Application of environmental decision analysis framework to identify potential *E.coli* sources in Lake Tuscaloosa Watershed, Alabama

L. Alfaqih[1,2]*, R. Pitt[1] and D. Hale[2]

[1] Civil, Construction, and Environmental Engineering Department,
University of Alabama, Tuscaloosa, AL 35487, USA
[2] Aging Infrastructure Systems Center of Excellence (AISCE),
University of Alabama, Tuscaloosa, AL 35487, USA

* Corresponding author, e-mail laithfaqih@gmail.com

ABSTRACT
Lake Tuscaloosa in the State of Alabama in the United States is an important water source for the region. It is an attraction for residential, commercial, and industrial developers. Recent studies and monitoring of the lake have shown high levels of *E. coli* bacteria in the upper parts of the lake during periods of high stream flow. The City of Tuscaloosa is currently facing a challenging situation: dealing with the increased development in the watershed and protecting the lake. The Environmental Decision Analysis Framework (EDAF) was used to study, analyze and develop alternatives to address the *E.coli* problem in the lake. After data were collected and analyzed using the model, it was found that the problem was mainly from the agricultural practices in the watershed such as feedlot operations and chicken farms. Better management plans should be put in place to operate and control these practices.

KEYWORDS
Watershed, *E.coli*, Lake Tuscaloosa, decision analysis, stormwater

INTRODUCTION
Lake Tuscaloosa Watershed is located in Tuscaloosa and Fayette counties in the State of Alabama, in the Southeastern United States. The Lake, which was constructed on North River in 1970, serves as the major public water supply for the surrounding communities and is an important recreational water body in an area lacking in natural lakes especially during warm weather when people go out to the lake to enjoy swimming, skiing, fishing, or just taking in the scenery. The watershed covers an area of approximately 1100 km^2. This area normally has high rainfall (long term average of about 1400 mm/year), but is currently undergoing a severe drought, with about half of the normal rainfall. Even with this shortage, Lake Tuscaloosa has proven to be a reliable and sustainable water supply for the area. The reliability of this water supply has been an important component for the economy in the area.

The Alabama Department of Environmental Management (ADEM) monitored lake water quality during 1998 and 2002 (ADEM, 2004). These studies indicated that the lower part of the lake was between oligotrophic (unproductive) and mesotrophic (moderate productive) nutrient levels. The middle and upper parts of the lake showed mesotrophic to eutrophic (very productive) conditions, especially in late summer. In water quality terms, when the water system has oligotrophic conditions, the lake is infertile and unproductive for algae and is a good water supply, but generally has sparse fish populations. On the other case, when the system is eutrophic, it is highly fertile and has high productivity of algae, indicating that the water source is undesirable as a water supply.

Recent studies and monitoring of the lake have shown high levels of *E. coli* bacteria in the upper parts of the lake (near the main stream entrances) during periods of high stream flow (O'Neil, 2005). These high levels of *E. coli* have been identified as a concern for many different interested parties in the area. *E. coli* is a type of fecal coliform bacteria that is usually found in the intestines of warm blooded animals such as human, cattle, birds, and different wild animals.

E. coli microorganisms can be introduced to the environment in various ways such as failing septic tanks, failing sewer systems (sanitary sewer overflows, (SSOs)), discharges of poorly treated sewage, contaminated urban stormwater, runoff from pastures and feedlots, and even human fecal discharge from boats (Aslan-Yilmaz et al, 2004; Dietz et al, 2004; O'Shea and Field, 1992). *E. coli* occurrences in natural waters can be from direct sources other than sewage and animal wastes, such as reported in a recent study by Whitman et al (2006) where they found out that once *E. coli* are established in the soil, the eroding soil can be a continuous source of *E. coli* to the nearby streams.

E. coli can persist in soils for relatively long periods after being discharged with the feces of these animals. They can then be transported to receiving waters during rains. These bacteria need warm soil and nutrients, promoting recolonization and growth in the soil (Whitman et al, 2006). Additionally, *E. coli* can persist in streams and stream sediments. High concentrations can be found at stormwater outfalls and are lowest at the headwaters of streams (Byappanahalli et al, 2004; Whitman and Nevers, 2003). Many factors can affect the *E. coli* flux for a watershed, such as: the presence of activities in the watershed associated with concentrations of animals or wastewater treatment and disposal; rainfall characteristics, with the *E. coli* count usually increasing quickly during a rain but then may decline to relatively low levels after the rain ends: and even the wind direction, with onshore winds causing an increase in *E. coli* count in shallow near-shore waters (Whitman et al, 2006).

The City of Tuscaloosa is currently facing a challenging situation: dealing with the increased development around the lake and watershed and protecting the lake (this important infrastructure) from various pollutants, especially bacteria and nutrients. The city is therefore under pressure to strengthen its management, monitoring, and control of existing and future pollutant sources (mostly land development) around the lake that is in its jurisdiction. Additionally, the city has to consider other sources in the watershed outside its jurisdiction as potential pollutant sources that are turning the lake into an urban reservoir with increasing pollution problems that are starting to adversely affect its water quality. In order to address the whole range of issues impacting the lake a comprehensive framework needed to be developed.

ENVIRONMENTAL DECISION ANALYSIS FRAMEWORK (EDAF)

A great deal of decision complexity comes from the necessity to incorporate an interdisciplinary set of theories and methodological approaches in order to address all the data, stakeholders and constraints involved in the problem. The EDAF (Alfaqih, 2008) was developed to introduce this decision complexity at the early stages of the project decision making. This introduction would reduce the risk of failure of these infrastructure systems.

The EDAF covers a wide range of facets such as, but not limited to, public health, education and training, environment and ecology, economic, social and cultural, resources, ancillary infrastructure and regulatory. Additionally it covers a wide range of stakeholders that affect or are affected by the infrastructure. These facets with stakeholders introduce the infrastructure objectives for the project and would act as the road map for the success of the project.

Additionally, these objectives should be supported by data. Data may be hard to obtain, expensive, sensitive, or respondents may misrepresent information. All of these data issues are categorized as uncertainty. Therefore, seeking these data can cause decision problems such as delays in making the decision or affecting the project outcome. It is important for decision makers to know how defensible a chosen policy option is over other options when the uncertainties of the data are considered. As part of the framework solution, these uncertainties are considered.

Before implementing EDAF

The City of Tuscaloosa conducts monthly sampling for *E.coli* around the perimeter of the lake. It has 31 sampling locations. Based on high *E.coli* readings in the lake the City of Tuscaloosa took actions to eliminate this pathogen. The city decided that the sources of *E.coli* are from residential areas septic tanks and from the effluent of a wastewater treatment plant in the watershed north of the lake. Ordinances were enforced on the residential areas and the wastewater treatment plant was requested to improve its effluent.

Implementing EDAF

The EDAF was used to study, analyze and develop alternatives for the *E.coli* problem in the lake. The first step was to identify the stakeholders related with the project. These stakeholders were interviewed in order to identify their objectives and to collect information from them regarding the *E.coli* problem. Additionally, some of the stakeholders had access to data that helped in the analysis and in developing the overall view of the problem.

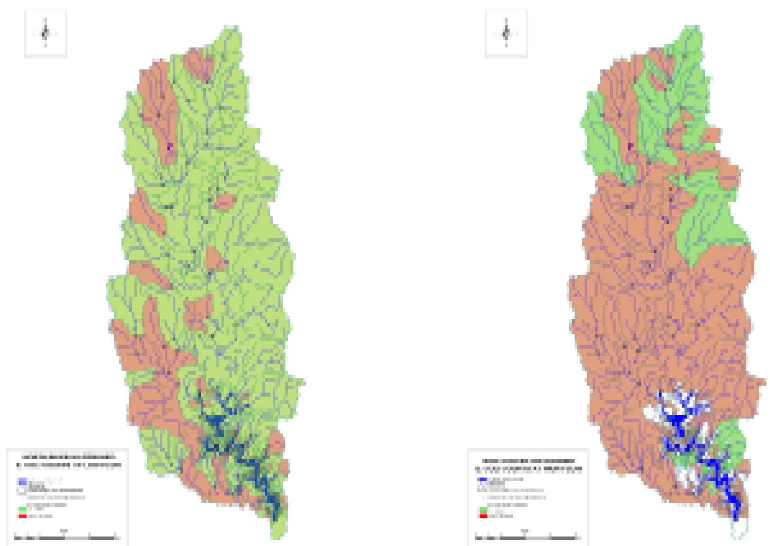
Example of stakeholders interviewed were residents around the lake, developers, general public, City of Tuscaloosa water and wastewater management, city council, geological survey of Alabama (GSA), farmers, forest management, environmental watchdogs and local and national engineers. A long list of objectives was produced from the stakeholders. These objectives were combined and short listed. A sample of these objectives for some of the facets is in Table 1.

Table 1. Sample of objectives collected from stakeholders for some facets

FACETS	OBJECTIVES
Public Health	Make water safe, no E.coli threat, for different public use (swim, ski, fish, boat)
Finance & Economic	Maintain a long term investment in the watershed especially around the lake
Environment & Ecology	Reduce water quality threats from E.coli on fish and other species
Education & Training	Educate the public about the watershed and its importance locally and regionally
Regulatory	Make different government entities work together to protect watershed from E.coli threats

These stakeholders' objectives were used to help identify and set the bases for the alternatives that may be used to help in reducing the *E.coli* problem in the watershed. Additionally, these alternatives would be sustainable with lower risks of failure because all the stakeholders contributed in identifying the main specification of the alternatives.

The GSA during the year 2005 conducted sampling in the whole Lake Tuscaloosa Watershed. They took samples during two periods. The first period was during low flow events and the second period was during high flow events. The results from the sampling showed that during high flow events more than 90% of the watershed samples had *E.coli* counts more than the City of Tuscaloosa's limit. The city's *E.coli* count limit is 200 cfu/100mL. These results are presented in Figure 1, where Figure 1.A is the sampling results during low flow and Figure 1.B is the sampling results during high flow. The green color on the plot represents *E.coli* levels below 200 cfu/100mL and the red color represents *E.coli* levels above 200 cfu/100mL.



A B

Figure 1. A) *E.coli* count during low flow events **B)** *E.coli* count during high flow events

The Black Warrior River Keepers provided aerial photos for the watershed. The River Keepers survey the area every few months by taking aerial photos for the watershed to find out if there are any changes or if there are any ecological problems occurring in the watershed. Part of these photos was for some chicken farms in the watershed. A closer look and analysis was conducted to these aerial photos. The analysis showed that the manure produced from these farms was not managed properly. Additionally these farms were located close to the rivers and creeks in the watershed. A chicken farm and a zoom in to the manure pile are presented in Figure 2. In the photo on the left side it shows proximity to the river. This manure pile is zoomed in and it shows that the tarp does not cover the manure properly.

In order to have a closer look at the situation on the banks of the rivers and creeks, a boat trip up North River was conducted. The trip was during the summer of 2007. During this trip many observations were recorded. The main observation was the accessibility of pasture animals to the river. Animals have been using the river as a drinking source and to cool down from the summer heat. This accessibility has caused the water and the soil to become polluted with manure. This provides a continuous source of E.coli pathogens into the water. In Figure 3.A the manure on the river banks are pointed out and in Figure 3.B some of the cows that have access to the river.

Figure 2. Aerial photo of a chicken farm located in the watershed with a zoom in to the uncovered manure pile close to the river

Figure 3. A) Cow manure on the side of the river banks **B)** Cows in the shade close to the river

Data analysis

Using data obtained from the City of Tuscaloosa and the GSA many statistical analyses were conducted. One of these analyses is the analysis of the variance test (ANOVA). The results of the analyses showed that there is a strong correlation between landuse and precipitation in the watershed and the *E.coli* counts. The precipitation analysis showed that rain events higher than 25 mm triggered *E.coli* counts above the city's limit. Additionally, the landuses that had chicken farms and pastures had the highest *E.coli* counts of all the landuses. This result can be observed in Figure 4, where the landuse noted as F,P,C (Forest, Pasture, and Chicken farm) had the highest *E.coli* count. In Figure 5 the number of chicken houses had a high correlation with increasing *E.coli* counts. The greater the number of chicken houses the higher the *E.coli* count in the water samples.

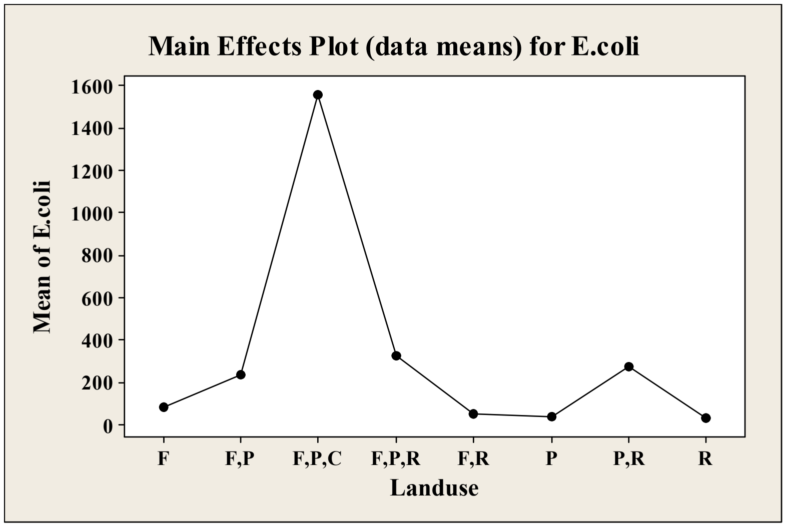


Figure 4. Landuse effect on *E.coli* counts in the watershed (F: Forest, P: Pasture, R: Residential, C: Chicken farm)

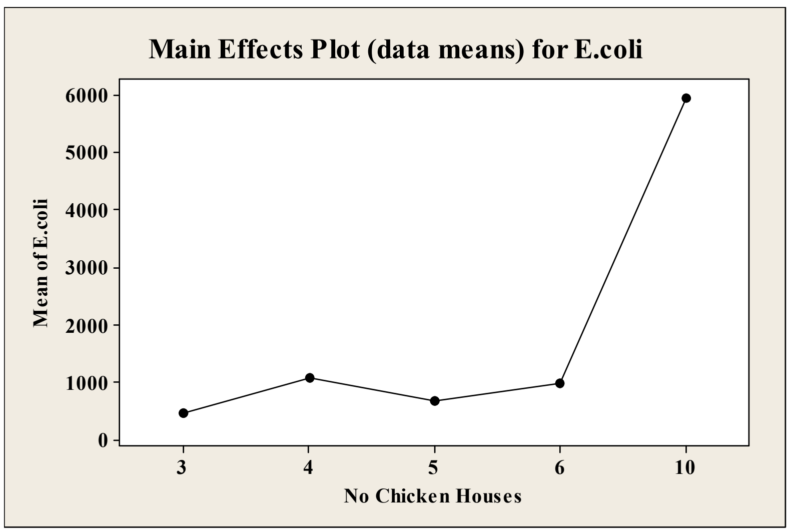


Figure 5. Effect of number of chicken farm houses on *E.coli* counts.

CONCLUSIONS

Lake Tuscaloosa Watershed is an important asset to the City of Tuscaloosa and the neighboring cities in West Alabama. It has been a reliable drinking water source for many decades. People enjoy this lake for recreation and site seeing. It is very important to protect and develop comprehensive watershed management plans to reduce the effect of point and nonpoint source pollutants.

The EDAF was instrumental in collecting and organizing the different stakeholders' objectives. It helped in gather the data from stakeholders and their input about reasons casing the problem. Additionally, using EDAF has assisted in identifying the sources of the pollutants.

Rivers and creeks are very dynamic systems and upstream highly impacts downstream water quality. Watersheds need to be looked at using a comprehensive (big picture) view.

Agriculture activities have become a serious problem on the quality of downstream urban areas. These activities should be monitored and their risk on water quality should be continuously assessed. Additionally, sampling locations and activities should be well managed and controlled. Samples should be more frequent at areas that are considered sources or have the potential of affecting the water quality.

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