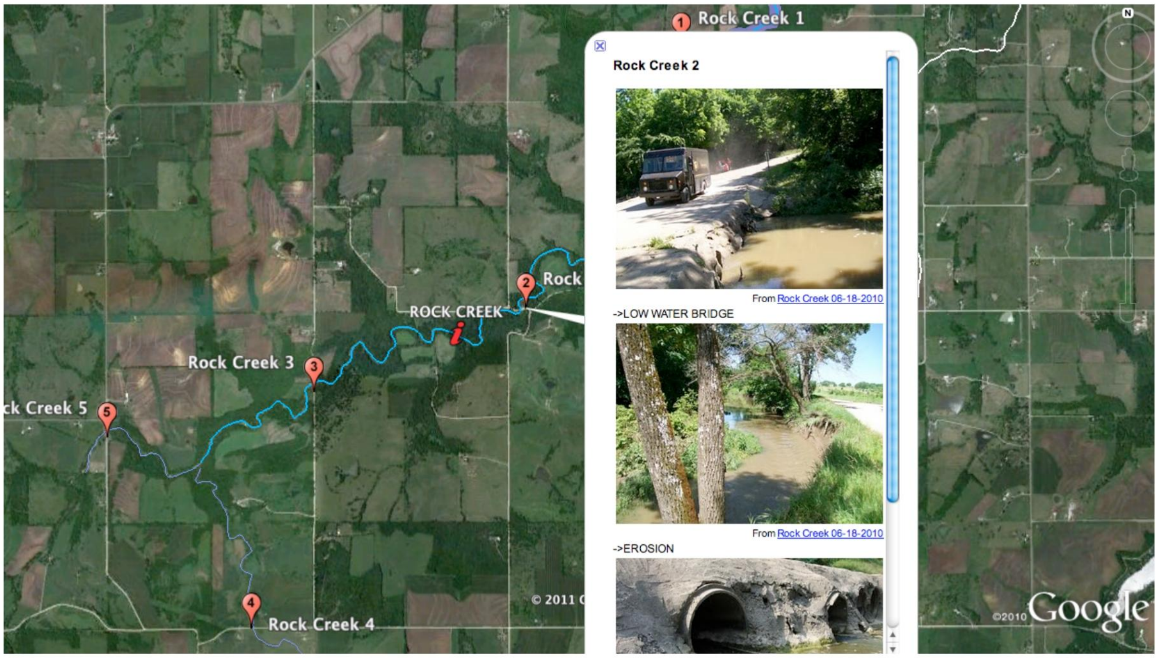


Figure 9. Factors Affecting Water Quality and Quantity of Rock Creek

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[6] The watershed is an area of land that receives snow or rain and drains or seeps into a collective spot

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