Introduction

Since the Clean Water Act passed in 1972, the condition of the nation's waterways has become a priority. A stated goal of the legislation is to make the nation's waterways fishable and swimable. One critical parameter of interest is bacteria. Bacteria are a concern because of the potential for harming human health. Immersion in bacteria-contaminated water can result in infections, and swallowing the water, as swimmers often do, can lead to a variety of gastrointestinal illnesses[1].

The State of Oregon, as part of its efforts to protect and improve water quality, has set a standard for bacterial contamination of streams and rivers. The state has chosen to use *Escherichia coli* (*E. coli*) as its indicator of bacterial contamination. Specifically it is an indicator of sewage or fecal sources. The presence of high levels of *E. coli* tells us that other disease-producing microorganisms might be present, and the risk of disease to the public for recreational activities like fishing and swimming is too high.

The standard's criteria to determine compliance is as follows:

- A 30-day log mean of 126 *E. coli* organisms per 100 milliliters, based on a minimum of five (5) samples;

- No single sample may exceed 406 *E. coli* organisms per 100 milliliters[2].

Malheur County, located in far eastern Oregon, is an area highly dependent on agriculture for its economic well being. Agricultural production in turn depends on an abundant supply of high quality water. Beginning in 1997, local agencies and groups worked with landowners to assess the quality of the streams and rivers in the area. One basin, Willow Creek, became a focal point of these efforts because preliminary monitoring data showed this creek to have consistently high *E. coli* levels. Intensive sampling of the lower part of the basin continued until the spring of 2003.

Objectives

The objectives of this study were to examine the bacteria data for:

- Differences among locations within the watershed;
- Seasonal variation;
- Relationship to stream flows.

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[1] 1992-1994 Water Quality Standards Review. 1995. ODEQ.
[2] **Oregon Administrative Rule 340-041-0009**

Methods

Sample Sites

Nine sites were selected for sampling. Because agriculture is the primary land use, samples were taken above and below the intensive agricultural production area along the lower part of Willow Creek and at regular intervals in between (Figure 1; Table 1).

Table 1. Sample site description and number of samples taken at each site from spring 1997 to spring 2003.

Site number	Site Description	Number of samples
1	Willow Creek at Rail Road Crossing East of Vale (Close to the mouth)	230
2	Willow Creek at 5th Avenue Bridge	241
3	Willow Creek at 6th Avenue Bridge	161
4	Willow Creek at 7th Avenue Bridge	153
5	Willow Creek at 8th Avenue Bridge	154
6	Willow Creek at 9th Avenue Bridge	155
7	Willow Creek at 12th Avenue Bridge	154
8	Willow Creek Above Jamieson	240
9	Willow Creek at Brogan Canyon (Above intensive agricultural production area)	83

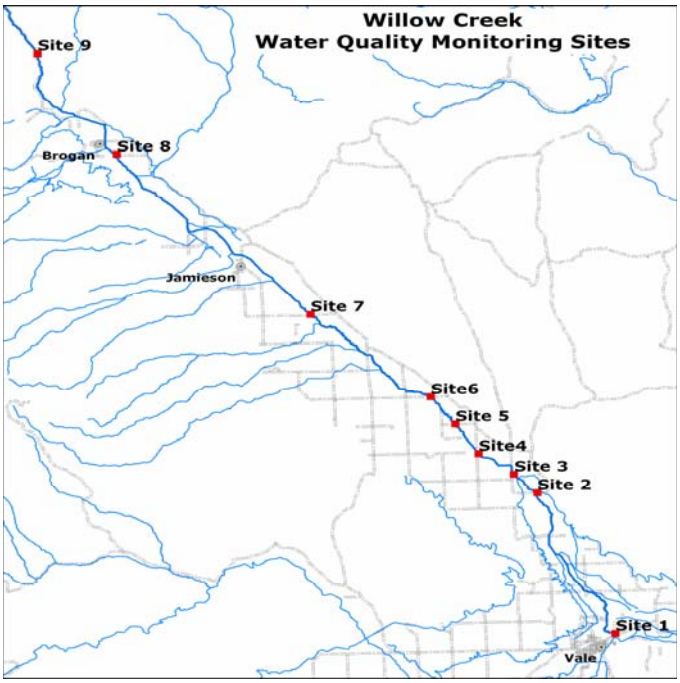

Figure 1. Water quality monitoring sites in the Willow Creek drainage.

Sampling Frequency

In 1997, samples were taken from Sites 2, 8, and 9 on a monthly basis as part of the preliminary survey of the basin. In 1998, Site 1 was added and sampling frequency increased to weekly intervals. By late 1999, the monitoring program managers decided to add Sites 3, 4, 5, 6, and 7 and they tried to sample 5 times with a 30-day period. This sampling intensity continued until January 2002 when the frequency was reduced to twice per month.

Sampling Methods

Field sampling procedures and laboratory methods followed the standard procedures outlined by the Bureau of Reclamation's analytical laboratory staff. All water samples were collected with sterile bottles, put on ice, and shipped to the lab in Boise, Idaho the same day they were collected. Lab analysis was completed within 24 hours of collection.

Stream Flow Measurements

Technicians measured stream flow at Sites 3, 6, and 8 from April 2000 to November 2001. The measurements followed standard USGS methods and were taken at the same time water samples were obtained. 92 measurements were taken at each site during this period.

Results and Discussion

Summary Statistics

E. coli levels in the samples varied greatly in time and space (Figure 2; Table 2). The highest concentration was 100,000 counts/100 mL at Site 2 on March 14, 1999. Seven samples contained no *E. coli* at all. Three of these "zero detection" samples were taken at Site 9, two at Site 8, two at Site 2 and one at Site 1.

Table 2. Summary statistics of *E. coli* levels in samples collected at 9 sites in the Willow Creek Sub-basin from 1997 to 2003.

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9
Number of Samples	230	241	161	153	154	155	154	240	83
Maximum	35,700	100,000	20,000	10,000	20,000	20,000	20,000	30,000	50,000
Minimum	0	0	2	8	6	1	2	0	0
Mean	821	1,499	936	888	1,009	966	883	1,076	1,889
Standard Deviation	2,903	6,896	2,284	1,681	2,648	2,244	2,607	3,226	6,531
Median	240	300	330	400	280	320	184	203	78

The samples taken at Site 9 had the highest average *E. coli* level, 1,889 counts/ 100 mL. However, this same site had the lowest median level, 78 counts/100 mL. These statistics are an indication that Site 9 had a few samples with high counts, but most samples contained less *E. coli* than the other sites.

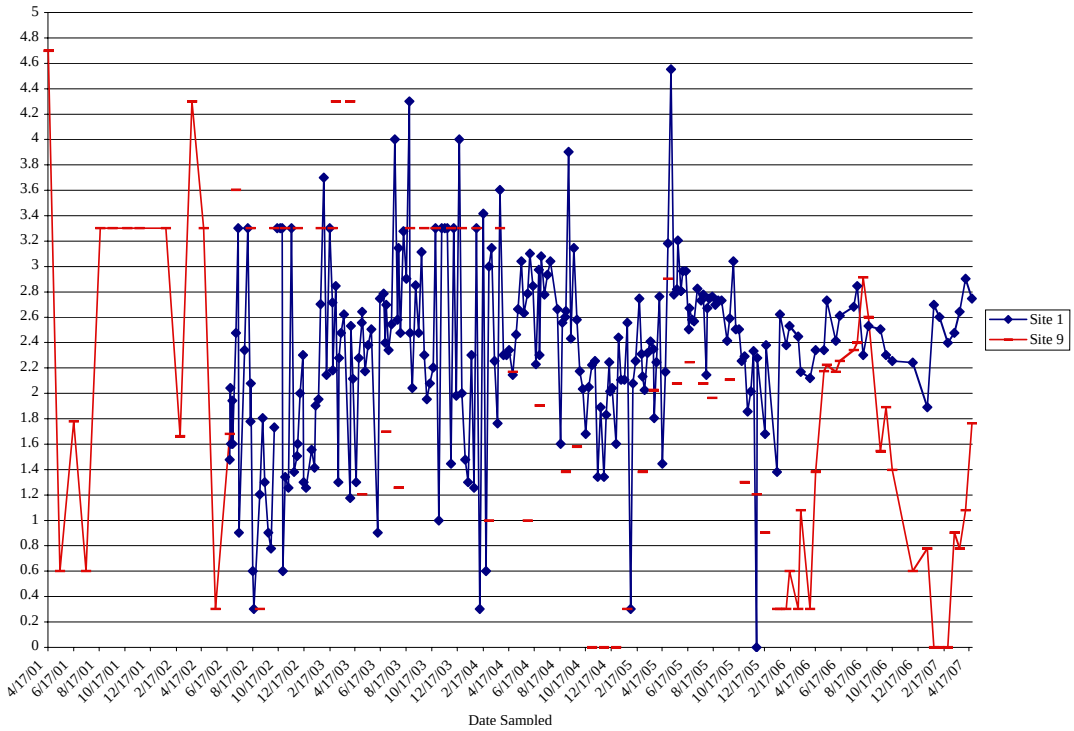

Figure 2. Willow Creek *E. coli* data, 1997 to 2003, for Sites 1 and 9. Bacteria counts per 100 mL converted to Log_{10} scale**.** Site 1 was near the mouth and Site 9 was above the intensive agricultural area.

Differences Among Sites

E. coli levels varied greatly from site to site. Site 9, the site above the intensive agricultural production area, generally had the lowest *E. coli* levels (Figure 3). Median levels of *E. coli* gradually increased until they peaked at Site 4 and there was a gradual decline at the remaining downstream sites.

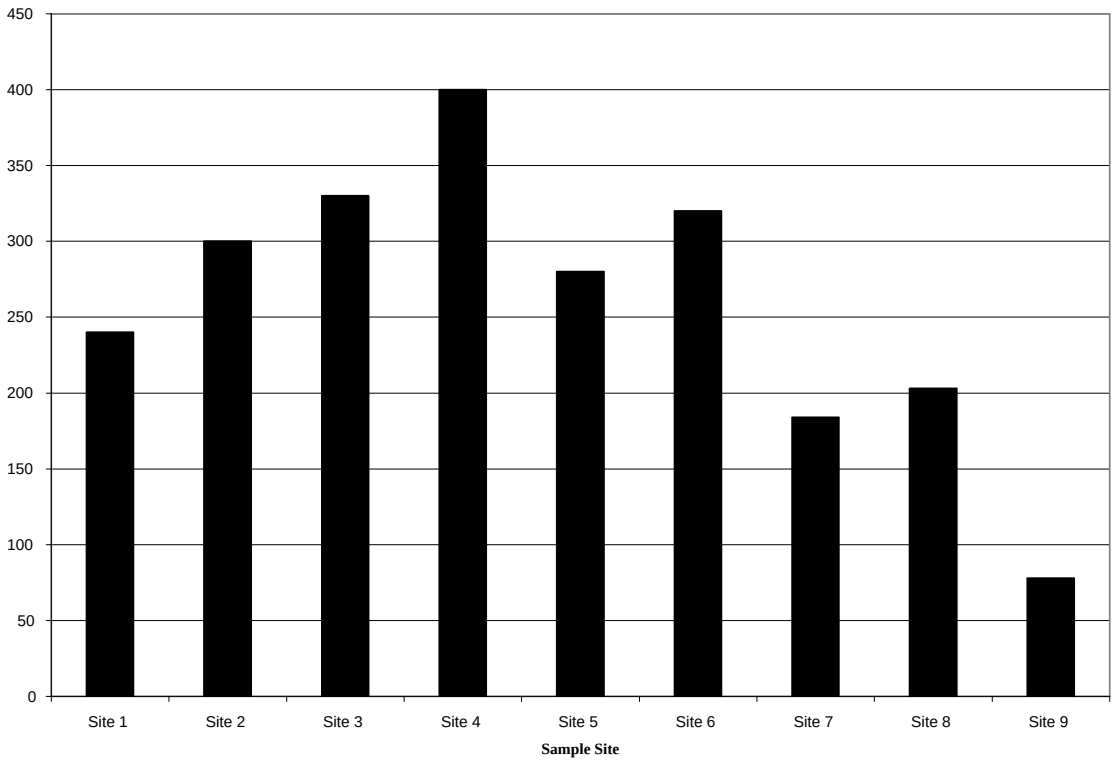

Figure 3. Median *E. coli* levels in samples taken from 9 sites in the Willow Creek sub-basin, 1997 to 2003. Site 9 is above the intensive agricultural area and Site 1 is near the mouth.

To test if there were a statistical difference between Site 9 (above the intensive agricultural area) and Site 1 (near the mouth; below the agricultural area) we used the Wilcoxon Signed Rank Test.[3] This is a distribution free or non-parametric test that uses the ranks of differences between median values of paired samples. We used the large sample approximation method.

The results indicated there was a significant difference in median *E. coli* counts between Site 1 and Site 9 ($z = 3.098$; $p = 0.001$). However, because of the limitations of this experimental design, it may be possible that the differences may actually be the result of an inherent watershed difference between the upstream and down stream stations. More work needs to be done to

[3] Analysis of Water Quality Monitoring Data. 2002. USDA Natural Resources Conservation Service. National Water Quality Handbook. Sub Part 615.08. Nonparametric Statistical Methods. 1999. Hollander and Wolfe. John Wiley & Sons, Inc.

investigate the differences at these sites.

Seasonal Effects

Visual inspection of Figure 2 shows a trend of higher counts in the spring and summer and a decline in the fall and winter. This trend is more pronounced when examining the 30-day geometric means of *E. coli* counts (Figure 4). During the winter of 2000-2001, all sites were in compliance or close to compliance with the state ambient criterion of 126 *E. coli* counts per 100 mL as a 30-day geometric mean. However, in April 2001 the counts increased substantially and they peaked in May. Site 2 had the highest count, 2,680 in May and generally was the site with the highest geometric mean for the rest of the year. Again, the pattern was to have counts decline to near compliance levels in October.

An exception to this pattern of low counts in the fall and winter, and higher counts in the spring and summer was the winter of 2000. The highest geometric mean, 3,808, was for Site 7 in February 2000.Sites 2,3 and 6 had high counts as well. Examination of the weather data taken by

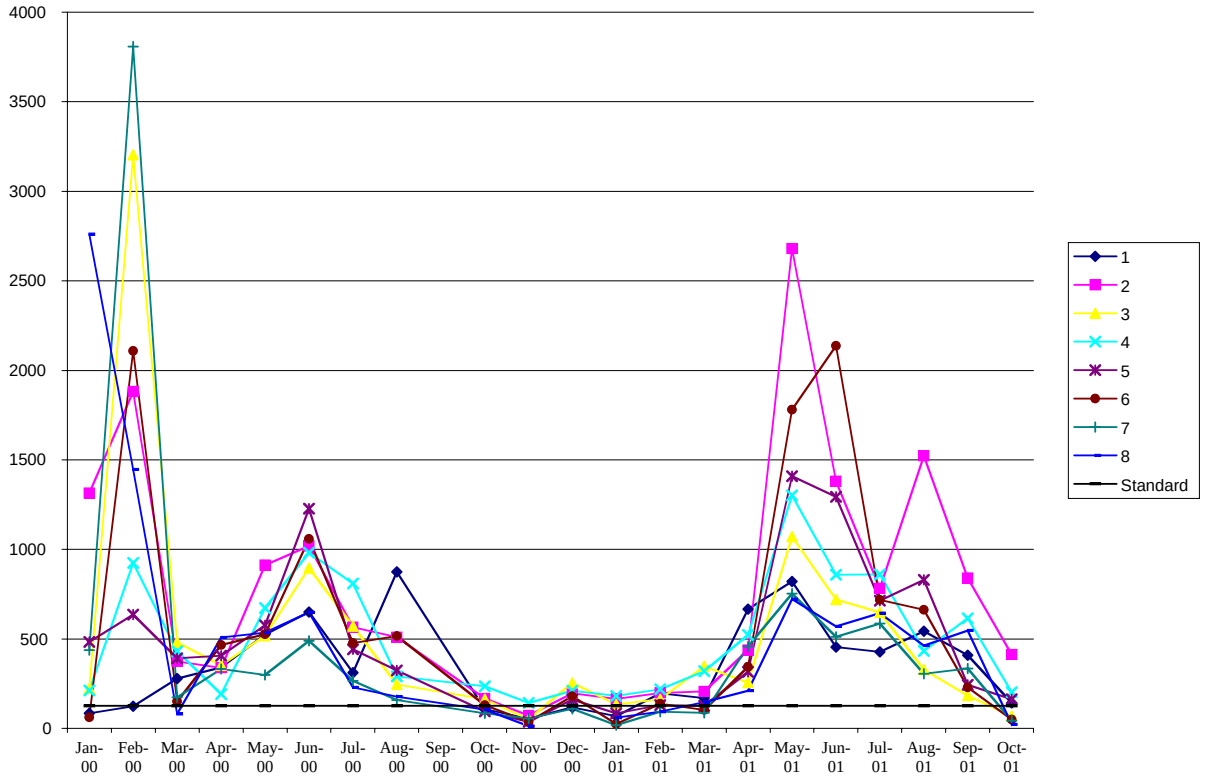

Figure 4. 30-day geometric means for 8 sites in the Willow Creek Sub-basin, January 200 to October 2001. Site 9 did not have sufficient data for this calculation**.**

the Malheur Experiment Station shows that the winter of 1999 – 2000 had a few more storm events than the winter of 2000 – 2001, but the difference is not great.

Another way to examine these seasonal trends, one that includes the entire data set, is to divide the percentage of samples that exceed the state's single sample criterion of 406 counts per 100 mL into seasons. Samples from January to March were classified as "Winter," April to June as "Spring," July to September as "Summer," and October to December as "Fall." With only one exception, at each site the percentage of samples exceeding the state's standard was greater in the Spring and Summer than in the Fall and Winter. The one exception was Site 9 where there was a greater percentage of violations in the Fall than for other times of the year (Figure 5).

Relationship to Flow

To examine the relationship between *E. coli* levels and flow, we classified flow measurements into High, Medium high, Medium low and Low categories for each site where flow measurements were taken (Site 3, 6, and 8). Flow was considered high if the level was in the top 25 percent of all flow measurements, Medium high if it was in the next 25 percent of all measurements and so on. The general trend was to have more samples that exceed the state's standard when flow was High and to have the percentage gradually decline as flow levels declined (Figure 6).

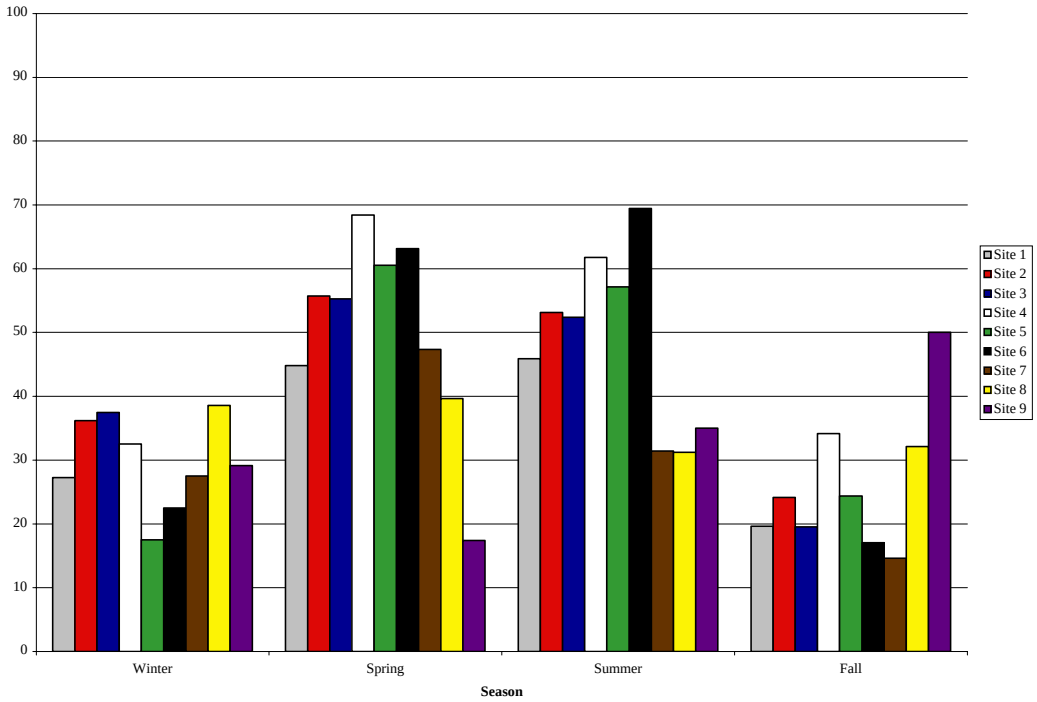

Figure 5. Percent of samples with *E. coli* counts higher than the state's standard of 406 counts per 100 mL as it relates to time of year.

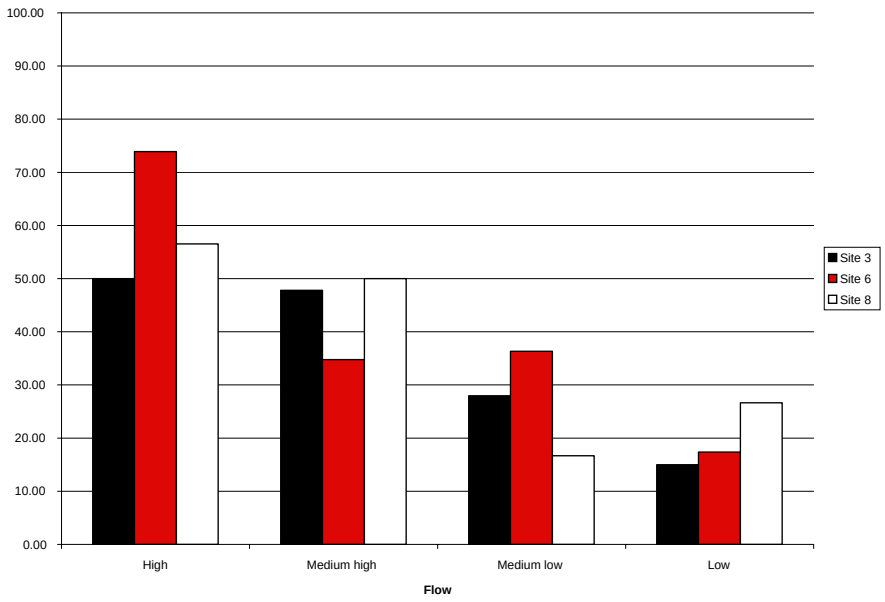

Figure 6. Relationship of flow to *E. coli* in Willow Creek . Sites 3, 6, and 8 were the sites where flow was measured from April 2000 to November 2001.

Conclusions

The Willow Creek system has high levels of bacteria. The patterns of variation in the bacteria levels tend to follow season, (higher in the Spring and Summer) stream flow, (higher bacteria levels with higher flow) and site (Site 9 generally had the lowest levels and Site 4 the highest).

These are only general patterns, however. Bacteria levels were highly variable and there were exceptions to every trend. This type of variation is typical of non-point source pollution. There are multiple sources of the contamination, and they can range from natural sources, such as wildlife, to human influences such as runoff from feedlots and irrigated pastures. Thus, it is very difficult to assign direct causes and effects for the available data.

Recommendations for Future Study

The Willow Creek Working Group should focus their efforts on determining the precise amount of *E. coli* present in irrigation return flow. A preliminary survey of the area has identified at least six sites. An intensive sampling of these sites during the irrigation season will help determine the human contribution to the observed bacteria levels.

They should reduce the number of sampling sites on the main stem to perhaps three sites. These sites should be one (Site 9) above the intensive agricultural production area, one near the mouth (Site 1) and one somewhere near the half way point between these two sites (Site 4). It may also be desirable to continue sampling at Site 4 because it generally had the highest levels of bacteria.

They may also want to estimate the bacteria levels found in the Willow Creek sediments. Several studies have shown that bacteria can survive and re-grow even after substantial time in sediment.