Lone Star Healthy Streams

Final Report

Prepared for:
Texas State Soil and Water Conservation Board

By:
Kevin Wagner, Texas Water Resources Institute
Larry Redmon, Texas AgriLife Extension Service
College Station, Texas

Texas Water Resources Institute Technical Report 410

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Funding was provided through a FY2006 Section 319(h) Nonpoint Source Program Grant from the U.S. Environmental Protection Agency through the Texas State Soil and Water Conservation Board .

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Executive Summary

Runoff of *Escherichia coli (E. coli)* and other fecal indicator bacteria from grazing lands has been identified as a significant source of bacterial contamination in need of reductions to improve water quality. Development of best management practices to address these bacterial issues is critical to the success of watershed restoration efforts. The effects of alternative water supplies and grazing management were evaluated to assess their effectiveness as best management practices (BMPs).

Providing alternative water supplies for cattle reduced the time cattle spent in the creek by 43% from 3.0 to 1.7 minutes/animal unit/day. Observed pre- and post-treatment *E. coli* loads suggested similar reductions (57%); however, this project could not conclusively attribute the observed *E. coli* loading reductions to providing alternative water because of the lack of statistical significance of these observations, the decrease in flow observed during the post-treatment period, and the observed increase in *E. coli* levels during the post-treatment period. Lack of producer response to extreme drought conditions may have confounded these data.

The evaluation of grazing management found rotational grazing, if timed appropriately, was an effective practice for reducing *E. coli* runoff. The impact of grazing timing in relation to runoff events was much more significant than the impact of the level of grazing (i.e. moderately stocked or heavy stocked) or stocking rate. When runoff occurred more than two weeks following grazing, *E. coli* levels in runoff were decreased more than 88%. As a result of these findings, it is recommended that creek pastures and other hydrologically connected areas be grazed during periods when runoff is less likely (e.g. summer and winter in much of Texas) and upland sites be grazed during rainy seasons when runoff is more likely to occur. Background levels were considerable and relatively consistent among sites, with median levels typically ranging from 3,700 to 5,500 cfu/100 mL. These levels should be considered when applying water quality models to develop total maximum daily loads and other analyses. Finally, project members observed more than 80% of the samples exceeded Texas Water Quality Standards for *E. coli*. In light of this and other findings of this project, project members recommend that exemptions from the current standards be made for storm flows and wildlife, or additional research be conducted to accurately define bacterial quality for runoff and establish rational water quality standards.

Based on the review of existing programs and compiled literature on bacterial runoff and BMPs; input from the Texas State Soil and Water Conservation Board (TSSWCB), Lone Star Healthy Streams (LSHS) Steering Committee, and internal Texas AgriLife Extension Service Planning Team; and results from the field demonstrations, the LSHS education program for grazing beef cattle was developed. The LSHS program consists of a PowerPoint presentation, Voice-Over PowerPoint presentation, and an accompanying *Lone Star Healthy Streams Beef Cattle Manual*. Portions of this program were delivered to audiences at over 40 events throughout the state, reaching well over 2,200 participants. In addition, unique visitors to the “Improving Water Quality of Grazing Lands” website exceeded 1,100. This highly beneficial program will continue to be carried out throughout the state in coordination with the TSSWCB and other project partners.

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List of Acronyms and Abbreviations

A - Area
Ac—acre
AgriLife Extension—Texas AgriLife Extension Service
ANOVA—Analysis of Variance
ARS—Agricultural Research Service
AU—Animal Unit, 1000 pounds live weight
AUD—Animal Unit Day
AUM—Animal Unit Month
AUY—Animal Unit Year
BCSC—Beef Cattle Systems Center
BMP—Best Management Practice
BST-Bacterial Source Tracking
CEU-Continuing Education Unit
CFU-Colony Forming Units, measure of fecal bacteria present in samples
CIG—Conservation Innovation Grant
Conc.—Concentration
CWA—Clean Water Act
d – Observed Depth
D – Culvert Depth
E. coli—Escherichia coli
EMC—Event Mean Concentration
EPA—Environmental Protection Agency
EQIP—Environmental Quality Incentives Program
FSA—Farm Services Agency
FY—Fiscal Year
Geo Mean—Geometric Mean
GI - gastrointestinal
GLCI—Grazing Lands Conservation Initiative
ha—hectare
Hvy—Heavy
ICAT—Independent Cattlemen's Association of Texas
IPM — Integrated Pest Management
LSHS—Lone Star Healthy Streams
Max.—Maximum
Min.—Minimum
mL—milliliter
Mod.—Moderate
mos.—months
n – Manning Roughness Coefficient
NRCS—USDA Natural Resources Conservation Service
PI—Principal Investigator
Q1—First Quartile (25th percentile)
Q3—Third Quartile (75th percentile)
R – Hydraulic Radius
RTD—Rapid Transfer Device
S - Slope
SR—Stocking Rate in acres per animal unit
Std. Dev.—Standard Deviation
SWCD—Soil and Water Conservation District
TCEQ—Texas Commission on Environmental Quality
TCFA— Texas Cattle Feeders Association
TDA—Texas Department of Agriculture
TFB—Texas Farm Bureau
TNTC – Too Numerous To Count
TSCRA—Texas and Southwestern Cattle Raisers Association
TMDL—Total Maximum Daily Load
TSSWCB—Texas State Soil and Water Conservation Board
TWRI—Texas Water Resources Institute
USDA—United States Department of Agriculture
WPP – Watershed Protection Plan

Introduction

Problem/Need Statement

According to the 2004 Water Quality Inventory and 303(d) List, 306 water bodies are impaired in Texas with a total of 419 impairments. Of these, approximately one-half of the impairments are the result of excessive bacteria. Bacterial Source Tracking (BST) work completed in some of these water bodies (e.g. Peach Creek and Leon River) has identified a noticeable contribution from grazing cattle to the bacteria loading of these streams. Grazing lands, which represent the dominant land use in the majority of watersheds in Texas, have received little attention until now regarding the effect of grazing livestock on water quality. Thus, implementation of watershed management principles and practices on grazing lands will be critical to the success of future water resource protection efforts in the state.

Education of landowners and voluntary adoption of BMPs could substantially reduce bacterial contamination of streams and water bodies as well as reduce the likelihood of increased regulatory oversight of production practices and systems. The Texas State Soil and Water Conservation Board (TSSWCB), local soil and water conservation districts (SWCDs) and the U.S. Department of Agriculture Natural Resources Conservation Service (USDA NRCS) support producers through technical and financial assistance programs enabling implementation of BMPs. For such measures to be effective, however, they must be properly implemented and managed to ensure sustainability. In addition, these practices must be compatible with the overall management system and result in limited additional economic burden to agricultural producers.

Extension education programs are designed to target specific audiences and deliver current, unbiased, science-based information and technology. The primary goal of these educational programs is to optimize sustainable production. Recently, the dominant environmental education components of these programs have focused on supporting the Texas Department of Agriculture (TDA) Pesticide Applicator Certification Program. Private pesticide applicator re-certification requires a licensed individual to obtain 15 hours of continuing education units (CEUs) every 5 years, with at least 2 hours addressing integrated pest management (IPM) and 2 hours addressing laws and regulations. The Texas AgriLife Extension Service (AgriLife Extension) is one of the primary providers of training and continuing education for this program. With an increasing focus on more holistic watershed management, however, there is an opportunity for AgriLife Extension personnel to use the Lone Star Healthy Streams (LSHS) Program as a vehicle to expand the overall knowledge base of beef cattle producers regarding watershed management and measures for reducing bacterial contamination of streams. Through linkages with existing programs, the burden on producers and county AgriLife Extension agents could be minimized, while the knowledge base and potential for producers to participate in, and ultimately affect changes in watershed protection, could be realized.

General Project Description

This project is a partnership among the primary federal and state agencies interfacing with beef cattle producers relative to environmental management. A Project Steering Committee was established and coordinated by the Texas Water Resources Institute (TWRI) and included representatives from the TSSWCB, SWCDs, NRCS, TWRI, AgriLife Extension, Texas AgriLife Research,),TDA, Grazing Lands Conservation Initiative (GLCI), and other state and federal agencies as appropriate, and representatives from key commodity groups and organizations including the Texas Farm Bureau (TFB), Texas and Southwestern Cattle Raisers Association (TSCRA), Texas Cattle Feeders Association (TCFA), Independent Cattlemen's Association of Texas (ICAT), and other allied industries as appropriate. In addition, local producers were asked to serve on the Project Steering Committee. This committee provided input into the evaluation of BMPs, curriculum development, program delivery and CEU processes.

AgriLife Extension then assessed and compiled current knowledge regarding BMPs designed to protect grazed watersheds from bacterial contamination. Based on that initial task, educational programs and materials were developed and tested. Concurrent with the development and testing of the educational programs, grazing management and alternative off-stream water were demonstrated and evaluated to determine the efficacy of these value-added BMPs. This evaluation included an assessment of the effects of these BMPs on cattle behavior, bacteria levels and streambank stability. At the grazing management sites, both *E. coli* (enumeration only) and *Bacteroides* (library-independent PCR Bacteria Source Tracking) were assessed in runoff to determine the portion of observed loadings from cattle. The evaluation of *Bacteroides,* if successful, may assist the state in developing cheaper, library-independent methods for BST. At the stream sites, in addition to bi-monthly collections of *E. coli* and flow data, a primary cattle crossing was assessed before and after BMPs were implemented to assess the impacts of BMP implementation on streambank stability.

Based on the results of the testing of the education program and BMP demonstration/evaluation, an educational program and associated materials were developed and delivered statewide to grazing lands owners and managers in priority watersheds to (1) bring heightened awareness of the issue regarding bacterial contamination of watersheds by grazing animals and (2) to encourage adoption of BMPs designed to reduce bacterial loading to Texas streams and water ways.

An Extension Assistant was employed was to help develop, adapt and tailor the environmental and commodity specific LSHS educational program. The Extension Assistant coordinated with various specialists within AgriLife Extension to form an internal planning team. Program development, modifications, and delivery were subject to review by a multi-agency steering committee consisting of representatives from, but not limited to, TSSWCB, TDA, NRCS, GLCI, other state and federal agencies as appropriate, and representatives from key commodity groups and organizations including TFB, TSCRA, TCFA, ICAT and other allied industry as appropriate. In addition, producers and SWCDs were solicited to provide input into the curriculum development and program delivery processes. The AgriLife Extension State Water Quality Coordinator also provided guidance for the project.

Project Goals

The goal of this project is to reduce the levels of bacterial contamination of Texas watersheds from beef cattle by:

1) developing an educational curriculum delivering current knowledge in production and environmental management of grazing lands and their associated watersheds,
2) evaluating and demonstrating the effectiveness of value-added BMPs in reducing bacterial contamination of streams and water bodies from grazing lands,
3) testing the functionality of the education program in priority watershed(s) and making necessary changes and program modifications based on the results of the pilot project, and
4) promoting statewide adoption of appropriate BMPs and other watershed/water quality protection activities through education, outreach, and technology transfer.

Measures of Success

- As measured by surveys and pre/post evaluations, increased knowledge and understanding by beef cattle producers within the target area regarding production practices and related environmental issues.
- As measured by the adoption of recommended practices and other activities to address potential impairments caused by agricultural nonpoint source pollution.
- As measured by a reduction in bacterial contamination in the pilot watershed.

Texas Nonpoint Source Management Program Document Reference

This project assisted the State in meeting Short-Term Goal Three for NPS Management - Education by conducting education and technology transfer activities to help increase awareness of NPS pollution and prevent activities contributing to the degradation of water bodies, by NPS pollution.

This project assisted the State in meeting the Objective of reducing the amount of NPS pollution entering the water bodies of Texas through pollution prevention activities and education by enhancing existing outreach programs at the state, regional, and local levels to maximize the effectiveness of NPS education; administering programs to educate citizens about water quality and their potential role in causing NPS pollution; and conducting outreach through the AgriLife Extension to facilitate broader participation and partnerships.

This project assisted the State in meeting Milestone (F) Implementation of Voluntary Actions in 2005 Texas Nonpoint Source Management Program Priority Watersheds considered to be threatened by bacteria from beef grazing operations. Priority Watersheds included Plum Creek (1810), Copano Bay (2472), and the Brazos River above the Navasota River (1242) watersheds.

Methods and Results

Task 1: Project Coordination and Administration

Objectives: (1) To effectively coordinate and monitor all work performed under this project including technical and financial supervision, preparation of status reports, and maintenance of project files and data. (2) To organize a Project Steering Committee to help coordinate project efforts with all project partners. (3) To perform accounting functions for project funds and develop timely and accurate reports.

Subtask 1.1: Coordination of Lone Star Healthy Streams Steering Committee

TWRI, in coordination with the AgriLife Extension, organized a Project Steering Committee to coordinate project efforts with project partners. This committee was composed of representatives of the following organizations:

- Hall-Childress Soil and Water Conservation District
- Independent Cattlemen's Association of Texas
- Little Wichita Soil and Water Conservation District
- Texas AgriLife Extension Service
- Texas AgriLife Research
- Texas Cattle Feeders Association
- Texas Department of Agriculture
- Texas Grazing Lands Conservation Initiative
- Texas Farm Bureau
- Texas and Southwestern Cattle Raisers Association
- Texas State Soil and Water Conservation Board
- Texas Water Resources Institute
- USDA-Agricultural Research Service
- USDA-Natural Resources Conservation Service
- Victoria Soil and Water Conservation District
- Welder Wildlife Foundation

This committee met annually to provide input on the evaluation of BMPs and the education program; provide input into curriculum development, program delivery and CEU processes; discuss project status; provide input on demonstration and BMP evaluation efforts; and coordinate project activities. With the exception of the first meeting, which was held on November 29, 2007 following the TSSWCB Board Meeting, the LSHS Steering Committee met in conjunction with the Annual Meeting of Texas Soil and Water Conservation District Directors in October of 2008, 2009, and 2010. Agendas, presentations and sign-in sheets can be found on the Lone Star Healthy Streams website as follows: (http://lshs.tamu.edu/projects/steering-committee).

Subtask 1.2: Preparation of progress reports

TWRI prepared and submitted Quarterly Progress Reports, which can be viewed online at http://lshs.tamu.edu/projects/reports as follows:

- April 13, 2007 — TWRI submitted Quarter 1 Progress Report
- July 16, 2007 — TWRI submitted Quarter 2 Progress Report
- October 15, 2007 — TWRI submitted Quarter 3 Progress Report
- January 15, 2008 — TWRI submitted Quarter 4 Progress Report
- April 15, 2008 — TWRI submitted Quarter 5 Progress Report
- July 15, 2008 — TWRI submitted Quarter 6 Progress Report
- October 15, 2008 — TWRI submitted Quarter 7 Progress Report

- January 15, 2009 TWRI submitted Quarter 8 Progress Report
- April 15, 2009 TWRI submitted Quarter 9 Progress Report
- July 15, 2009 TWRI submitted Quarter 10 Progress Report
- October 9, 2009 TWRI submitted Quarter 11 Progress Report
- January 15, 2010 TWRI submitted Quarter 12 Progress Report
- April 13, 2010 TWRI submitted Quarter 13 Progress Report
- July 15, 2010 TWRI submitted Quarter 14 Progress Report
- October 13, 2010 TWRI submitted Quarter 15 Progress Report
- January 14, 2011 TWRI submitted Quarter 16 Progress Report

Subtask 1.3: Coordination of project meetings

TWRI conducted more than 27 coordination meetings during the project. TWRI and AgriLife Extension met approximately semi-monthly to discuss project activities, status of tasks, project timeline, upcoming deadlines, the budget, deliverables and other requirements as follows:

- February 15, 2007
- February 19, 2008
- June 19, 2008
- November 13, 2008
- February 5, 2009
- February 27, 2009
- April 8, 2009
- May 1, 2009
- June 12, 2009
- August 27, 2009
- September 11, 2009
- September 28, 2009
- October 2, 2009
- October 19, 2009
- November 12, 2009
- January 21, 2010
- March 16, 2010
- March 26, 2010
- April 19, 2010
- April 29, 2010
- June 10, 2010
- June 22, 2010

In addition to these coordination meetings, TWRI, AgriLife Extension and AgriLife Research met on February 26, 2007 with the Welder Wildlife Refuge to discuss monitoring the effects of grazing management on bacterial runoff at the Welder Wildlife Refuge. TWRI, AgriLife Research and AgriLife Extension met on May 18, 2007 to discuss the BMP evaluations. TWRI and AgriLife Research met on May 23, 2007 to discuss using *Bacteroides* to quantify loadings from cattle versus other species as part of the BMP evaluations. On December 3, 2007, TWRI coordinated a tour for staff from TSSWCB and TCEQ of the Welder Wildlife Refuge watershed sites where grazing management was being evaluated. Finally, on October 17, 2008, TWRI met with Agricultural Research Service (ARS) to discuss the data collected to date.

Subtask 1.4: Participation in TSSWCB meetings

TWRI attended meetings with the TSSWCB project manager and other TSSWCB meetings, to review project status, deliverables and other project related issues. In addition to face-to-face meetings, TWRI routinely communicated with the TSSWCB project manager on project status and issues.

The TSSWCB, AgriLife Extension, and TWRI generally met semi-annually to discuss project activities, status of tasks, findings, upcoming meetings, project timeline, future activities planned, contract, budget, deliverables and other project related issues as follows:

- February 26, 2008
- May 19, 2008
- September 4, 2008
- October 27, 2008
- February 13, 2009
- June 26, 2009
- October 2, 2009
- June 24, 2010
- September 28, 2010
- October 25, 2010

TWRI attended more than eight TSSWCB Board Meetings and/or Work Sessions (as listed below) to maintain appropriate communication with the TSSWCB Board.

- July 19, 2007
- November 29, 2007
- March 19, 2008
- November 19, 2009
- July 22, 2010
- September 15, 2010
- November 10, 2010
- January 27, 2011

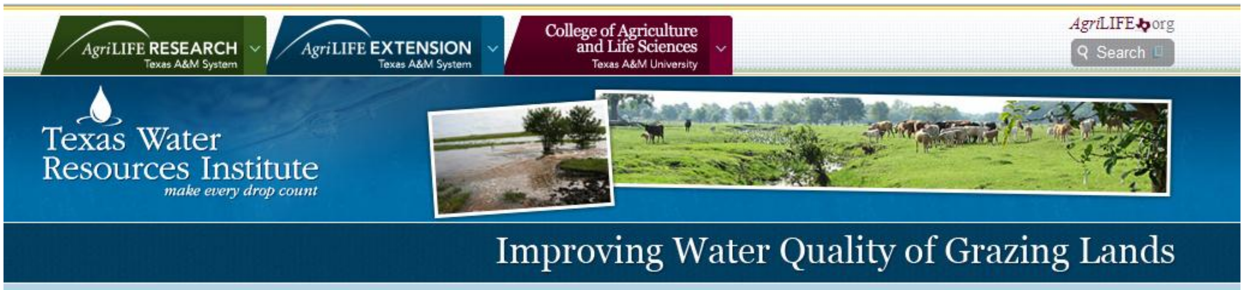
Finally, TWRI attended the Association of Texas Soil and District Director's Annual Meeting in 2007, 2008, 2009, and 2010 to help maintain communication with TSSWCB staff and Soil and Water Conservation District Directors.

Subtask 1.5: Reimbursement form submission

The Lone Star Healthy Streams contract (#06-05-07-02) was initiated on December 27, 2006. The contract was amended four times during the course of the project. The contract was first amended in September 7, 2007 to clarify the following in the scope of work: project location, project partners, role of steering committee, BST method to be used and other methods to be used to evaluate impact of BMPs. The second amendment was approved on May 13, 2009 to provide a no-cost extension that extended the project end date from September 30, 2009 to September 30, 2010. The third amendment was approved on July 2, 2009 to amend the scope of work to reflect the change in end date throughout the work plan and to make other minor edits throughout the document such as the AgriLife name change. Amendment four was approved on July 1, 2010 to provide a 6-month no-cost extension that extended the project end date to March 31, 2011 to allow completion of the *Bacteroides* analysis and development of the final report.

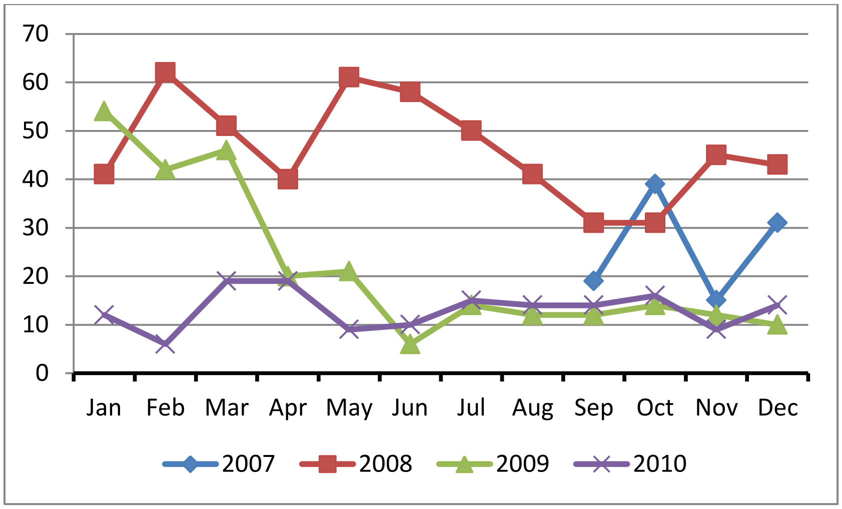
Subtask 1.6: Development and maintenance of project website

In September 2007, TWRI developed the website titled "Improving Water Quality of Grazing Lands." This website displayed the efforts associated with this project and other related projects evaluating conservation practices and developing education programs to address bacteria. It can be found at the following web address: http://grazinglands-wq.tamu.edu/.



Between September 2007 and December 2010, there were 1,101 unique visitors to the website (Figure 1). As materials for the project were developed, they were added to the website. Materials found on the website include project work plan, reports, presentations and publications, project personnel, links, and other relevant information.

Figure 1. Number of unique visitors to the website between September 2007 and December 2010.



Task 2: Compilation of Existing Information

Objective: To compile current knowledge regarding the effects of grazing animals on bacterial runoff and BMPs designed to minimize these impacts.

Subtask 2.1: Compilation of literature on bacterial runoff and BMPs

AgriLife Extension hired an Extension Assistant to assist with LSHS program efforts and conduct a literature review to assess the current state of knowledge regarding the effects of grazing animals on bacterial levels and BMPs designed to minimize these impacts. The LSHS Extension Assistant was hired on April 23, 2007. The compilation of literature continued throughout the project and, in fact, continues today. AgriLife Extension submitted the Lone Star Healthy Streams Bibliography to TSSWCB in July 2010. The Lone Star Healthy Streams Bibliography was then converted into an online searchable database accessible from http://lshs.tamu.edu. As information was collected, it was incorporated into the LSHS Power Point presentation and guidance manual for dissemination to the public. The database will continue to be updated with journal articles and other publications pertinent to the LSHS project to ensure the most up to date information is presented.

Subtask 2.2: Internal AgriLife Extension Planning Team organization

Dr. Mark McFarland and Nikki Dictson served as the internal AgriLife Extension Planning Team throughout the project. The Extension planning team provided input on development of the LSHS program and reviewed the LSHS program prior to submission to the TSSWCB. Following review of the program, changes were made to facilitate improved targeting of the presentation and educational materials to protect waterways from bacteria.

Subtask 2.3: Assessment of existing education/training materials available

AgriLife Extension assessed and inventoried education/training materials within AgriLife Extension and related materials developed through similar efforts in other states addressing bacteria from grazing cattle. Educational materials addressing nutrient and sediment runoff from grazing lands and proper grazing land management were also assessed and inventoried.

Task 3: Beef Cattle Bacteria Education Program Development

Objective: To develop statewide educational programs that provide beef cattle producers and allied industries with a combination of production and environmental training enabling them to better manage and protect their valuable land and water resources.

Subtask 3.1: Integration of existing materials into the Lone Star Healthy Streams program

AgriLife Extension transformed information collected in subtask 2.3 into a PowerPoint presentation for dissemination to the public. The PowerPoint presentation covers a wide range of grazing management topics, including the issue of bacteria in water bodies and the potential for reducing the levels of bacteria through BMPs that modify animal behavior. AgriLife Extension delivered a DRAFT version of the PowerPoint presentation to the LSHS Steering Committee on October 27, 2008 and requested comments. AgriLife Extension delivered the PowerPoint presentation to the TSSWCB on June 26, 2009 and received a number of very helpful comments that were incorporated into the presentation. AgriLife Extension presented the PowerPoint to the LSHS Steering Committee again on October 19, 2009 and October 25, 2010 and received a number of verbal comments that were subsequently incorporated. The LSHS PowerPoint presentation (Appendix A) was reviewed to ensure consistency between the resource manual and presentation and submitted to the TSSWCB in February 2011.

AgriLife Extension developed a LSHS BMPs publication based on the PowerPoint educational program for distribution via hard copy and web (Forages and TWRI web sites). The *Lone Star Healthy Streams*

Beef Cattle Manual was based on the PowerPoint presentation and the information compiled during the development of the PowerPoint. The DRAFT resource manual was provided to TWRI on August 27, 2009 for review. AgriLife Extension again provided the DRAFT LSHS resource manual to the TSSWCB on October 2, 2009 for review and comment. AgriLife Extension provided the DRAFT LSHS resource manual to the LSHS Steering Committee on October 19, 2009 and October 25, 2010 for review and comment and received verbal and written comments at the LSHS meeting. Based on these comments and those provided by TSSWCB, the *Lone Star Healthy Streams Beef Cattle Manual* was modified and submitted to TSSWCB in February 2011 (Appendix B).

Subtask 3.2: Development of land/grazing management educational component

AgriLife Extension worked in cooperation with the AgriLife Extension Planning Team, LSHS Steering Committee, other agencies and organizations, and with the local producers to gain input on the core curriculum and overall program. The AgriLife Extension Planning Team and Steering Committee were used as the primary review panels to ensure that the program was compatible with other programs conducted through state and federal agencies, organizations and industry.

Subtask 3.3: Integration of LSHS with Texas Watershed Steward

Dr. Mark McFarland and Nikki Dictson served on the internal AgriLife Extension Planning Team to facilitate integration and coordination of the LSHS with the Texas Watershed Steward program. This team met as needed to discuss integration of LSHS with Texas Watershed Steward training programs and training manual. AgriLife Extension will integrate and coordinate the LSHS program with the Texas Watershed Steward program as appropriate to provide producers in target watersheds with a more comprehensive environmental education.

Subtask 3.4: Establishment of continuing education units for LSHS program

The LSHS program was approved for 4 hours of credit for the Texas Certified Crop Adviser Program and 1 CEU through TDA for Certified Pesticide Applicators (Appendix A).

Subtask 3.5: Development of certificate of completion for LSHS program

On June 10, 2010, AgriLife Extension developed and submitted to the TSSWCB a certificate of completion for participation in the education program (Appendix A).

Task 4: Education Program Testing and Delivery

Objective: To test the educational program, assess the effectiveness of the program, make necessary modifications and disseminate educational materials on a statewide basis to promote adoption of BMPs that best protect riparian areas from bacterial contamination due to grazing livestock.

Subtask 4.1: Deliver and evaluate the educational program

Even before full development of the program, AgriLife Extension began to integrate discussion of the effects of grazing animals on bacteria levels in water bodies and BMPs designed to minimize these impacts into educational programs. Below are the meetings (and number of attendees where possible) that AgriLife Extension introduced the LSHS concept during presentations:

- April 2007—PALMAN (38); Jefferson Co. (50); O.D. Butler Field Day (40); Grayson Co. (40); Limestone Co. (25); Travis Co. (20); Montgomery Co. (12)
- May 2007—Jefferson, Chambers, Hardin Cos. (35); Freestone Co. (12); Bastrop Co. (40); Burleson Co. (12); Bell Co. (75)
- June 2007—Veterinary Food Animal Conference in Brazos Co. (50) and Stiles Farm Field Day in Williamson Co. (145)
- On October 14, 2009—National Devon Cattle Association in Freestone Co.
- On October 23, 2009—Washington Co. cow-calf clinic
- On October 26, 2009—Gonzales Co. forage program
- On November 6, 2009—Van Zandt Co. at North Texas Environmental conference and expo
- On December 3, 2009—Texas Plant Protection Conference in College Station
- On December 10, 2009—Robertson Co. forage program
- On January 11, 2010—Texas Pasture and Forage Work Group and the Texas Beef Workers at the Annual Staff Conference (31)
- On January 21, 2010—Jackson County educational program (61)
- On January 26, 2010—Bell County educational program (413)
- On January 27, 2010—National Cattlemen's Beef Association annual meeting, San Antonio (246)
- On January 29, 2010—Burleson County (269)
- On February 9, 2010—Blackland Income Growth educational program (71)
- On February 18, 2010—Williamson County educational program (176)
- On March 30, 2010—AgriLife Pasture & Livestock Management Program for Novices educational program (66)
- April 13, 2010—Victoria County (23)
- April 30, 2010—Fayette County (90)
- May 19, 2010—San Angelo - Texas Beef Workers (14)
- June 7, 2010—Liberty and Limestone Counties (42)
- July 9, 2010—Austin County
- July 15, 2010—Mid-Tex Chapter, Independent Cattlemen's Association, Lockhart
- September 17, 2010—Travis County
- September 24, 2010—McGregor Research Center Field Day – McLennan County
- October 12-15, 2010—Ranch Management University
- October 21, 2010—Burnet County
- October 26, 2010—Comanche County
- October 29, 2010—Luling Foundation Water Field Day
- December 14, 2010—Guadalupe County (98)

The LSHS Program and its concepts will continue to be delivered. AgriLife Extension has visited with the San Antonio River Authority and other river authorities about partnering in their watersheds to conduct LSHS meetings.

Subtask 4.2: Development of Web-based program delivery tools

AgriLife Extension developed a voice-over presentation and submitted it to the TSSWCB in March 2011. Once approved, it will be placed on the LSHS website.

Subtask 4.3: Evaluate changes in producer knowledge and awareness

In June 2010, a survey instrument (Appendix D) was developed to evaluate changes in producer knowledge and awareness of important production and environmental issues as well as identify any barriers to producer participation and successful program implementation. The survey was provided to the TSSWCB for comment. The survey was used on October 29, 2010 at the Luling Foundation Water Field Day. Survey results indicated that 97% of participants were mostly or completely satisfied with the educational program; 100% would recommend the program to others; and 82% were likely to adopt one or more of the BMPs presented during the program to improve water quality. Further, the survey indicated that as a result of the education program, the average knowledge gained among participants was 52%.

Subtask 4.4: Identify and address barriers to producer participation

The survey distributed at Luling on October 29, 2010 did not identify any barriers.

Subtask 4.5: Modify program to facilitate greater producer participation and BMP adoption

The program has been well received by all audiences to date. Following the presentation of the LSHS PowerPoint to the National Devon Cattle Association in Freestone Co. on October 14, 2009, AgriLife Extension made modifications to the presentation based on producer response. Minor modifications will continue to be made as new material becomes available and to improve the format of the material.

Task 5: Evaluate and Demonstrate Value-Added BMPs

Objective: To evaluate and demonstrate the effectiveness of grazing management, shade, and alternative water source development in reducing bacterial contamination from grazing lands.

Subtask 5.1: Develop a Quality Assurance Project Plan (QAPP)

The QAPP was submitted to the TSSWCB on June 13, 2007 for review and was approved on September 24, 2007 (http://lshs.tamu.edu/projects/reports).

Subtask 5.2: Provide annual revisions to QAPP and amendments as necessary

The first annual revision was submitted on September 23, 2008 and approved on November 20, 2008. The second and final annual revision was submitted to TSSWCB on November 13, 2009 and approved on February 1, 2010. All Blanks yielded *E. coli* levels of 0 cfu/100 mL, meeting quality control criteria as outlined in the Quality Assurance Project Plan. Seventy-seven duplicate samples were analyzed throughout the project. With the exception of the first sampling event on July 12, 2007 (at the 2S Ranch), all duplicates met quality control criteria. The data collected on July 12, 2007 was not included in the analysis and thus, the first sampling date (and beginning of year 1 of the alternative water project) is considered July 26, 2007.

Subtask 5.3: Identify cooperators for BMP demonstrations/evaluations

Three cooperators agreed to participate in the BMP demonstration and evaluation: (1) the Welder Wildlife Refuge, located in the Copano Bay Watershed, (2) the 2S Ranch, located in the Plum Creek watershed, and (3) the USDA-ARS Grassland Soil and Water Research Laboratory near Riesel, located in the Brazos River watershed (above the Navasota River). The Welder Wildlife Refuge, located in the Copano Bay Watershed, has three existing 1 hectare watersheds for the evaluation of the effects of grazing management on bacteria runoff. On April 19, 2007, TWRI and AgriLife Extension met with the 2S Ranch in the Plum Creek Watershed to discuss its potential participation in the project. On May 14, 2007, TWRI and AgriLife Extension conducted a site visit to the 2S Ranch to evaluate its suitability for the project. The site was found to be suitable and the ranch agreed to participate.

Subtask 5.4: Assess cattle behavior using GPS collars

As outlined in the QAPP, GPS collars were used to track cattle on a quarterly basis at the 2S Ranch before and after providing alternative off-stream water (Table).

Table 1. GPS monitoring dates

Start Date	End Date	Treatment
7/4/07	7/25/07	No trough
10/3/07	10/25/07	No trough
1/11/08	2/2/08	Trough
4/4/08	4/26/08	No trough
9/19/08	10/9/08	Trough
11/7/08	11/29/08	Trough
2/5/09	2/27/09	Trough
4/10/09	5/2/09	Trough

The project found that when alternative off-stream water was provided, the amount of time cattle spent in the creek was reduced 43% from 3.0 to 1.7 minutes/animal unit/day. As a result of this, direct deposition of *E. coli* into Clear Fork of Plum Creek was estimated to be reduced from 1.11E+07 to 6.34E+06 cfu/animal unit/day (Appendix E and Appendix G).

Subtask 5.5: Assess water quality before and after implementation of BMPs

Alternative Off-Stream Water

To assess the effects of providing off-stream water, a total of 84 samples were collected from the two water quality stations (PC1 and PC2), of which 48 were collected during the pre-treatment period (July 2007 to July 2008) and 36 were collected during the post-treatment period (July 2008 to July 2009) and analyzed for *E. coli* concentration (Appendix G). Fewer samples were collected during the post-treatment period as a result of no flow being present in the creek during six of the sampling events.

Observed pre- and post-treatment *E. coli* loads suggested a 57% reduction; however, this project could not conclusively attribute the observed *E. coli* loading reductions to providing alternative water because of the lack of statistical significance of these observations, the decrease in flow observed during the post-treatment period, and the observed increase in *E. coli* levels during the post-treatment period (Appendix E). A drought during the post-treatment period, which reduced flows by 79% and influenced ranch management decisions to increase stocking rate 34%, explain much, but not all, of the increase in *E. coli* levels observed. Other probable factors affecting the observed *E. coli* levels include natural variability, changes in fate and transport due to the drought, and potentially increased contributions from wildlife.

Although this project did not provide conclusive evidence of reduced *E. coli* levels resulting from providing alternative off-stream water supplies, this practice is still highly recommended as a result of the significant reductions observed in the time cattle spent in and near the stream, the 51% reduction in fecal coliform documented by Sheffield et al. (1997), and the 85 to 95% decrease in median baseflow *E. coli* load found by Byers et al. (2005). These reductions are comparable to those provided by fencing of streams that reduces *E. coli* 37-46% (Meals 2004; Meals 2001) and fecal coliform 30-94% (Hagedorn et al. 1999; Line 2002; Lombardo et al. 2000; Line 2003; Meals 2001; Meals 2004; Brenner 1996; Brenner et al. 1994; and Cook 1998). Further, this project supports McIver (2004) which noted that alternative water supplies alone will not achieve water quality improvements unless it is implemented in conjunction with good grazing management (i.e. balance stocking rate with available forage, evenly distribute grazing, avoid grazing during vulnerable periods, and provide ample rest after grazing). Because of the severe drought, these principles were not adhered and water quality improvements were not observed. Results will be submitted to a peer reviewed scientific journal for publication and reference provided on the LSHS website.

Grazing Management

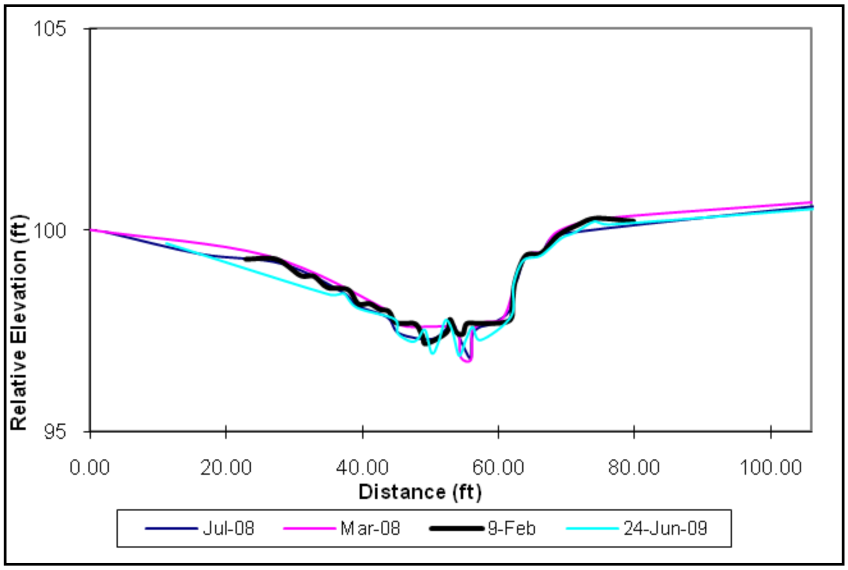
The effect of grazing management was evaluated to assess its effectiveness as a best management practice. *E. coli* levels in runoff from grazed and ungrazed rangeland, improved pasture, and native prairie sites were monitored from November 2007 through October 2010. Results indicate that rotational grazing, if timed appropriately, is a very effective practice for reducing *E. coli* runoff (Appendix F and Appendix G). The impact of grazing timing in relation to runoff event was much more significant than the impact of level of grazing (i.e. moderately stocked or heavy stocked) or stocking rate. When runoff occurred more than two weeks following grazing, *E. coli* levels in runoff were decreased more than 88%. As a result of these findings, it is recommended that creek pastures and other hydrologically connected pastures be grazed during periods when runoff is less likely (e.g. summer and winter in much of Texas) and upland sites be grazed during rainy seasons when runoff is more likely to occur. Results will be submitted to a peer reviewed scientific journal for publication and reference provided on the LSHS website.

Subtask 5.6: Further evaluation of impacts of BMP implementation

Evaluation of impact of alternative water on stream bank stability

To evaluate changes in bank stability, stream cross-sections were surveyed in March and July 2008, and February and June 2009 at the 2S Ranch (Figure 2). No significant bank erosion or changes in bank stability were observed throughout the project.

Figure 2. Stream cross sections conducted in 2008 and 2009 on Clear Fork of Plum Creek.



Evaluation of Bacteroides qPCR as a method for assessing E. coli contributions from cattle

Finally, the suitability of *Bacteroides* qPCR assays was evaluated for assessing total bacterial runoff and the proportion contributed by cattle. This work is needed to develop a quantitative method for assessing contributions from each of the predominant sources of bacteria. Current methods are based on animal numbers, presence of wastewater discharges, or BST, which provides either presence/absence of source markers or semi-quantitative assessment of source markers. Layton et al. (2006) at the University of Tennessee developed a qPCR assay to determine total *Bacteroides* present in water (AllBac) and the bovine-associated *Bacteroides* (BoBac).

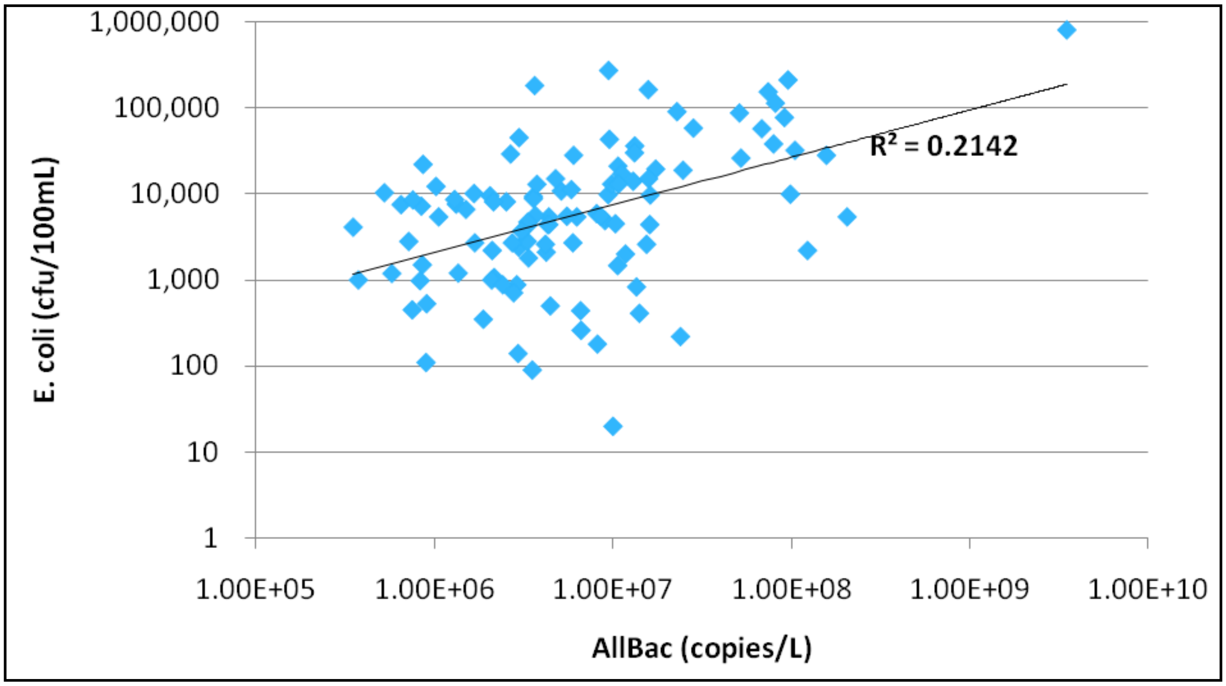
Bacteroides are a genus of bacteria found in the gastrointestinal (GI) tract of warm-blooded animals. They are not pathogens and are more abundant in feces than *E. coli. Bacteroides* do not survive long in the environment, as they are strict anaerobes. As such, they are a promising indicator of fecal contamination. Further, they appear to be host specific, and markers for humans, ruminants, horses, swine and other species have been developed.

Layton et al. (2006) tested this method on seven creek samples in three watersheds with mixed landuse. Layton reported that AllBac was correlated with *E. coli* (r^2=0.74). The project did not assess the correlation of BoBac to cattle numbers. However, Layton concluded that the AllBac assay allowed estimation of total fecal contamination in water and the BoBac assay allowed estimation of the amount and percent of bovine-associated fecal contamination in water.

The project's objective was to take this new method and test and evaluate it for use in Texas. The runoff samples from seven grazing management sites (three sites located at the Beef Cattle Systems Center and the four previously discussed sites at Riesel and Welder Wildlife Refuge) were used. These sites all had uniform landuse and good records on cattle numbers and management. Both AllBac and BoBac copy numbers and fecal concentration in 108 water samples were analyzed.

When the AllBac copy numbers were compared to *E. coli* concentration, there was a significant relationship ($p<0.001$) however, not a strong one (Figure 3). The relationship exhibited a low coefficient of determination (r2=0.21) and significant variability. Establishment of a significant correlation of AllBac to *E. coli* is very important as regulations and water quality standards are based on *E. coli* and thus to relate results, *Bacteroides* must also correspond to *E. coli*.

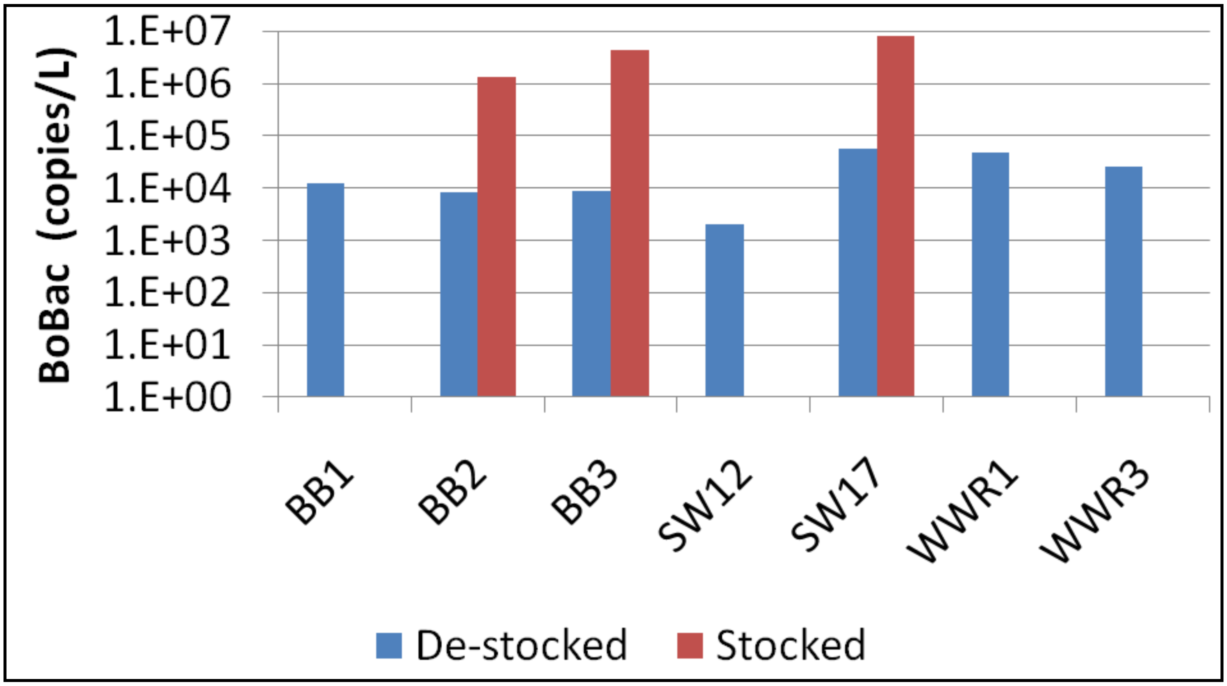
Figure 3. Relationship of *E. coli* to AllBac (copies/L).



This observation led to further evaluation of Layton's data and the discovery that the relationship reported by Layton et al. (2006) was in fact driven by one sample and as such not a legitimate comparison. Upon removal of the one sample observed to be driving the reported regression, the coefficient of determination for Layton's published data was decreased to 0.10. Additional work is planned to further evaluate this method in hopes of improving its capability for predicting *E. coli* levels in runoff.

In contrast to AllBac, the bovine marker, BoBac, performed well, providing a good indicator of cattle presence. As Figure shows, BoBac copies were generally around 1.0E+06 copies/L when the sites were stocked and approximately 1.0E+04 copies/L when the sites were destocked**.** In fact, the marker was sensitive enough to detect an incident when the electric fence briefly went down at BB1 on 2/4/10. During this event, *E. coli* concentrations did not increase appreciably; however, BoBac copy numbers increased to 1.0E+06 copies/L indicating cattle presence (Appendix G). Additional work is planned to assess the percent of the total *Bacteroides* attributable to bovines, compare this to estimates based on *E. coli* runoff, and finally compare these results to cattle numbers and stocking rate to assess consistency. Upon completion of this work, it will be submitted to a peer reviewed scientific journal for publication and reference provided on the LSHS website.

Figure 4. Comparison of BoBac levels (copies/L) when sites were stocked and destocked.



Subtask 5.7: Provide funding to cooperators

Funding was provided to the 2S Ranch for grazing management on its creek pasture for two years. Four portable shade facilities were also installed on the 2S Ranch in June 2008 and removed in May 2009 following the final removal of the GPS collars. GPS collar data collected over this 2-year period indicated that the cattle at the 2S Ranch did not use the structures provided.

Conclusion

The goal of this project was to reduce the levels of bacterial contamination of Texas watersheds from beef cattle by evaluating and demonstrating the effectiveness of value-added BMPs in reducing bacterial contamination of streams and water bodies from grazing lands; developing, testing, and modifying as needed an educational program; and promoting statewide adoption of appropriate BMPs and other watershed / water quality protection activities through education, outreach, and technology transfer.

Literature regarding bacteria runoff and BMPs was compiled and made available online (http://lshs.tamu.edu). From the results of the literature review, two BMPs were selected for demonstration and evaluation, alternative water supplies and grazing management. The effect of providing alternative off-stream watering facilities to reduce manure and thus bacterial deposition in or near surface waters was evaluated from July 2007 to July 2009 in Clear Fork of Plum Creek in central Texas. The project found that when alternative off-stream water was provided, the amount of time cattle spent in the creek was reduced 43% from 3.0 to 1.7 minutes/animal unit/day. Observed pre- and post-treatment *E. coli* loads suggested similar reductions (57%); however, this project could not conclusively attribute the observed *E. coli* loading reductions to providing alternative water because of the lack of statistical significance of these observations, the decrease in flow observed during the post-treatment period, and the observed increase in *E. coli* levels during the post-treatment period. A drought during the post-treatment period that reduced flows by 79% and influenced ranch management decisions to increase stocking rate 34% explain much, but not all, of the increase in *E. coli* levels observed. Other probable factors impacting the observed *E. coli* levels include natural variability, changes in fate and transport due to the drought, and potentially increased contributions from wildlife.

E. coli levels in runoff from grazed and ungrazed rangeland, improved pasture and native prairie sites were also monitored from November 2007 through October 2010. The project found that rotational grazing, if timed appropriately, was a very effective practice for reducing *E. coli* runoff. The impact of grazing timing in relation to runoff events was much more significant than the impact of level of grazing (i.e. moderately stocked or heavy stocked) or stocking rate. When runoff occurred more than two weeks following grazing, *E. coli* levels in runoff decreased more than 88%. As a result of these findings, it is recommended that creek pastures and other hydrologically connected areas be grazed during periods when runoff is less likely (e.g. summer and winter in much of Texas) and upland sites be grazed during rainy seasons when runoff is more likely to occur. Background levels were considerable and relatively consistent among sites, with median levels typically ranging from 3,700 to 5,500 cfu/100 mL. These levels should be considered when applying water quality models to develop TMDLs and other efforts. Finally, it was observed that over 80% of the samples exceeded Texas Water Quality Standards for *E. coli*. In light of this and other findings of this project, it is recommended that exemptions from the current standards be made for storm flows and wildlife, or additional research be conducted to accurately define bacterial quality for runoff and establish practical water quality standards.

Based on the review of existing programs and compiled literature on bacterial runoff and BMPs; input from the TSSWCB, LSHS Steering Committee, and internal AgriLife Extension Planning Team; and results from the field demonstrations, the LSHS education program for beef cattle producers was developed. The LSHS program consists of a PowerPoint presentation and an accompanying Beef Cattle Resource Manual. Portions of this program were delivered to audiences at over 40 events throughout the state, reaching well over 2,200 participants. In addition, unique visitors to the “Improving Water Quality of Grazing Lands” website exceeded 1,100. This highly beneficial program will continue to be carried out throughout the state in coordination with the TSSWCB and other project partners.

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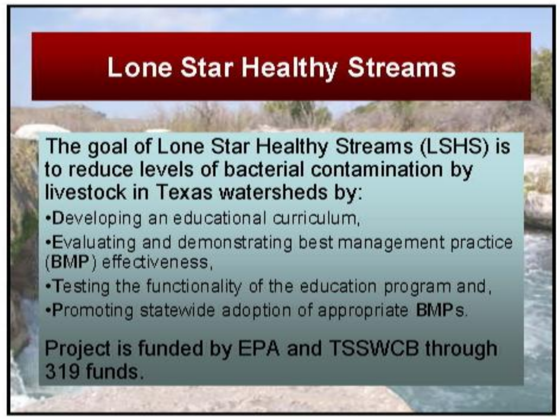
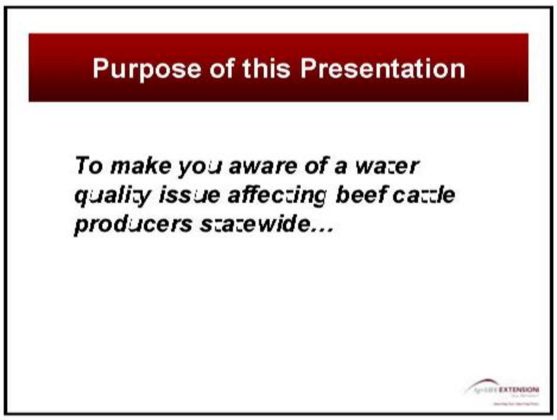
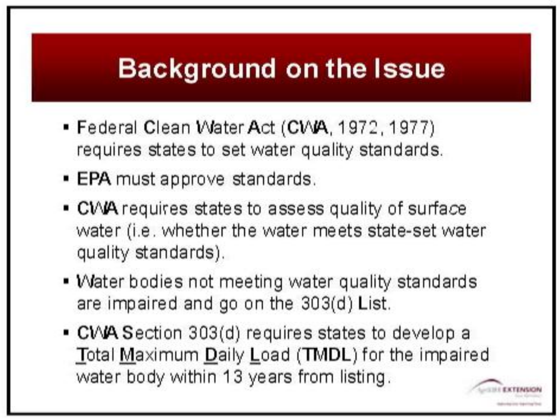
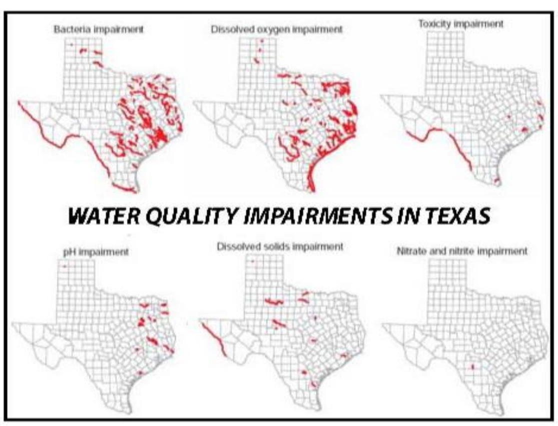
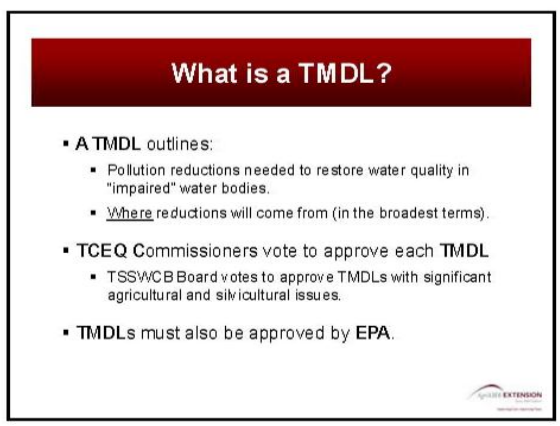
Appendix A Lone Star Healthy Streams PowerPoint

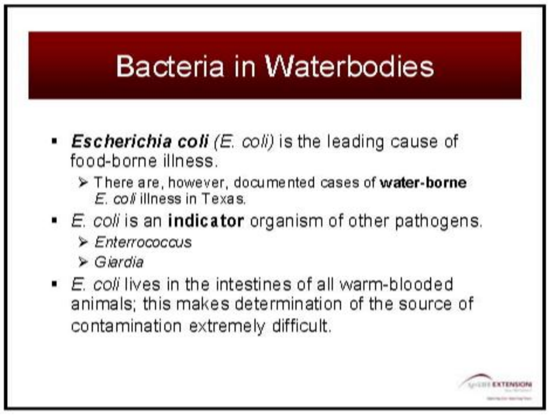




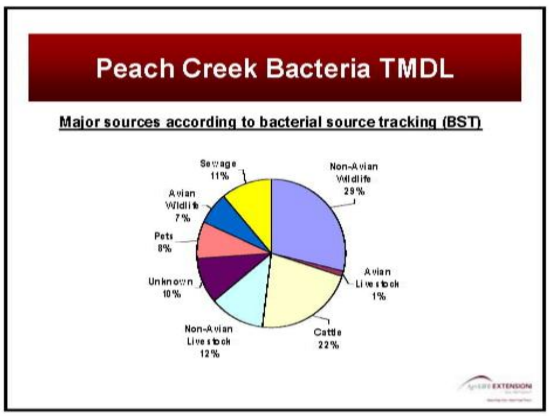


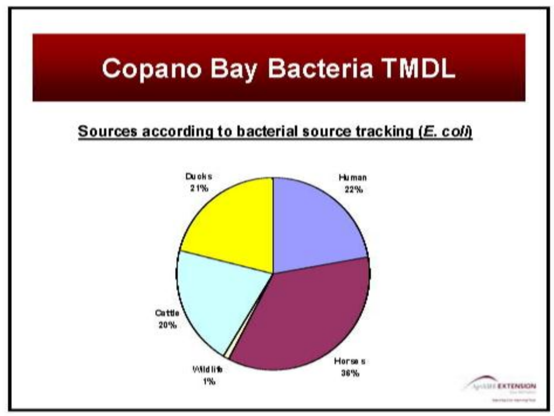


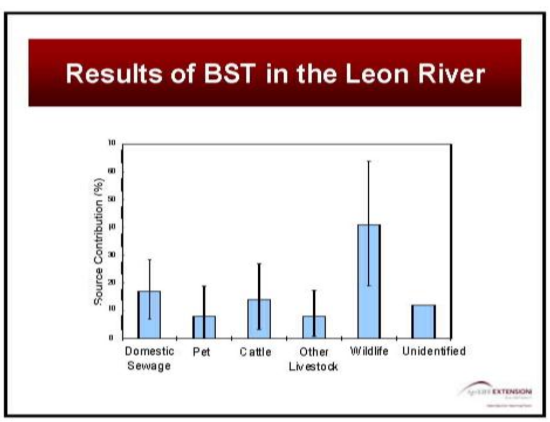


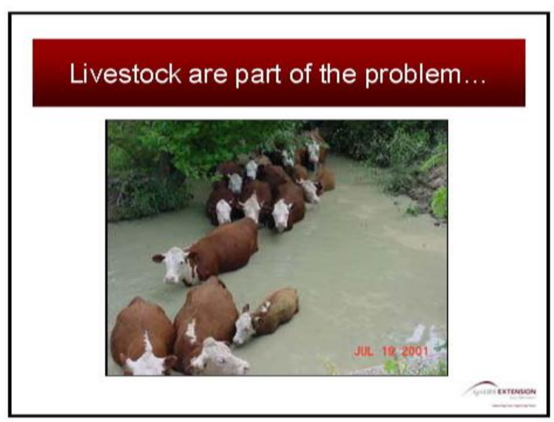

Bacteria in Waterbodies
▪ Escherichia coli (E. coli) is the leading cause of food-borne illness.
➢ There are, however, documented cases of water-borne E. coli illness in Texas.
▪ E. coli is an indicator organism of other pathogens.
➢ Enterrococcus
➢ Giardia
▪ E. coli lives in the intestines of all warm-blooded animals; this makes determination of the source of contamination extremely difficult.
EXTENSION


Bacteria: #1 Water Contaminant in Texas
Sources of Bacteria
EXTENSION


Peach Creek Bacteria TMDL
Major sources according to bacterial source tracking (BST)
Sewage 11%
Non-Avian Wildlife 29%
Avian Wildlife 7%
Pets 8%
Unknown 10%
Avian Livestock 1%
Non-Avian Livestock 12%
Cattle 22%
EXTENSION


Copano Bay Bacteria TMDL
Sources according to bacterial source tracking (E. coli)
Ducks 21%
Human 22%
Cattle 20%
Wildlife 1%
Horses 36%
EXTENSION


Results of BST in the Leon River
Source Contribution (%)
Domestic Sewage
Pet
Cattle
Other Livestock
Wildlife
Unidentified
EXTENSION


Livestock are part of the problem…
JUL 19 2001
EXTENSION

LSHS: BMPs to Reduce Fecal Contamination by Grazing Cattle

Two Types of BMPs

Riparian Protection

- Designed to protect environmentally sensitive streamside areas.

Vegetation Management

- Maintenance of adequate ground cover.
  - Involves use of appropriate stocking rate.
    - Reduces overland water flow
    - Reduces bacteria and nutrient transport
    - Reduces sediment production (soil erosion)

Riparian Protection BMPs

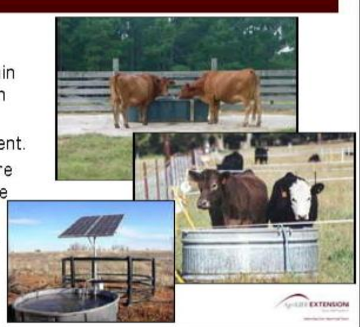
- No Exclusion – Full Access
  - Development of alternative water source
  - Shade
  - Mineral and/or salt locations
- Exclusion – Limited Access
  - Hardened single-point stream watering points
  - Hardened stream crossings
- Full Exclusion
  - Fence entire stream out
  - Use of rip-rap
  - Filter strips
  - Prescribed Grazing

No Exclusion, Full Access

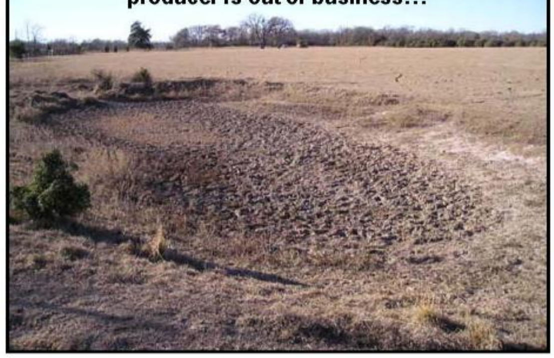
- With full access, cattle will destroy creek banks and defecate directly into streams.
- Careful management is required when full access is allowed.
- Consider rotational stocking with limited access to riparian pastures.

Alternative Water Source

- Encourages livestock to obtain water away from the stream.
- Easy to implement.
- NRCS cost-share programs reduce costs.
- Consider solar-powered wells.



Without an alternative water source, this producer is out of business…



Alternative Water Source

Fecal Coliform Reduction	Reference
57 – 95%	Byers et al. 2005
51 %	Sheffield 1997
Peduced time in riparian area 48 – 53%	Wagner et al. 2009 (unpublished Texas data)

Shade Structures

- Can be permanent or portable…
- May improve nutrient distribution & recycling in the pasture.
- Improves weight gain of cows and calves.
  - Turner, L. W. 2000.

Shade Structures

- Coupled with alternative water & salt/mineral locations, encourages cattle to spend less time in riparian areas.
  - Schonenberg, 2006. Keeping Livestock Out of Streams in Georgia.
  - EPA, *Agricultural Management Practices for Water Quality Protection.*
- Moderate cost associated with building and maintaining.
- Easy to implement following construction.

Salt, Mineral, & Feeder Locations

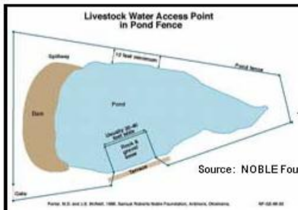
When used in conjunction with alternative water sources or shade, this BMP encourages cattle to spend less time in riparian areas.

- Inexpensive.
- Easy to implement.

Exclusion with Limited Access

In-Stream Watering Points

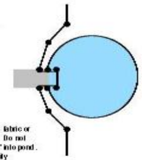
- Firm footing, single-point water locations along streams designed for 1 – 2 animals reduces time spent loafing in stream.
- Moderate cost associated with building & installation.
- Can be used for streams or ponds.



Good ideas, but possibly too wide a watering point…

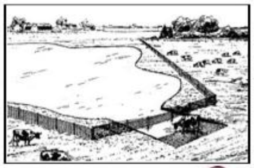
Source: NOBLE Foundation

Better idea...



Gravel alley with geotextile fabric or concrete. Alley width = ?'. Do not extend alley more than 25' into pond. Source: NC State University

Think about alternative water delivery from ponds…



Hardened Stream Crossings

- Establish hardened stream crossings using geotextile and gravel.
  - Reduces bacteria levels in streams.
  - Facilitates cattle movement.
  - Reduces loafing time in stream.
  - Reduces stream turbidity and sediment loading.
- Moderate cost associated with building and maintaining.

Geotextiles provide base support.

Panels are often used.

Fine layer of top gravel encourages cattle to readily travel across.

In some cases, a bridge over the creek may be preferred; here is a novel use of an old stock trailer.

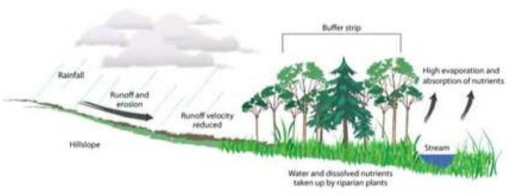
Full Exclusion

- Eliminates cattle access to streams.
- Permanent fences are expensive to construct & maintain.
  - Cost-share from NRCS.
- Not feasible to fence-off entire stream in many cases.
- Electric fencing may provide a lower-cost alternative.

Exclusionary Fencing

Fecal Coliform Reduction	Reference
30%	Brenner et al. 1994
41%	Brenner 1996
66%	Line 2003

Exclusion = Filter Strips



How a riparian buffer strip functions to protect the stream from contaminants.

Use of Filter Strips

Note denuded stream banks, sand depositions in creek, and algal bloom.

Note the effectiveness of a vegetative filter strip in trapping sediment that would have wound up in the creek or reservoir. Nutrients, pesticides and bacteria were also trapped.

Filter Strip Effectiveness in Reducing Fecal Coliform Levels

Figure 3. Effectiveness of filter strips in reducing fecal coliform levels under varying conditions

Fecal Coliform Reduction	Slope	Buffer Length	Runoff Source	Reference
94.8% – 99.9%	5% - 35%	.1 – 2.1m	Grazing cattle	Tate et al. 2006
43% - 74%	9%	9m	Poultry litter on no-till cropland	Coyne et al. 1995
64% - 87%	4%	9m	Manure	Fajardo et al. 2001
>99%	4%	1 - 25m	Manure on pastureland	Sullivan et al. 2007

Filter Strip Specifications

Minimum width for vegetative filter strips.
Source: Standards and Specifications No. 393, USDA-NRCS Field Office Technical Guide, 2009.

Slope	Minimum width of buffer strip
1-3%	25 ft
4-7%	35 ft
8-10%	50 ft

Use of Rip-Rap Instead of Fencing

- Cattle will not travel where there is >30% rock cover.
- Can we use rip-rap to modify cattle travel patterns?
- Depending on the amount used, there may be a reduced cost compared to fencing.
  - Reduced maintenance.

Summary of Riparian Protection

- Riparian areas are environmentally sensitive areas that deserve protection.
- Full exclusion offers the highest level of riparian protection.
- Where full exclusion is not practical, alternative BMPs provide enhanced protection of riparian areas.

Vegetation Management BMPs

- Vegetation Management BMPs are designed to:
  - Reduce soil erosion.
  - Improve forage production.
  - Enhance water conservation.
- Vegetation Management BMPs also:
  - Improve animal performance.
  - Enhance long-term sustainability of beef cattle production systems.

Grazing Management

- Grazing Management
  - Maintaining adequate ground cover is essential for watershed protection and optimum beef cattle performance.
  - The correct stocking rate is *the* most critical component of grazing management.
  - Consider the total amount of grazeable acres...
  - Is drought management a part of the grazing management strategy?
  - What grazing system is appropriate?

- Additional *Grazing Management* module available through LSHS.

Sources of Cost-Share Funds

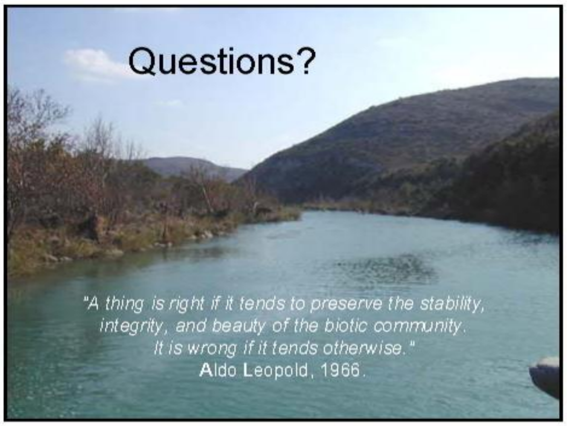
- Environmental Quality Incentive Program (EQIP):
  - Cost-share programs for cross-fencing, water development, erosion control, etc.
  - http://www.tx.nrcs.usda.gov/Programs/EQIP/index.html
  - Select EQIP 2010 Standard Rate (XLS; 82 KB)
- Section 319(h):
  - Clean Water Act money from EPA passed through to TSSWCB.
- Water Quality Management Plans (WQMPs):
  - Affords producer protection from regulation.

Conclusion

- Bacteria in Texas waterways is a concern for everyone.
- BMPs can reduce bacterial contamination.
- Where full exclusion is not practical, alternative BMPs provide enhanced protection of riparian areas.
  - Alternative water sources
  - Shade
  - Hardened crossings
  - In-stream watering points
  - Others
- Full exclusion offers the highest level of protection for Texas waterways.
  - Exclusionary fencing

For More Information Contact:

- Texas State Soil & Water Conservation Board.
- Your local NRCS office.
- Your local Soil & Water Conservation District office.
- Your local County Extension office.



Appendix B Lone Star Healthy Streams Beef Cattle Manual

AgriLIFE EXTENSION
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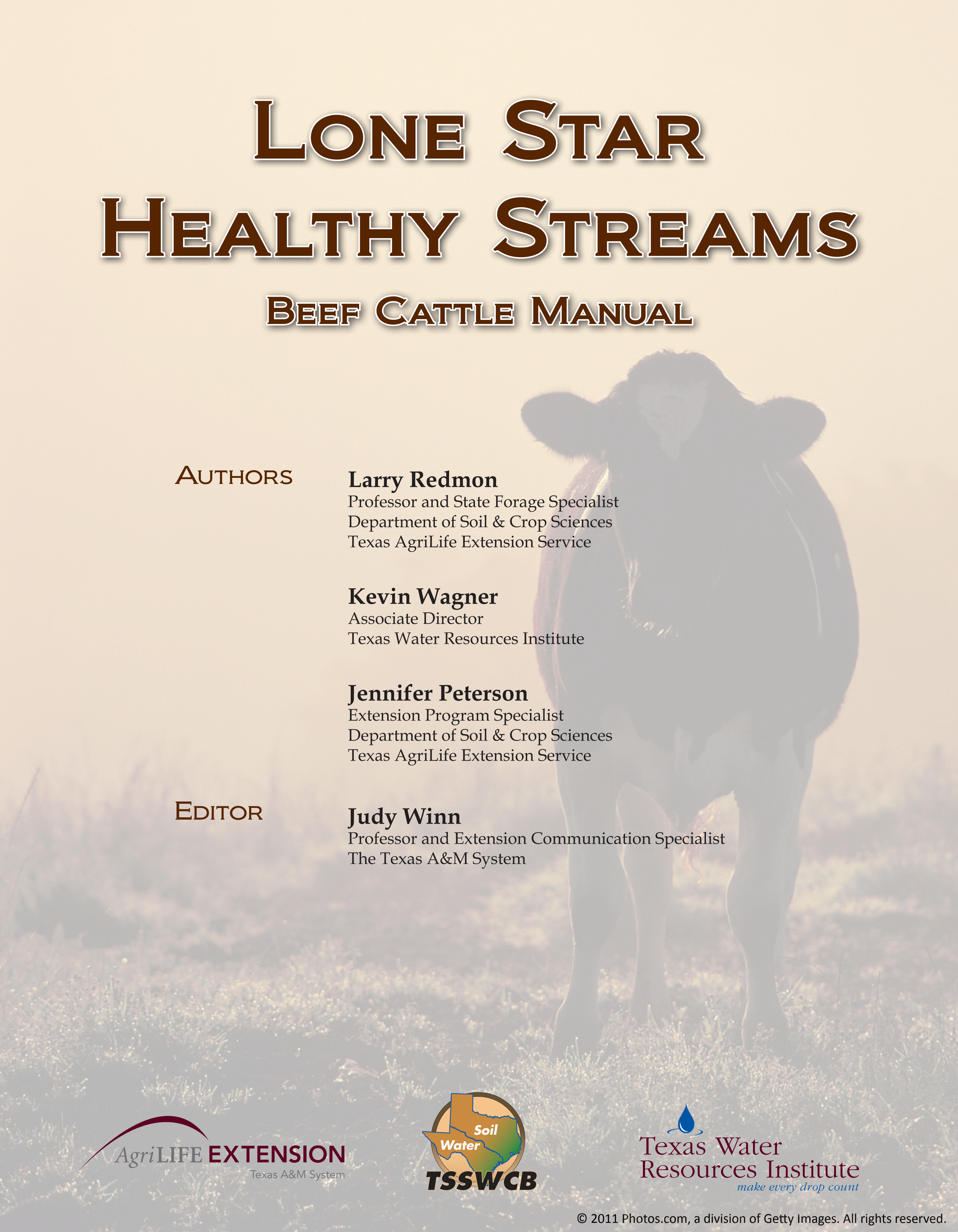
Lone Star Healthy Streams

Beef Cattle Manual

Keeping Texas Waters
Safe and Clean...

Cover picture courtesy of Matt Berg, Texas A&M University.



Lone Star Healthy Streams

Beef Cattle Manual

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Soil
Water
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Texas Water Resources Institute
make every drop count

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- Hall-Childress Soil and Water Conservation Districts

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Preface

The goal of the Lone Star Healthy Streams program is the protection of Texas waterways from bacterial contamination associated with the production of cattle that may pose a health risk to Texas citizens. To achieve this important goal, the program's objective is the education of Texas livestock producers about proper grazing management and riparian area protection to reduce the contribution of cattle bacterial contamination of streams and rivers.

As part of this educational program, current best management practices (BMPs) and novel BMPs are being evaluated to provide important information to livestock producers regarding BMP effectiveness relative to implementation costs and load reduction. Through enhanced education regarding riparian protection and vegetation management on grazing lands, Lone Star Healthy Streams will further protect Texas waterways from sediment, nutrient, and pesticide runoff with the concomitant loss of water and topsoil.

We wish to make clear from the outset that the BMPs noted in this manual are not mandatory at this time and participation in the Lone Star Healthy Streams program is voluntary. We trust livestock producers will find the following information helpful in their pursuit of being the best natural resource stewards they can be.

Chapter 1

Background on Water Quality in Texas

Water Quality Law and Policy

The Federal Water Pollution Control Act, commonly referred to as the Clean Water Act (CWA) was passed in 1972 and amended in 1977, and is the foundation for surface water quality protection in the United States. The CWA was enacted to restore and maintain the chemical, physical, and biological characteristics of the nation's waters. In brief, the CWA requires states to set standards for surface water quality and requires public and private facilities to acquire permits for discharging wastewater.

At the federal level, the U.S. Environmental Protection Agency (EPA) is responsible for administering the water quality standards outlined in the CWA. At the state level, the EPA delegates water quality management to the specific state environmental agency. In Texas, it is the Texas Commission on Environmental Quality (TCEQ). The TCEQ is the primary water quality agency in Texas and is responsible for establishing water quality standards, for planning how water quality will be managed, for issuing permits for point source dischargers, and for abating all types of nonpoint source pollution except those from agricultural and silvicultural (forestry) sources (Fig. 1). Nonpoint source pollution originates from multiple locations and is carried primarily by precipitation runoff, while point source pollution can be traced to a specific location and point of discharge (i.e., pipe or ditch).

In 1991, the Texas Legislature delegated some water quality authority to the Texas State Soil and Water Conservation Board (TSSWCB). The TSSWCB is responsible for administering Texas' soil and water conservation law and for managing programs for the prevention and abatement of agricultural and silvicultural nonpoint source pollution.

In compliance with Section 303(d) of the CWA, the TCEQ must report to the EPA the extent to which each surface waterbody is meeting water quality standards. The report must be submitted every 2 years and is comprised of two different parts: 1) Texas Water Quality Inventory (TWQI); and 2) CWA 303(d) List. The TWQI describes the status of all surface water bodies in the state that were evaluated and monitored over the most recent 7-year period. The TWQI is the basis for the 303(d) List that identifies all impaired surface bodies of water that do not meet water quality standards. Water quality standards specify numeric levels of water quality criteria such as

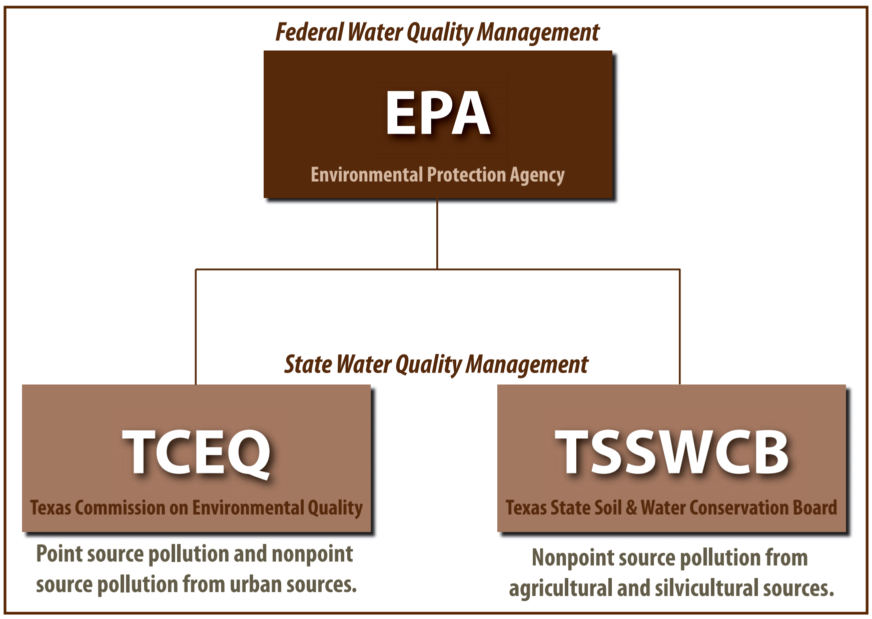

Figure 1. Hierarchy of federal and state agencies primarily involved in water quality management in Texas. Illustration courtesy of Jennifer Peterson.

bacteria, temperature, dissolved oxygen, pH, and others that can be measured in a lake, river, or stream without impairing the beneficial or designated use(s) assigned to that water body. Designated uses include contact and noncontact recreation, aquatic life, and public drinking water supply.

The CWA requires the development of a Total Maximum Daily Load (TMDL) for waters on the 303(d) List within 13 years of being listed. If the state does not develop a TMDL within the required time limit, the EPA will. A TMDL is a calculation of the pollutant reductions necessary to restore the impaired water body to its designated use(s). Both the TCEQ and TSSWCB are responsible for developing TMDLs in Texas. All TMDLs must be approved by TCEQ Commissioners before submission to EPA. TMDLs involving agricultural or silvicultural issues must be approved by the TSSWCB before submission to EPA.

According to the 2008 Texas Water Quality Inventory and 303(d) List, 386 waterbodies were impaired in Texas. Of these, approximately half of the impairments are due to excessive bacteria. As of fall 2009, there have been 110 TMDLs for 69 waterbodies developed in Texas.

Once a TMDL is complete, TCEQ or TSSWCB develops a TMDL Implementation Plan (I-Plan). The TMDL I-Plan provides a detailed description of the a) regulatory measures, b) voluntary management measures, and c) parties responsible for carrying out identified measures needed to restore the waterbody quality in accordance with the TMDL. Regulatory measures are typically only applicable to point sources such as Concentrated Animal Feeding Operations (CAFO) or wastewater discharges; however, regulatory nonpoint source measures are in place in some watersheds across the nation. Unlike the actual TMDL, the I-Plan only requires approval from the TCEQ Commissioners or the TSSWCB, but not EPA approval.

In some watersheds, the development and implementation of a Watershed Protection Plan (WPP) may be a more viable approach to achieving restoration of water quality than through the establishment of a TMDL. A WPP is a community-driven framework that uses the watershed approach to solve complex water quality problems in a watershed. WPPs are developed and managed through partnerships among federal and state agencies and local groups and organizations. They rely heavily on stakeholder involvement at the local level. The EPA created a guide to assist communities, watershed organizations, and local, state, and federal agencies develop and implement WPPs. The "Handbook for Developing Watershed Plans to Restore and Protect Our Waters" outlines 9 key elements that each WPP should contain:

- Causes and sources of the water quality problem.
- Load reductions needed to restore water quality.
- Management measures needed to achieve the load reductions.
- Technical and financial assistance needed to implement the management measures.
- Information and education programs needed.
- Schedule for implementation.
- Implementation milestones.
- Criteria to determine success.
- Monitoring needed to determine effectiveness of implementation.

The main difference between a WPP and a TMDL is that TMDLs are regulatory

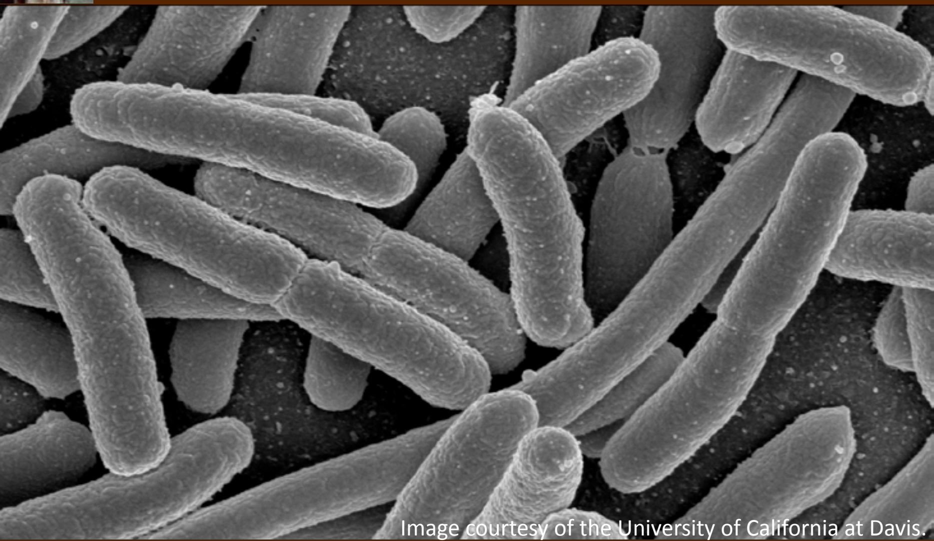
Image courtesy of the University of California at Davis.

Escherichia coli, commonly abbreviated as *E. coli*, is a rod-shaped bacterium found in the lower intestine of warm-blooded organisms. It was first discovered in 1885 by German pediatrician and bacteriologist, Theodor Escherich.

Perhaps the most recognized strain is O157:H7 which can cause serious food poisoning in humans and is often the cause of product recalls. In 2006, more than 200 people became sick and 3 people died after consuming spinach contaminated with *E. coli.*

E. coli are important in water quality because they act as indicator organisms - their presence in water can indicate the potential prescence of other harmful pathogens that are capable of causing disease in humans.

in nature, meaning they are required by federal law. WPPs are voluntary programs and are not mandated by federal law. In general, WPPs are a way of restoring water quality, removing the body of water from the 303(d) List, and avoiding regulatory action in a watershed. In some cases, however, development of a TMDL is unavoidable especially if the impairment is seen as an emergency situation.

Bacteria Fate and Transport

Fecal bacteria are microscopic organisms found in the feces of humans and other warm-blooded animals. By themselves, they are usually not harmful, but they are important because they are indicator species and can suggest the presence of pathogenic organisms like bacteria, viruses, or parasites that can cause waterborne illnesses such as typhoid fever, dysentery, and cholera. In addition to the potential health risks, elevated bacteria levels can also cause unpleasant odors, cloudy water, and increased oxygen demand.

Total coliform, fecal coliform, fecal streptococci, enterococci, and *Escherichia coli* (*E. coli*) are the most common types of fecal bacteria that are measured to indicate the potential presence of harmful pathogens. The Environmental Protection Agency (EPA) recommends *E. coli* as the most reliable indicator of fecal bacteria contamination in freshwater and enterococci as the best indicator in saltwater.

Bacterial contamination of surface waters is a major problem – it is the leading cause of impairment not only in Texas, but nationwide. Potential sources of bacteria in water are numerous and can include wildlife, livestock, septic systems, and even the family pet.

The behavior of bacteria in water is not well understood simply due to the many confounding factors that exist in the natural environment and the complexity of the organism itself. Rainfall is strongly correlated to bacteria conditions making the comparison between wet and dry weather bacteria data quite difficult. As a result, accurately measuring the efficiency of Best Management Practices

(BMPs) that are implemented to reduce bacterial contributions to waterways can be challenging.

Fecal bacteria are subject to a number of fate and transport processes. Fate processes include die-off, which is dependent on temperature, pH, nutrients, toxins, salinity and sunlight intensity, death by predation, as well as growth (cell division) and recovery of non-culturable cells. Transport processes include advection and dispersion, as well as settling to and re-suspension from the sediment bed.

Computer models (Soil and Water Assessment Tool (SWAT), Hydrological Simulation Program-FORTRAN (HSPF)) can be used to simulate the fate and transport of bacteria at the watershed-scale, however, the predictive strength of these models is highly dependent on the accuracy of the data entered into the model.

A clear understanding of the fate and transport of bacteria is critical for understanding the potential impacts of the contaminant and for developing management strategies in a watershed. Research is ongoing at Texas A&M University and other locations to evaluate current and novel BMPs to provide important information to livestock producers and other stakeholders regarding BMP effectiveness relative to implementation costs and bacteria load reduction.

Sources of Bacteria in Texas Waterways

The current methodology for determining bacterial contamination of waterways involves testing for *E. coli*. While *E. coli* is the leading cause of food- borne illness, there have been a few documented cases of water-borne illnesses in Texas due to *E. coli*. *E. coli*, however, is typically used as an indicator organism of other pathogens that can cause water-borne illnesses such as *Enterococcus spp.* or *Giardia lamblia.*

Many sources of bacteria, including wastewater treatment plant discharge, ineffective septic systems, wildlife, feral animals (including hogs, dogs, and cats),

Figure 2. Bacteria in Texas waterways can come from a variety of sources including wastewater treatment facilities, wildlife, pets, and livestock. Illustration courtesy of Jennifer Peterson.

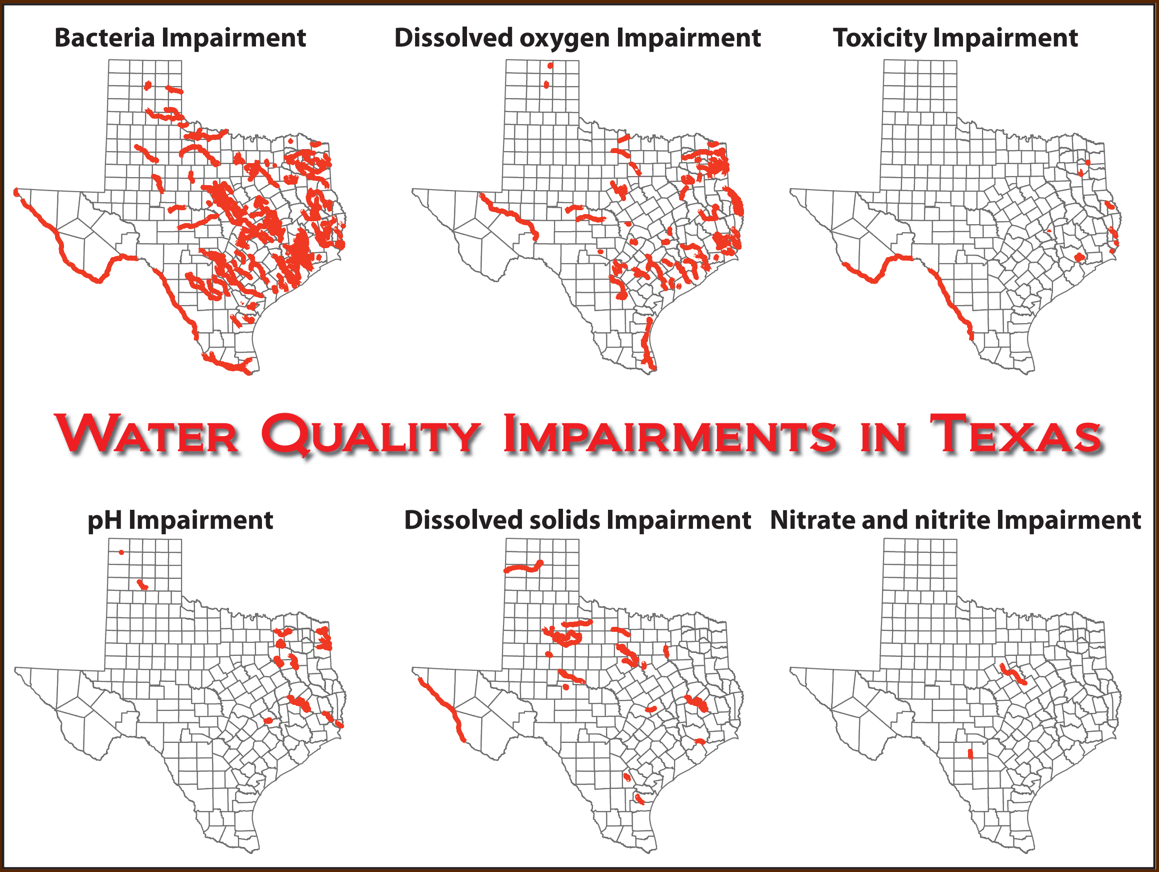

Figure 3. Waterbodies in Texas experiencing impairments for various reasons according to the TCEQ, 2008.

and grazing livestock can contaminate Texas waterways (Fig. 2).

Discharges from wastewater treatment plants, especially from plants that are not up to code or are functioning improperly, can discharge bacteria directly into streams and rivers. Leaky septic systems likewise may contribute to bacterial contamination of streams or rivers. Pet waste and runoff from neighborhood streets and parking lots can also pollute waterways with bacteria. Wildlife, including large flocks of birds resting on public waters, deer, and rodents are potential sources of bacterial contamination. Likewise, feral hogs can also cause an increase in bacteria levels in streams. Grazing livestock also contribute to the problem of bacteria in Texas waterways.

Bacterial Source Tracking (BST) is a method that can be used to determine the sources of fecal bacteria. The process is expensive and looks at the DNA structure to determine if the bacteria originated from human, agricultural, wildlife, pet waste, or avian sources. BST is still in its developmental stages, but can be a useful tool in watershed planning.

Recent BST analyses of bacteria found in Peach Creek, Copano Bay, and the Leon River in Texas indicate that, on average, cattle have accounted for approximately 19% of the bacteria contamination, wildlife have accounted for 26%, and humans (septic and pets) have accounted for 23%.Thus, while cattle are a contributing factor to bacterial contamination of Texas waterways, they apparently account for less contamination than wildlife and humans. Regardless of the source, excess bacteria levels account for more than 50% of the water quality impairments in Texas (Fig 3).

The Value of Clean Water to Texas Agriculture

Effective natural resource management and conservation, especially as it pertains to our precious water resources, can result in significant biological, social, and economic benefits. Roughly 200,000 miles of streams and rivers and nearly 1.7 million acres of reservoirs are found within Texas. These water bodies support an extensive array of agricultural and recreational enterprises for Texans as well as provide diverse habitats for a wide variety of plant and animal species. In order for these activities and associated benefits to be realized, however, the state's water bodies must be of sufficient quality to support agricultural production, recreation, aquatic life, drinking water supply, and other beneficial uses.

Clean water is vital to agricultural producers in Texas. Water used for irrigating crops and raising livestock helps farmers and ranchers produce and sell almost $200 billion of food and fiber each year (Fig. 4). Clean water can also result in healthier animals, improved reproduction, better gains, and increased recreational opportunities on the farm or ranch.

Figure 4. Clean water is vital to crops and livestock in Texas. Photo courtesy of Blair Fannin, Texas AgriLife Extension Service.

A bacterial impairment, or any water quality impairment for that matter, can severely reduce or even eliminate some of these valuable water-based activities and associated benefits. Degraded ecosystems, limited agricultural production, reduced recreational opportunities, increased government regulation, increased water treatment costs, and threats to human health are all costs of poor water quality.

Through a proactive approach, federal and state natural resource agencies continue to encourage the voluntary use of effective conservation practices that work to improve water quality. Farmers and ranchers can do their part to minimize the unintentional runoff of agricultural pollutants into waterways by implementing practices that better manage water use, chemical applications, and runoff. These practices can often result in tangible benefits, although improvements in water quality from farmers' efforts can often take years to detect. In one study, water quality benefits from erosion control on cropland totaled over $4 billion per year. In another study, erosion reduction measures on private lands in the United States resulted in increased water-based recreation valued around $373 million.

Clearly water is important to the state of Texas, however, it is a finite resource and can be significantly impacted by pollution originating from a variety of sources across the landscape. Not one person, industry, or activity is to blame, but the agricultural sector often gets singled out as a major contributor of pollutants to Texas's waterways. While this claim is thought to be unjust by many, the agricultural sector is in a position to regulate itself through stewardship and the use of conservation practices rather than have the process placed in the hands of those who may not understand the industry.

While the implementation of conservation practices is voluntary and may even require financial input on the side of the landowner, the benefits of having clean water resulting from these practices far outweigh the associated costs. The goal of the LSHS program is to provide agricultural producers and landowners information on these beneficial practices that can specifically help reduce bacterial contributions, so that the agricultural sector can do its part to help improve water quality.

Chapter 2

Best Management Practices: Beef Cattle

Photo courtesy of the Texas AgriLife Extension Service

Best Management Practices For Riparian Area Protection

Because *E. coli* lives in the intestines of all healthy mammals, including cattle, BMPs that act as proactive, preventive measures on cattle ranches are being recommended and are a significant part of the Lone Star Healthy Streams Program. The following discussion relates to current BMPs designed to reduce fecal contamination of Texas waterways.

Two primary categories of BMPs for livestock producers are riparian area protection and vegetation management. Riparian areas are environmentally sensitive areas along streams and rivers that require special protection from grazing livestock. Vegetation management, which applies to upland areas away from streams, is designed to reduce soil erosion, increase water capture on-site, reduce the amount of sediment production that makes its way into waterways and reservoirs, and reduce the amount of overland transport of bacteria, nutrients, and pesticides into sensitive riparian areas.

BMPs for riparian area protection are designed to reduce the time cattle spend in the area, using practices that range from strategies that may help modify animal behavior and reduce the time cattle spend in the area to total exclusion. BMPs related to vegetation management involve the use of appropriate grazing management, stocking rate, and practices that help protect riparian areas from inappropriate uses of fertilizer and pesticides in upland areas. The first section will discuss BMPs designed to protect riparian areas and reduce the likelihood of fecal contamination of waterways, while the second section will discuss BMPs associated with vegetation management.

Within these categories, beef cattle producers can use several BMPs to potentially reduce bacteria levels in waterbodies associated with grazing livestock. These BMPs include the use of:

1. *Alternative water sources* to reduce the time livestock spend drinking from streams.
2. *Salt and mineral locations* that encourage livestock to move away from riparian areas.
3. *Shade facilities* to encourage livestock to spend time loafing in areas away from the riparian area.
4. *Single-animal, hardened water points* in streams that do not facilitate loafing in the stream or riparian area.
5. *Rotational stocking systems* that reduce the time livestock spend in pastures with riparian areas.
6. *Appropriate stocking rates* that ensure an adequate amount of ground cover remains in pastures; thus, allowing pastures to trap bacteria and/or nutrients in the vegetation and reduce the level of potential pollutants that leave the field and enter the waterbody.
7. *Exclusionary fencing* of riparian areas. Producers should give special consideration to riparian area pastures used only during the year when impact to the riparian area and water quality could be minimized.

Using one or more of the suggested BMPs can measurably reduce the amount of bacteria in waterbodies associated with grazing livestock. Producers should realize that bacteria in waterbodies is a serious issue and brings with it the potential for regulation. Instances where bacteria-impaired waterways have led to regulations via TMDLs include the Vermillion River watershed in Illinois, the Fourth Creek watershed in North Carolina, the Chesapeake Bay watershed drainage counties in Delaware, and many others across the US. Therefore, any proactive measures beef cattle producers can take should be carefully considered to minimize the potential for regulation.

Exclusion of grazing livestock is the surest protection for riparian areas (Fig. 5). With full access, grazing cattle may spend a significant amount of time in the sensitive streamside areas because of shade and water availability. Many times, these areas are overgrazed, thus reducing the filtering ability of forage plants to reduce the amount of bacteria, sediment, nutrients, and pesticides that enter the waterway following precipitation events. Cattle trails can degrade stream banks, creating an unstable situation prone to increased erosion. One of the greatest sources of fecal bacteria entering waterways is through direct deposition of feces into the stream while cattle are drinking or loafing in the water. When cattle are totally excluded from the riparian area, bacteria levels in the waterway are reduced significantly.

Riparian Area Protection: No Exclusion With Full Access

In many beef cattle production systems, total exclusion of cattle from the riparian pastures is not desirable or feasible. As stated ealier, if these systems are not managed properly, water quality may be reduced through fecal deposition of bacteria and nutrients, sediment production, and destruction of vegetative filter strips, which are important in protecting waterways from runoff of bacteria, nutrients, pesticides, and sediment. Full access of grazing livestock to streams may also destroy stream banks (Fig. 6).

Figure 5. Cattle obtaining water directly from streams can lead to an increase in bacteria levels due to direct deposition. Photo courtesy of Doug Boyer, USDA.

If there is no exclusion from the riparian areas, managers must follow careful management steps to minimize the negative effects of cattle grazing riparian pastures. Rotational stocking should be considered an integral part of riparian area protection. Additionally, if other BMPs are implemented that effect cattle behavior such as those

Figure 6. Effects of uncontrolled access by cattle to stream and the resultant streambank destruction. Photo courtesy of Lynn Betts, USDA-NRCS.

listed above, negative impacts to the riparian area can be minimized. Below are suggested BMPs for riparian pastures that do not use exclusionary fencing.

Alternative Water Sources

When the riparian area is completely protected by exclusionary fencing, producers must develop an alternative water source. But even when cattle have full access to the waterway, an alternative water source is an effective tool for riparian area protection and improvement of water quality by dramatically changing the amount of time cattle spend loafing in a stream, thus helping to improve overall water quality, especially as related to bacteria.

Many producers consider the development of an alternative water source as nothing more than an expense. With cost-share programs from various state and federal agencies providing up to $13.74 per foot of well depth based on 2009 EQIP Standard Rate, however, alternative water sources can be developed at a significantly lower cost than previously. During droughts when surface water sources are depleted, an alternative water source provides the water necessary for beef cattle producers to remain in business.

Alternative water sources take several forms and usually require drilling a water well. Where electricity is readily available, electric water pumps can provide a source of water that may be gravity-fed to satellite water locations, thus allowing one well of appropriate capacity, to provide water to several locations on the ranch. Where electricity is not available, as is generally the situation, there are other methods of providing power to pump water. One of the oldest alternative water sources is the windmill (Fig. 7) and many are currently still in use using wind power to pump water from groundwater aquifers to the soil surface. Like the electric water pump, water can be gravity-fed from a central holding location to provide water to several additional sites. Some beef cattle producers today, however, are using solar-powered pumps (Fig. 8) to replace traditional windmills in remote locations where electricity is not available or is not the desired source of power. Again, one well location, if situated appropriately on a high point on the ranch, may be used to gravity-feed several other satellite water locations. Solar pumps are a little less expensive.

Figures 7 and 8. One of the oldest alternative water sources, the windmill, is still popular in many parts of Texas today. Solar-powered water wells are becoming an increasingly popular option for alternative water source development. Photos courtesy of Oklahoma Farm Bureau (left) and Cheney Lake Watershed, Inc. (right).

NRCS Standard Cost Rates show that solar pumps range in cost from $4,000-$8,500 depending on well depth. Costs for windmills range from $5,700-12,500 depending on size.

Where situations do not warrant the complete exclusion of riparian pastures, alternative water sources have a significant effect on how much time cattle spend in the water loafing and therefore how much fecal material will be deposited into the waterway. Where alternative water sources have been established and cattle still had full access to riparian pastures, studies have indicated fecal coliform levels may be reduced anywhere from 51%– 85% (Table 1) compared to waterways in which there was no alternative water and cattle were forced to obtain water from streams.

Using the Clean Water Act §319(h) nonpoint source grant funds provided by EPA through the TSSWCB, Wagner (2009, unpublished data) used GPS collars to demonstrate that cattle spent from 48% – 53% less time in streams when provided an alternative water source. Wagner's data compare very well with an observed 51% reduction in cattle use of the stream area by Sheffield et al. (1997). Not only do cattle prefer to drink from water troughs compared with streams, water quality from alternative water sources may generally be of higher quality and contain less sediment and fecal coliform. Studies have found that when presented with alternative water sources, cattle spend much more time drinking from troughs than they do from streams and calves gained 9% more weight from cows drinking clean water compared with pond water (Willms et al., 2002). Therefore, clean water from alternative water sources not only helps protect riparian area waterways, but also may improve animal performance. An alternative water supply alone, however, will not achieve targeted

Table 1. Fecal coliform reductions in streams where alternative water sources were available.	
Fecal Coliform Reduction	**Reference**
85%	Byers et al., 2005
51%	Sheffield, 1997
Reduced time in riparian area by 48% - 53%	Wagner et al., 2009

improvements unless implemented in conjunction with good grazing management (McIver, 2004).

Shade Structures

When temperatures are high during the spring through fall months, grazing livestock may benefit from shade and cooling, and some studies indicate an increase in animal performance due to shade in the grazing pastures (Paul and Turner, 2000). Beef cattle are sensitive to temperatures above 75°F and will seek relief from the sun's rays during the heat of the day. Natural shade is generally most abundant in riparian areas, which increases the opportunity for cattle to make direct fecal deposition into the waterways, thereby increasing the fecal coliform levels in the stream. Using constructed shade facilities is a valuable BMP that can help reduce the time cattle spend in the riparian area. The total shade requirement for grown beef cattle is approximately 30 - 40 square feet per head (Turner, 2000).

Producers may construct either permanent or temporary shade facilities. Construction materials can be either treated lumber or steel (Fig. 9). The roof of the shade structures may be constructed out of tin, but in many cases, 80% shade cloth is used. Shade cloth shade structures, while restricting most of the sun's rays and heat, also allow for heat dissipation through the weave of the cloth and are relatively inexpensive and easy to repair. Producers should remove the cloth and store it during winter to add to the useful life of the cloth.

The use of shade structures has been shown to reduce the amount of time cattle spend in riparian shade areas and is a recommended BMP in most states and by the EPA. Byers et al. (2005) suggested

Figure 9. Shade structures constructed with a tin roof (left) and a shade cloth (right). Photos courtesy of The Samuel Roberts Nobel Foundation, Inc. (left) and Dr. Larry Redmon, Texas AgriLife Extension Service (right).

the results of their study would indicate that potential BMPs to reduce phosphorus, sediment, and *E. coli* contamination from beef cattle–grazed pastures would be to build or encourage non-riparian shade and to provide cattle with alternative water sources away from the stream. The researchers further suggested that additional work on the use of non-riparian shade to improve water quality should be conducted. Remember, however, that shade does not always have to be a constructed unit. Natural shade (Fig. 10) may be abundant in pastures and used to draw cattle out of the riparian area. Consideration should be given to natural shade especially when clearing and establishing new grazing pastures. While maximizing stocking rate in newly established pastures is a consideration, several shade trees should be left in the pasture as a BMP that will have zero establishment cost.

Figure 10. Cattle resting beneath a natural shade facility...a mesquite tree. Photo courtesy of Hank Prinsen.

Above-Water Cattle Crossings

Producers may also use above-water crossings in some instances depending on whether or not the site is subject to an increased likelihood of flooding that may preclude the use of the hardened stream crossings. For example, Figure 11 indicates an above-water cattle crossing with little negative effects to the adjacent stream banks, indicating cattle are moving over the bridge and not travelling up and down the fragile stream banks.

Figure 11. Above-water cattle crossing structure. Note the unaffected adjacent streambanks. Photo courtesy of Garnet Baker.

Salt, Mineral, and Feeder Locations

Grazing BMPs from Florida (Florida Cattlemen's Association, 1999) to Washington (Adams, 1994) and most states in between recommend locating salt, mineral, and/or feeders in areas away from riparian areas to help minimize the time cattle spend in the sensitive areas and thus reduce the



Figure 12. Examples of feeders that may be used to help draw cattle away from unprotected riparian areas. Photos courtesy of Behlen Country (left) and Socha Farms (right).

negative effects of uncontrolled access by cattle to these sensitive areas (Fig. 12). Using alternative water sources, shade, and feeder locations are important management strategies of a planned grazing system that can provide better grazing distribution and encourage cattle to use upland pastures as much as possible. Additionally, strategic placement of salt, mineral, and feeder locations can be an important management tool for reducing bacterial contamination of sensitive waterways.

Riparian Area Protection: Exclusion With Limited Access

In-Stream Watering Points

In many instances, full exclusion of cattle from the riparian area may not be a practical option, and some limited access by cattle may be warranted. Such instances include cattle needing access to pastures on both sides of a stream or no other sources of water are available. In these situations, providing limited access to the riparian area and stream while excluding access to a majority of the riparian area may be a feasible alternative. One BMP providing riparian protection with limited access includes fencing the riparian area and providing limited access to water whereby cattle are provided small, in-stream watering points. This technique (Fig. 13) still allows cattle to water in the stream, but the design is such that cattle do not spend as much time loafing in the stream, thus reducing the amount of fecal material deposited into the waterway. The


Figure 13. Example of an instream watering point installed to prevent cattle from disturbing the adjacent riparian area. Photo courtesy of Jeff Vanuga, USDA-NRCS.

design should not be so wide as to provide cattle too much room to spend time loafing in the stream area. Observations of cattle watering at in-stream water points indicate that more confined areas encourage cattle to simply water and move on. Depending on the size of the cattle herd, multiple in-stream water points may be required.

A hardened surface is typically extended to the stream at access points thus providing the additional benefits of protecting stream bottoms and reducing the amount of sediment that is routinely produced by cattle with full access to the stream. This in turn improves water quality, maintains aquatic habitats, and reduces reservoir filling due to sediment transport.

Hardened Stream Crossings

BMP providing riparian protection with limited access is the use of geotextile and gravel to provide hardened stream crossings. Once established in conjunction with exclusionary fencing (Fig. 14), hardened stream crossings are readily used by cattle and become preferred travel routes instead of typical cattle trails up and down stream banks. Hardened stream crossings facilitate cattle movement and reduce loafing time in the stream, thus reducing bacteria levels in the waterway. Additional benefits include a reduction in stream turbidity and sediment loading. Building and maintaining hardened stream crossings incurs moderate costs if the stream is small to moderate in size. Larger stream crossings may involve significant costs to construct.

Figure 14. Hardened crossing points constructed of geotextile fabric, concrete panels, and fine gravel to facilitate cattle movement across specific points in the stream. Photo courtesy of Chenago County Soil & Water Conservation District.

Riparian Area Protection: Full Exclusion

Exclusionary Fencing

The use of exclusionary fencing is the primary means of protecting riparian areas. Once fences are erected, and if properly maintained, protection of the riparian area is assured. Using exclusionary fencing eliminates the primary means of bacterial contamination, that is, direct deposition of feces into the water. Studies have indicated the use of exclusionary fencing provides

Table 2. Reductions in fecal coliform levels associated with exclusionary fencing.	
Fecal Coliform Reduction	**Reference**
30%	Brenner et al., 1994
41%	Brenner, 1996
66%	Line, 2003

reductions in fecal coliform levels of 30 – 66% (Table 2). Additional benefits include development and persistence of effective filter strips and enhanced wildlife habitat.

Exclusionary fencing, however, may not completely protect the riparian area if adequate vegetative filter strips are not maintained along the waterway. Riparian areas protected from overstocking and overgrazing develop effective vegetative filter strips that further protect stream integrity from runoff of bacteria, nutrients, pesticides, and sediment that may move from slopes following heavy precipitation events (Fig 15).

Depending on slope, filter strips should be a specific minimum width to provide adequate protection to waterways. Table 3 indicates NRCS specifications for minimum filter strip widths.

Table 4 indicates the effectiveness of filter strips in reducing fecal coliform levels depending on slope, buffer length, and source of fecal contamination. The data in Table 4 clearly indicate the importance of vegetative filter strips in protecting riparian areas; thus the need in most instances for the use of exclusionary fencing or other BMPs that provide protection for these environmentally sensitive areas.

There are, however, concerns with fencing depending on how long the stream segment is to be fenced out, and there are ongoing issues with fence maintenance in areas subject to periodic flooding. Many ranchers that use this practice opt to place

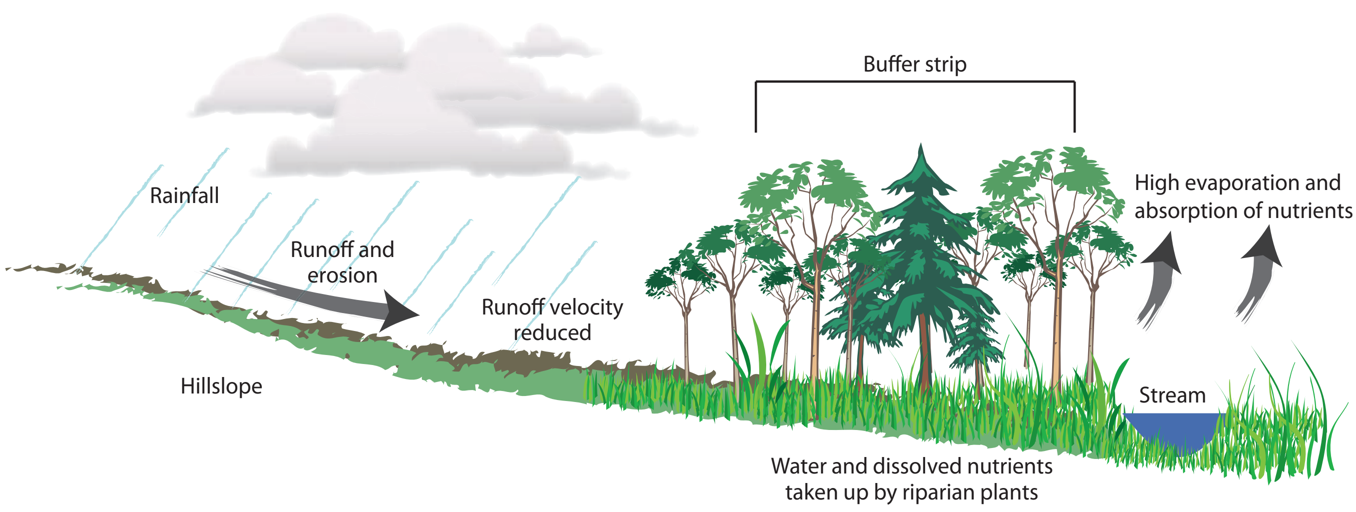

Figure 15. Conceptual model of how vegetated filter strips function to protect the stream from contaminants and the riparian area from erosion. Illustration courtesy of Jennifer Peterson.

Table 3. Minimum width for vegetative filter strips. Standards and Specifications No. 393, USDA-NRCS Field Office Technical Guide, 2004.

Slope	Minimum Width of Buffer Strip
1-3%	25 ft.
4-7%	35 ft.
8-10%	50 ft.

Table 4. Effectiveness of filter strips in reducing fecal coliform levels under varying conditions.

Fecal Coliform Reduction	Slope	Buffer Length	Runoff Source	Reference
95% > 99%	5% - 35%	0.1m - 2.1m	Grazing cattle	Tate et al., 2006
43% - 74%	9%	9m	Poultry litter on no-till cropland	Coyne et al., 1995
64% - 87%	4%	9m	Manure	Fajardo et al., 2001
> 99%	4%	1m - 25m	Manure on pastureland	Sullivan et al., 2007

their fences above the flood prone areas to reduce maintenance needs. The additional area could be used for hay production or periodic short-term mob grazing as needed, although grazing in the riparian filter strip should be carefully planned to minimize negative effects to the area.

Additionally, protected riparian areas generally develop into excellent wildlife habitat, which could provide enhanced opportunities for either consumptive or non-consumptive uses of specific wildlife species. Enhancing wildlife habitat, however, may come at a cost as wildlife species are concentrated in the riparian area with the potential of increasing bacteria contamination due to wildlife. Fencing costs ranges from $1.05 - $2.09 per linear foot according to NRCS 2009 standard cost rate.

Fortunately, NRCS and TSSWCB both have cost-share programs to assist with exclusionary fencing. Additional incentives that provide rental fees for the areas that are excluded (up to $259/acre) are also available through these programs to further encourage protection of riparian buffers.

Rip-Rap

Although not yet fully tested as an exclusionary device, large rocks (rip-rap) may also be used in limited areas to preclude cattle from using specific trails or stream crossings. Studies have indicated that cattle tend to avoid areas where large stone comprise 30% or more of the ground cover (Lyons et al., 2003). Understanding this particular aspect of cattle behavior, producers may have the option to use rip-rap in specific instances to alter cattle movement and afford some riparian protection. In fact, Ziehr (2005) suggested using large stones to reduce the time cattle spend loafing around watering areas and help strengthen these heavily used areas. Producers might use rip-rap to inhibit cattle movement into certain parts of riparian areas where stream banks are less stable and could provide a low-maintenance alternative to fencing in certain instances.

The use of rip-rap to alter cattle behavior for riparian area protection has not been well examined and needs further investigation.

Prescribed Grazing

The use of exclusionary fencing, however, does not preclude managers from using the pastures. In addition to being used for hay production, riparian area pastures may be some of the most productive fields on a ranch. These areas can be grazed provided appropriate grazing management maintains an adequate amount of ground cover so that the integrity of the vegetative filter strip is maintained.

Managers should consider riparian areas as "special use" pastures. With full exclusion, these pastures can be used as reserve or emergency pastures for use during the dormant season. Grazing can be helpful to the riparian plant community by removing standing dead grass, so that vigorous new grass production can occur. Managers should carefully monitor the riparian area and, when the forage has been reduced to a predetermined height, the cattle should be removed and rotated to a different pasture. A useful strategy that can help managers determine when it is time to remove the cattle from the riparian area is the use of "height stakes" that become visible when the forage is grazed to the proper height (Riparian Area Management Handbook, 1998). This would be the signal to rotate the livestock.

According to NRCS Field Office Technical Guide Practice #528A, appropriate grazing management (prescribed grazing) is the controlled harvest of vegetation by grazing animals and is used to maintain a stable and desired plant community, improve or maintain the health and vigor of selected plants, provide water quality benefits, and reduce soil erosion. NRCS further states that the duration, intensity, frequency, and season of grazing in or near surface waters should be managed:

- Based on plant health requirements and the expected productivity of key forage species to meet the management unit (pasture or paddock) objectives.
- To maintain enough vegetative cover to prevent accelerated soil erosion due to wind or water and to maintain soil moisture.
- To have positive impacts on vegetative and water quality.
- To enhance nutrient cycling through improved manure distribution and increased rate of decomposition.
- To ensure optimum water infiltration.
- To maintain or improve riparian and upland area vegetation.
- To protect stream banks from erosion.
- To manage for deposition of fecal material away from waterbodies.
- To promote ecological and economically stable plant communities throughout the management unit that meets landowner objectives.
- To have adequate upland grazing areas available to support riparian and wetland grazing sites.

Thus, while riparian areas should be protected to improve water quality, using appropriate grazing management BMPs allows for the use of the riparian pastures. Additional discussion of grazing management follows in a later section.

Summary of BMPs for Riparian Area Protection

While studies indicate that livestock can and do contribute to bacteria loading in waterbodies, beef cattle producers have many opportunities to be proactive in their approach to riparian area protection.

Management strategies have been identified that, in many instances, are low-cost to implement and maintain and provide increased protection of environmentally sensitive riparian areas.

BMPs for riparian area protection range from the total exclusion of cattle from sensitive areas using fencing to full access of riparian areas by cattle but with management practices in place to limit the time cattle spend in the riparian area by modifying cattle behavior. In-stream watering points and hardened stream crossings are effective management tools that can help limit the amount of time cattle spend loafing in the riparian area. A reduction in the time spent loafing thus reduces direct fecal deposition into waterways cattle. These strategies are beneficial when less than full exclusion practices are used.

In providing protection for riparian areas and their associated waterways, beef cattle producers also improve water quality and reduce the levels of bacteria, nutrients, and sediment that make their way into Texas waterways. Protection of riparian areas benefits all Texans.

Best Management Practices for Upland Vegetation Management

While abuses have occurred in the past that degraded forage and soil resources, current vegetation management BMPs seek to optimize livestock production in a manner that protects and/or enhances the environment in which the livestock are produced. The following discussion illustrates aspects of beef cattle production that should be addressed to reduce negative impacts to the environment. The discussion also describes various BMPs designed to help minimize those negative impacts. The overarching aspect of vegetation management is the amount of forage residue remaining in pastures. Maintaining an appropriate level of ground cover on grazing units is critical to optimize both animal production and plant persistence. The amount of ground cover remaining in a pasture directly affects animal performance, the level of soil erosion that may occur in the pasture, the quantity of water capture or loss from the site, and the amount of nutrients, sediment, and pesticides that may reach the waterway. Each of these topics will be addressed in the following section.

Soil Erosion Due to Water

Accelerated soil erosion begins with raindrop impact, but the effect is dramatically reduced by maintaining an appropriate level of ground cover. A raindrop falling on bare ground dislodges soil particles and destroys soil structure, and the splash can cause considerable soil movement (Brady, 1990; Branson et al., 1981). Soil particles are dislodged by raindrop impact, held in suspension, and removed from the site by overland flow (runoff). Dislodged particles also seal the soil surface by plugging micropores.

This sealing action reduces water infiltration rates and increases runoff. Raindrops striking ground cover, however, are intercepted by the plant canopy, which absorbs impact energy and protects the integrity of the soil surface. The energy of the runoff water is also diminished by ground cover, thus reducing erosion (Fig. 16). Precipitation intercepted by ground

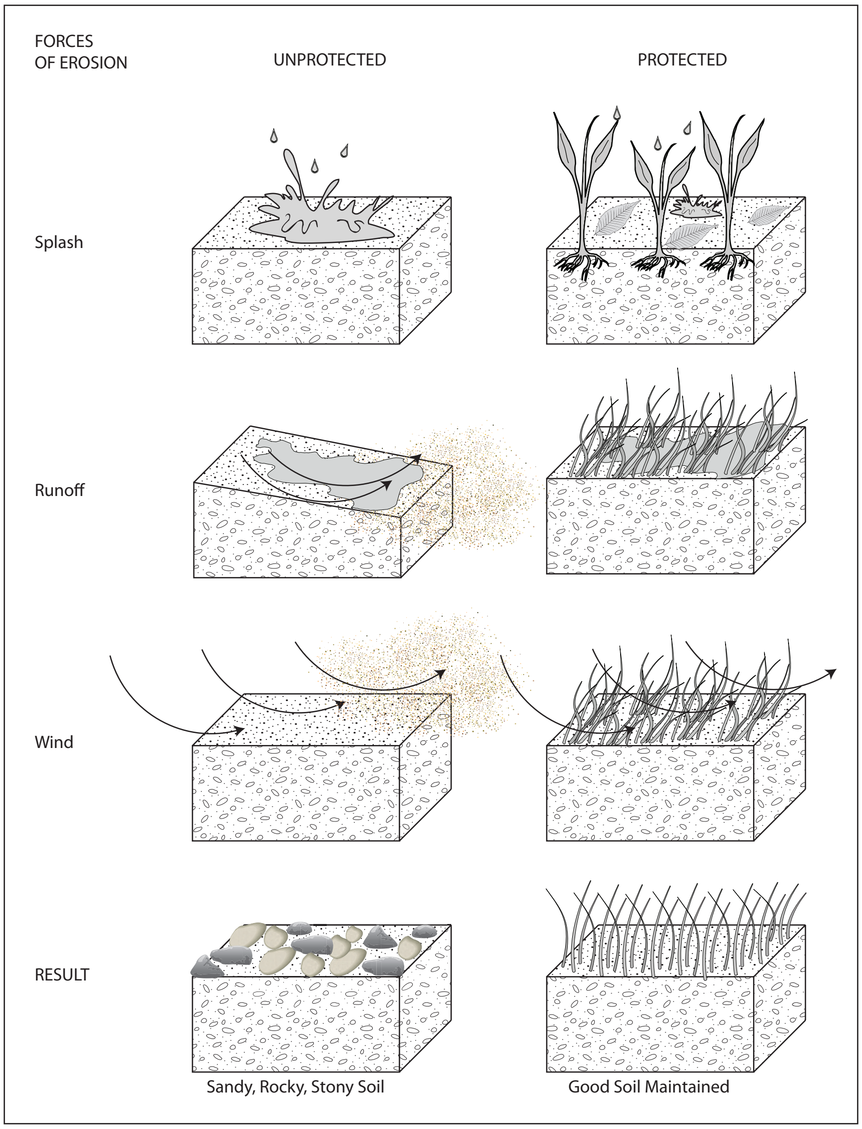

Figure 16. Vegetation effects on reducing soil erosion. Illustration courtesy of Jennifer Peterson (adapted from Nebel, 1981 as used by Holechek et al., 1998).

cover canopy is also subject to evaporation. This can be positive or negative depending on the moisture balance of the soil profile.

After a raindrop makes impact, it is subject to three fates: it can infiltrate, evaporate, or runoff (Holechek et al., 1998). Infiltration (movement into the soil) is primarily determined by soil texture. Fine-textured soils such as clays generally have low infiltration rates and slow percolation (movement through the soil) rates. Coarse-textured soils, such as sands, usually have high infiltration and percolation rates. Runoff occurs when precipitation rates exceed infiltration rates of the soil. Soil loss (erosion) then occurs due to detachment and transport of soil particles from the site (Fig. 17). Loss of soil particles can be uniform in nature (sheet or interrill erosion). Extreme interrill erosion is apparent when soil pedestals are created by erosion around an area covered by material resistant to raindrop impact, such as rock. The surrounded soil eroded without undercutting the soil under the resistant material illustrates the highly erosive nature of raindrop impact (Thurow, 1991). Further erosion results in creation of small, distinct flow paths that can be corrected with tillage (rill erosion). Erosion that continues unabated becomes severe enough that tillage cannot repair the damage to the site and vehicles cannot traverse the deepened channel (gully erosion). Stream bank erosion is defined as soil displaced from banks of rivers or streams. Besides loss of essential topsoil, erosion also causes valuable fertilizer nutrients such as nitrogen (N), phosphorus (P), and potassium (K) to be lost from the site with the potential for contamination of water sources.

Overstocked rangeland and introduced forage pastures reduce the quantity of

Figure 17. Typical erosion due to unprotected soil. Photo courtesy of Lynn Betts, USDA-NRCS.

grazing pressure of desirable plants decreases forage plant vigor and reduces plant persistence. Moderate use of forage plants usually does not reduce root production. Beyond about 50% use of the aboveground production, however, reduces root development (Fig. 18). Overuse decreases the amount of photosynthetic material remaining for the plant. Decreased photosynthesis has a negative feedback, reducing root development, which in turn reduces the amount of moisture and soil

ground cover. Reduced ground cover in turn increases overland water flow and sediment production. Along with sediment production, runoff associated with overstocked pastures moves more bacteria and pesticides into the adjacent waterways and thereby decreases water quality. Sediment production eventually reduces the capacity of surface water reservoirs. The use of proper stocking rates on rangeland and introduced-forage pastures maintains adequate permanent ground cover and reduces runoff and soil erosion potential, and thereby serves to maintain water quality and reservoir capacity.

Forage Production

Too heavy a stocking rate places excessive grazing pressure on forage resources. On either rangeland or introduced-forage pastures, heavy

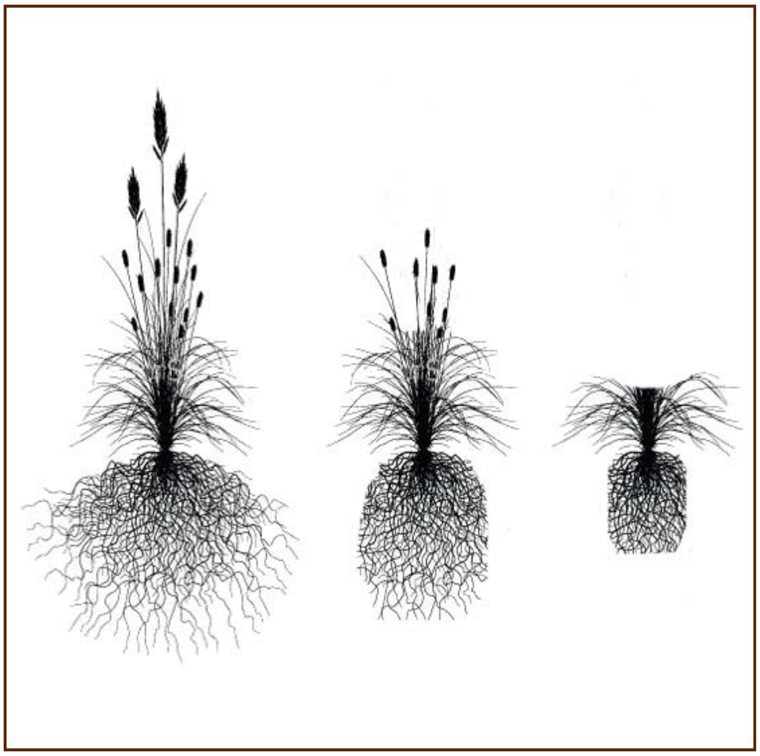

Figure 18. Effect of overuse of forage plants on root production. Illustration courtesy of Jennifer Peterson.

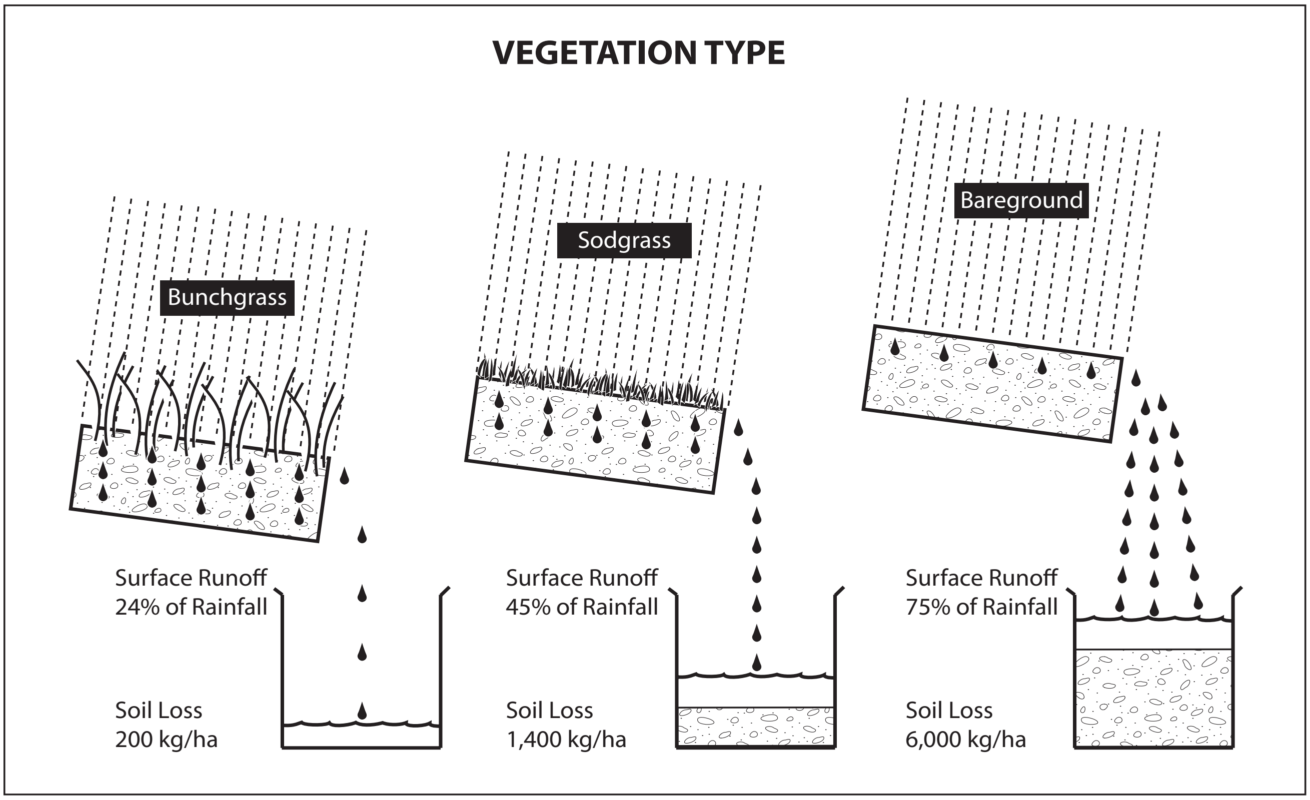

Figure 19. Influence of vegetation type on sediment loss, surface runoff, and rainfall infiltration from 10cm of rain in 30 minutes (adapted from Blackburn et al., 1996; by Knight, 1993; and as used by Holechek et al., 1998).

nutrients that may be taken up for plant production.

The long-term result of this situation is a reduction in plant vigor, plant frequency and abundance, and an increase in bare ground. Plant species composition shifts as an invasion of less desirable or undesirable species occurs. This species composition change is referred to as an overgrazed condition and leads to a degradation of range or introduced-forage pasture condition. Under these conditions, if the stocking rate is not reduced, carrying capacity is diminished, animal performance is decreased, and the potential for profit eliminated. Input costs (increased herbicide use, increased winter feeding costs) associated with the livestock production enterprise are increased, thus making a bad situation worse.

Water Conservation

Maintaining adequate perennial ground cover has a direct impact on how much precipitation is captured on-site versus how much is lost as runoff. Due to overstocking and overuse of more desirable forage species, earlier seral stage plant species increase in abundance and generally do not provide the type of ground cover required to reduce runoff rates and increase infiltration rates. On rangelands and introduced-forage pastures stocked at the appropriate rate, however, healthy stands of forage significantly reduce the velocity of overland flow of water during precipitation events allowing water to infiltrate the soil for use by plants or for recharge of groundwater aquifers. On overstocked sites, there is little forage to impede overland flow of precipitation. Subsequently, much of the precipitation is lost from the site, thus reducing forage production potential (Fig. 19). Overstocked pastures can also experience soil compaction of the more clayey soils. This compaction can lead to further reduction in infiltration rates and increases in overland flow.

Holechek et al. (1998) cite numerous studies indicating a reduction in infiltration rates associated with heavy stocking rates. Holechek et al. (1998) went on to summarize Gifford and Hawkins (1978) with the following statements:

1. Ungrazed plots have higher infiltration rates than those of grazed plots.
2. Moderate and light grazing intensities have similar infiltration rates.
3. Heavy grazing causes definite reductions in infiltration rates over moderate and light grazing intensities.

Beef Cattle Production Practices

Stocking Rate

The most critical aspect of livestock production related to water quality that is under direct control of the manager is stocking rate. Redmon and Bidwell (1997) have stated that no other single management practice has a greater effect on the sustainability of a livestock production enterprise. Stocking rate is defined as the relationship between the number of animals and the grazing management unit used over a specified time. Stated more simply, it is the number of acres required per animal unit for the grazing season that can be sustained on a long-term basis without forage, water, or soil resource degradation. A moderate stocking rate provides a good balance between plant and animal performance while maintaining adequate vegetative cover to protect soil and resources. Although moderate stocking rate will be different depending on-site and forage species, general guidelines can be obtained from Standard Soil Surveys produced by the NRCS. Other sources of information regarding appropriate stocking rates can be found in local extension or Soil and Water Conservation district offices or by interviewing successful producers who have a long history of production in the area.

Many pastures are overstocked, but producers do not realize that they are. One reason for overstocking is that producers are using larger cows than previous generations used. Forage intake is related to body size, and cows today are 50% larger or more than cows used two generations ago. Another reason many pastures are overstocked today is due to woody (brush) species encroachment. Woody species are continually invading and dominating previously productive pastures, thus reducing the carrying capacity of those pastures. Without brush removal, or livestock reduction, overstocking occurs. A lack of appropriate fertilizer and/or weed management inputs that reduce the amount of forage produced on the site also produces overstocked conditions.

Additionally, pastures become overstocked by basing stocking rate on total acres instead of *grazeable* acres. Factors such as brush density, rock cover, distance to water, and slope reduce the amount of property grazing animals are able to use and stocking rates should be adjusted accordingly. For all of the reasons cited above, stocking rates exceed the carrying capacity of the land in many instances, thus reducing the amount of ground cover and placing the pasture, production system, and environment at risk.

In order to discuss stocking rate and its effect on animal performance, some definitions are necessary. Stocking rate is defined as the number of animals on a given amount of land over a certain time. Stocking rate is generally expressed as animal units per unit of land area. Carrying capacity is the stocking rate that is sustainable over time per unit of land area. A critical factor to evaluate is how well the stocking rate agrees with the carrying capacity of the land. A term that is used to help understand and estimate forage requirements is the animal unit (AU) concept (Table 5). A simple example may serve to better illustrate the concept. Let us assume a livestock producer has 50 head of 1,000-lb cows on 200 acres for 12 months. The stocking rate of this operation would be calculated as follows:

Example 1: Calculation of Stocking Rate

Total Land Area ÷ [(#AUs) x (Grazing Season)]

200 acres ÷ [(50 AUs) x (12 months)] = 0.33 acres per AU month (AUM) ***or***
4.00 acres per AU year (AUY)

Because cattle and other grazing animals are not the same size, it is often necessary to convert to animal unit equivalents. The term animal unit equivalent (AUE) is useful for estimating the potential forage demand for different kinds of animals or for cattle that weigh more or less than 1,000 lbs. Animal unit equivalent is based upon a percentage (plus or minus) of the standard AU. Again, assuming a daily forage dry matter intake of 26 lbs. per day, the 1,000-lb. cow is used as the base animal unit to which other livestock are compared. The AUE for cattle that do not weigh 1,000 lbs. is calculated as:

$$\boxed{\text{AUE} = (\text{BODY WEIGHT}) \div 1{,}000}$$

Table 6 illustrates different kinds and classes of animals, their various AUEs, and estimated daily forage demand. With this information, it is easy to convert different sized animals to AUEs to determine how many different sized animals could be grazed compared with the typical AU.

Use of the appropriate stocking rate ensures an adequate amount of ground cover remains in the pasture. As noted previously, ground cover protects the soil resource, maximizes water capture on the site by improving infiltration rates, minimizes runoff and associated pollutants, and promotes plant persistence and vigor. Beyond these important attributes associated with the adequate ground cover that is directly related to stocking rate, the right stocking rate ensures an adequate forage supply for the animal. Ground cover that does not provide forage to meet animal

Table 5. Carry capacity in terms of the animal unit (AU) concept.

Concept	Abbreviation	Definition
Animal Unit	AU	1,000 lb. cow with calf
Animal Unit Day	AUD	26 lbs. of dry forage
Animal Unit Month	AUM	780 lbs. of dry forage
Animal Unit Year	AUY	9,360 lbs. of dry forage

Table 6. Animal unit equivalent (AUE) and estimated daily forage dry matter (DM) demand for various kinds and classes of grazing animals.

Animal Type	AUE	DM Demand (lbs. per day)
Cattle	-	-
Calves	-	-
300 lbs.	0.30	8
400 lbs.	0.40	10
500 lbs.	0.50	13
600 lbs.	0.60	16
Cows	1.00	26
Bulls	1.25	32
Horses	1.25	32
Sheep	0.20	5
Goats	0.17	4
White-tailed Deer	0.17	4

daily intake requirements has a profound negative effect on animal performance, while at the same time exposing the soil to extreme risk for erosion and increases the chance for bacteria and pesticides to move into the adjacent waterways (Fig. 20). Thus, using the appropriate stocking rate helps maintain adequate ground cover, improves animal performance, and decreases the level of pollutants (bacteria, pesticides, sediments) that are able to move overland into stream segments.

Grazing Management

Grazing management involves controlling *where*, *when*, and *how* much livestock graze. Close attention to grazing management (primarily stocking rate) is critical if the goal is to maximize profit or minimize loss. Many times, livestock production systems are overstocked.

Overstocking is characterized by low quantities of desirable forage and increasing

Figure 20. Effect of adequate (left) versus inadequate (right) forage resources on animal performance. Photos courtesy of Bob Nichols, USDA-NRCS (left) and Florida Cooperative Extension Service (right).

levels of undesirable plants. Too many animals for a given forage resource reduces animal performance, encourages weed infestation, and results in more off-farm purchases such as herbicide and supplemental feed. The objective of grazing management is to efficiently use the forage base while maintaining adequate livestock performance. No single grazing system will meet the requirements of all producers. Certain tracts of land lend themselves to one type of grazing system better than others, and management philosophies and experience levels of producers will likewise dictate how livestock will be manipulated. Generalized grazing systems that facilitate livestock movement, however, have been developed that provide improved control over forage use efficiency.

An important point to remember is that *grazing systems generally have less impact on animal performance than do stocking rate or soil fertility*. A grazing system has not been devised that will lessen the negative impacts of an overstocked pasture or a poor soil fertility program. Some form of rotational stocking system would probably benefit most commercial livestock producers, while producers of registered livestock may wish to use a continuous moderately stocked system.

Grazing Systems

Grazing systems impact infiltration, runoff, water quality, and soil erosion. Moderate-stocked, continuous grazing; moderate-stocked three-herd, four-pasture; and high-intensity, low-frequency grazing systems appear to have the least effect on infiltration rate and sediment production (Table. 7). Rest period appears to be the critical factor regarding compaction, reduced infiltration, and increased runoff. Most research has been consistent in demonstrating that short-duration grazing increases sediment production compared to moderate-stocked continuous grazing on rangelands (McCalla et al., 1984; Thurow et al., 1986; Weltz and Wood, 1986b; Pluhar et al., 1987). Warren et al. (1986 a,b,c) also demonstrated reduced infiltration rates and increased sediment production compared to no grazing under moderate, double moderate, and triple moderate stocking rates. In this study, 30 days was insufficient to allow for hydrologic recovery. The severity of the effect was increased as stocking rate increased.

Special attention should be paid to riparian areas. Inappropriate use of riparian areas by livestock can result in deterioration of the stream bank herbaceous community and increase the risk of stream bank erosion. Riparian areas also serve an important role as buffer strips filtering sediment from upland runoff. Once stream bank plant communities are disturbed, they are difficult, if not impossible, to re-establish through natural processes.

Concrete or gravel limited-access water points have become increasingly popular as a means to minimize damage to riparian areas. Likewise, freeze-proof tanks and stock ponds are alternative methods of providing water to livestock away from riparian areas. The objective of proper grazing management is to match forage nutritive value and availability with the nutrient requirements of grazing livestock for the optimum production of red meat, milk, and fiber. Many times the only management change required is to develop a controlled breeding season that matches seasonal forage availability with the nutrient requirements of gestating or lactating females and that of growing animals. If producers are not currently using a controlled breeding season, this may be a

Table 7. Infiltration rates and sediment production for two ypes of plant communities and five grazing treatments[1] (from Pluhar et al., 1987 and as used by Holechek et al., 1998).

	Infiltration Rate (mm hr $^{-1}$)		Sediment Production (kg ha $^{-1}$)	
Treatment	**Midgrass**	**Shortgrass**	**Midgrass**	**Shortgrass**
Short-duration (14 pastures)	-	-	-	-
Before grazing	95	75	37	63
After grazing	64	55	105	105
Short-duration (42 pastures)	-	-	-	-
Before grazing	81	86	41	61
After grazing	85	79	75	53
Merrill 3-herd/4 pasture	-	-	-	-
Before grazing	86	80	28	45
After grazing	81	68	71	54
Moderate continuous	89	85	35	30
Exclosure	88	-	23	-

[1] Stocking rate was the same for all treatments.

logical place to initiate an improved grazing management strategy.

No single grazing system will meet the requirements of all producers; that is, there is no "one size fits all program." Generalized grazing systems that facilitate livestock movement, however, have been developed to enable producers to have improved control over the forage budgeting process. Grazing systems that may have a practical application for the Texas livestock producer are discussed below. The systems discussed in this section relate to the producer who pastures livestock on introduced forages (i.e., bermudagrass, bahiagrass, kleingrass, Old World bluestem, and annual forages such as the cereal grains, ryegrass, and forage legumes) or on rangeland.

Continuous Stocking

Since by definition a grazing system involves movement of grazing livestock, continuous grazing is not actually a grazing system. Continuous grazing, however, is the type of system used by most producers because it requires the least level of managerial input from the livestock producer and is generally the least expensive to implement. Although criticized by some as an ineffective system, continuous grazing has several real

Table 8. Beef steer performance under continuous and rotational grazing systems (taken from Ball et al., 1991).

Pasture Species	Grazing Method	ADG (lbs.)	Change From Continuous Stocking (%)	Gain/acre (lbs.)	Change From Continuous Stocking (%)
Warm-season					
Bermudagrass + N	Continous	1.37	-	738	-
	Rotational - 4	1.27	-7	749	+1
Bermudagrass + N	Continuous	1.31	-	535	-
	Rotational - 4	0.99	-24	419	-22
	Strip	0.86	-19	434	-19
	Green chop	0.81	-38	577	+8
Sericea lespedeza[2]	Continuous	1.87	-	306	-
	Rotational - 3	1.65	-12	276	-10
Cold-season					
Orchardgrass + N	Continuous	1.30	-	364	-
	Rotational - 4	1.23	-5	388	+8
Tall fescue[3] + alfalfa	Continuous	1.70	-	313	-
	Rotational - 4	1.77	+4	308	-2
Tall fescue[3] + N	Continuous	1.62	-	290	-
	Rotational - 10	1.39	-14	354	+22
Tall fescue[4] + N	Continuous	1.28	-	243	-
	Rotational - 10	1.02	-20	349	+44
Wheat/ryegrass + N	Continuous	2.16	-	746	-
	Rotational - 6	1.72	-20	733	-2

[1] Number following rotational is the number of paddocks used in the system.
[2] *Sericea lespedeza* was a low-tannin type.
[3] Tall fescue was endophyte-free.
[4] Tall fescue was endophyte-infected.

advantages relative to other grazing systems including enhanced animal performance.

Individual animal performance, whether quantified as live-weight gain, calving percentage, or milk production is typically higher for livestock in continuous grazing systems (Table 8) under moderately stocked conditions. The improved performance is due to a higher degree of diet selectivity by the animal. Grazing livestock, if allowed the opportunity, will typically select a diet of higher nutritive value than would be indicated by a typical forage sample.

Other grazing systems that involve cattle movement between pastures do not allow the animal as much freedom in diet selection. This aspect generally results in reduced animal performance because the animal is forced to consume forage that it might not otherwise select. Table 8, however, indicates there is no "perfect" grazing system and the choice of grazing systems depends on the manager's goals and objectives. Likewise, animal performance is highly variable under different grazing systems and is dependent on the forage base, stocking rate, time of season, fertility level, moisture availability, and other factors.

The major disadvantage of continuous grazing relates to the variable growth rate of forage crops. For example, during early spring bermudagrass experiences a rapid growth rate that requires a relatively heavy stocking rate to achieve the desired harvest efficiency. Later, during periods of reduced precipitation levels associated with summer, forage growth rate declines and requires a reduction in animal numbers. To optimize forage use under continuous grazing, producers should use a variable stocking rate by adjusting either livestock numbers or pasture size.

The use of inexpensive electric fencing offers producers the opportunity to rapidly adjust pasture size and maintain a proper stocking rate relative to forage production rate. By simply opening or closing gates of a multi-paddock operation, producers may accomplish the same result. Excess forage from that part of the pasture not being grazed during the rapid growth phase should be cut as high quality hay. In fact, the opportunity to cut excess forage for hay or silage is one of the best methods for incorporating the "variable stocking rate" pasture management scenario.

If a variable stocking rate that matches varying forage levels is not used, pastures will be overstocked at some times and understocked at other times. Overstocking coupled with a poor fertility program typically leads to an invasion of weeds and undesirable grasses such as broomsedge and threeawn. Under these circumstances, animal performance begins to decline and the carrying capacity of the pastures is also reduced. Conversely, understocking results in "patch" (or spot) grazing. Patch grazing is where animals repeatedly graze the same area as soon as regrowth is available. Animals continue to use previously grazed areas because the immature regrowth is more palatable and of higher nutritive value. Ungrazed areas in the pasture continue to increase in maturity, decline in nutritive value, and become increasingly less palatable. The decline in harvest efficiency results in wasted forage and decreases profit potential from the livestock operation.

The bottom line regarding continuous grazing is that it can be a profitable system if a variable stocking rate is used to match the variable growth rate of the pasture. If livestock demand is matched to forage production using the "variable stocking rate" management option, producers will realize more efficient use of the forage.

Rotational Stocking

Rotational stocking requires that a single pasture be subdivided in two or smaller units, though not necessarily equal in size. In a rotational grazing system, livestock are moved from one pasture to another for short periods. The concentration of livestock results in a temporarily overstocked condition, which allows for a high forage harvest efficiency. A high harvest efficiency means that more of the available forage produced in the grazing unit is consumed by the animals and little forage is wasted.

Producers should pay close attention when rotationally grazing to determine the optimum time to move livestock to another paddock. Determining the optimum time is the critical element in rotational grazing and requires considerable management expertise. Because of the variable production rate of forage species, grazing time may vary from as few as 1-2 days up to 7-10 days per pasture depending on climatic conditions and the forage growth rate. Rotation grazing systems in which producers move livestock on a calendar basis may not achieve optimum results relative to animal performance or forage use.

Varying forage levels may require producers to skip one or more pastures in the grazing rotation and cut the skipped units for hay during periods of excess production. Forage removal as a hay crop will help control weed species and prevent mowed areas from becoming excessively mature with a resultant decline in forage nutritive value.

Some advantages of rotational stocking include the previously mentioned improved harvest efficiency. The improved harvest efficiency associated with rotational grazing may allow for a slight increase (10% to 15%) in livestock numbers compared with a poorly managed continuous grazing system. Other advantages of rotational grazing include better control of livestock and potential health problems observed at an earlier stage since, by default, the producer spends more time with the livestock. Rotational stocking early in the spring may also provide a means to control early weed species.

The primary disadvantage of rotational stocking relates to reduced individual animal performance. Livestock in a rotational stocking system do not have the diet selectivity that animals in a continuous stocking system have. This lack of diet selectivity typically results in reduced animal performance, especially when animals are grazing warm-season forages. Another disadvantage of rotational stocking involves the added expense of additional fence construction, although this may be somewhat offset by using low-cost electric fencing. Additional water development may be necessary and the extra labor costs involved in routinely moving livestock are additional considerations.

Some forage species may perform best under rotational grazing. Livestock may benefit from rotationally grazing warm-season perennial grasses due to increased harvest efficiency and nutritive value of the forage. For example, weeping lovegrass, if not rotationally grazed, is patch grazed by livestock and quickly becomes excessively mature and unpalatable. This results in livestock avoidance of the plants, and thus, much forage is wasted. Rotationally grazing cool-season forage crops may not be as important to the grazing animal, but rest between grazing events may benefit the plant in dry matter production. Reseeding annual clover species should also be rotationally grazed to promote seed production, and thus, stand persistence.

Rotational stocking can be a valuable livestock management tool that helps ensure an appropriate amount of forage residue remains in paddocks. Maintaining the correct amount of forage residue is critical to protecting waterways. Appropriate forage residue creates effective filter strips that absorb much bacteria, pesticides, and sediment, thus helping to improve water quality.

Grazing Systems for Growing Animals

Growing animals have a higher nutritive requirement than dry, pregnant females or mature males. Several grazing systems have been designed that attempt to provide a higher nutritional plane for growing animals.

A slight modification of rotational grazing known as forward creep grazing may be a valuable system for enhancing growing animal performance. With this approach, producers typically split the livestock herd into two groups: "first and last" or "leader and follower" grazers. The first grazers (leaders) are typically younger animals that have a higher nutritive requirement when compared to mature animals. The leaders are allowed to graze a paddock first and obtain forage of the highest nutritive value. When approximately one-third of the forage has been consumed, these first grazers are rotated to a new paddock. The last grazers (followers) are typically mature animals with lower nutritive requirements. This variation on rotational grazing results in an improved growing animal performance when compared with simple rotational grazing.

One variation of continuous grazing involves the installation of a creep gate to allow younger animals access to forage of higher value. With a creep-grazing system, younger animals have free access to other pastures generally planted to high-quality annual forages, but the size of the creep gate opening prevents entry into the pasture by mature animals. Allowing creep access will work with either warm- or cool-season forages. Those forage species typically used in creep-grazing systems include the small grains, ryegrass, and/or clovers for fall and winter grazing while forage sorghum, sorghum-sudan hybrids, various millets, and cowpeas make excellent choices for summer forage programs.

Construction and installation of a pasture creep gate is simple. The pasture creep gate can be constructed of wood or metal and installed either as a panel in the fence line or as a gate. The creep gate may also be used in electric fences. The opening in a creep gate used for calves is generally 18 inches wide. This opening will accommodate calves that weigh up to 600 pounds; however, width of the creep gate can be varied to meet the specific requirements of a producer and his livestock. A simple horizontal bar adjustable for height can also be used to limit calves of different sizes from entering the creep pasture. The typical adjustment range for the horizontal bar will vary from 24 - 48 inches measured from ground level. Since pasture creep gates are often permanently installed in a fence, a second horizontal bar can be used to completely close the gate.

Research has demonstrated that growing cattle with creep access to forages of higher nutritive value can result in calves that weigh an additional 50 pounds or more at weaning. Creep gates can provide an excellent return for their nominal investment.

Strip Grazing

Strip grazing is a grazing technique used primarily with dairy herds but can be adapted to other types of livestock operations. Strip grazing uses two portable fences (typically electric) to allot a small area of the pasture for grazing. This technique is actually an intensive form of rotational grazing with a somewhat higher labor requirement. Livestock are confined to an area smaller than that required for the entire herd. As with other rotational grazing systems, the temporarily overstocked condition associated with strip grazing results in high harvest efficiency, although animal performance is typically reduced.

Forage sorghums and sorghum-sudan hybrids and the various millets may be best suited for this type of grazing system although any forage may be strip grazed. Strip grazing allows the forage to be consumed with a minimum amount of trampling of good forage. Beef cattle often graze one of the field-cured forage sorghums during fall and winter using a slight modification of strip grazing. The use of one portable fence ahead of the animals serves as a valuable management tool to prevent livestock from trampling, and thus, wasting the field-cured forage.

Limit Grazing

Rather than purchase relatively expensive protein supplements during the fall and winter, many producers use a grazing system known as limit grazing. With limit grazing, livestock spend most of the time on dormant pasture/native range and receive an adequate quantity of good-quality hay. In addition, the livestock are allowed access to cool-season pastures for a limited time rather than on a continual basis. Properly fertilized cool-season forages generally provide nutrients in excess of that required by dry pregnant females, thus the requirements are met with less grazing time. Although most limit-grazing systems involve the use of cool-season forages, there is no reason why a producer could not use the same management strategy using warm-season forages.

Forages that are high in nutritive value can be managed to serve as supplemental protein for mature livestock and help enhance growing animal performance. Dry pregnant females can be limit-grazed one or two hours on alternate days or every third day to conserve forage and still meet the animal's protein requirements. Lactating cows and growing animals require more nutrients compared with dry cows and should be allowed to graze approximately two hours each day on the high quality forage.

A less efficient limit-graze schedule, but more practical for some people, is to allow one full day of grazing on forage of high nutritive value followed by two to four days of grazing on dormant grass depending on the crude protein requirements of the animal. More forage is lost, however, because of increased trampling, the presence of bedding areas, and dung and urine spots within the pasture.

This system depends upon an adequate supply of dry grass and/or good quality hay to serve as a source of energy during periods the animals do not have access to the higher quality forage. Animal performance is improved using limit grazing when compared with other fall-winter grazing systems using only dormant grass pastures or hay.

Final Thoughts on Grazing Systems

The key to proper grazing management is to obtain a balance between animal diet selectivity and harvest efficiency; the "right" system will vary between locations and producers. Producers should pay close attention to matching livestock nutrient requirements with forage availability. Using either a continuous or a rotational grazing system can result in the optimum use of available forage, acceptable animal performance, and thus, a profitable livestock operation depending on the producer's managerial expertise.

Producers considering changing the type of grazing system of their operation, or producers who may just be getting into livestock production should:

1. Think through the process with respect to their expectations and inputs required for each system and,
2. Seek an optimum balance among harvest efficiency, resource conservation, water
3. quality issues, including bacteria, and individual animal performance,

The most significant aspect of a grazing system, however, is to provide grazing livestock with an adequate amount of forage of appropriate nutritive value. This requires choosing the proper forage species for grazing, an appropriate soil fertility program based on soil test recommendation, and the proper stocking rate. One of the most important aspects of the adequate level of forage is to help improve water quality.

Nutrient Management

Many forage species used in livestock production systems are introduced from other parts of the world and have been selected for improvements in dry matter production, tolerance to grazing, cold tolerance, drought tolerance, and insect and/or disease tolerance. Generally, these introduced forage species offer these improved characteristics only when fertilized appropriately. Fertilizers are expensive production system inputs and can prove to be water pollutants if not applied appropriately. Therefore, BMPs for forage and forage-based livestock production includes the use of soil testing to determine the level of nutrients required for the optimum production of the target forage species. BMPs dictate that fertilizer materials be applied based only on soil test recommendations. Using soil testing to determine fertilizer requirements ensures optimal fertilization rates are used and reduces the potential for both soil and surface water contamination due to over-application of fertilizer nutrients.

Pest Management

An integrated pest management approach seeks to use routine management practices to minimize pesticide use on a regular basis. These routine strategies include:

1. *Use of the appropriate stocking rate for the grazing management unit*. This minimizes the number of unwanted weed species in the pasture environment, and thus the routine application of herbicides.
2. *Use of relevant grazing systems that allow for biological control of unwanted, but palatable and nutritious weed species.* This again minimizes the routine application of herbicides.
3. *Use of appropriate fertility programs on introduced-forage pastures*. This encourages the growth and vigor of desirable forage species that can out-compete less desirable weed species.
4. *Use of prescribed burning programs*. Prescribed fire can safely and efficiently reduce competition from many weed species, especially those that are woody in nature.
5. *Close adherence to label directions*. When pesticides are required, BMPs include following label directions carefully to optimize target species control and to eliminate negative effects to the environment. <u>**To use pesticides in a manner not consistent with label directions is a violation of state and federal laws.**</u>

Summary of BMPs for Upland Vegetation Management

In summary, forage-based livestock production systems can be sustainable with regard to maintaining or even enhancing the environment. Careful attention, however, to BMPS for the use of appropriate stocking rates, fertilizers, and pesticides is essential to protecting the environment while at the same time increasing the potential for profit from the production enterprise. Finally, use of the appropriate vegetation management BMPs helps protect Texas waterways from bacteria and other pollutants, thus improving water quality now and into the future.

Chapter 3

Sources of Technical and Financial Assistance for BMP Implementation

Photo courtesy of the Texas AgriLife Extension Service

Sources of Technical Assistance for BMP Implementation

There are many agencies available to you at no cost for consultations on issues you may be facing or plans you would like to implement. These agencies also routinely conduct short courses and seminars at no cost on current information and management practices in agriculture. They include your local Soil and Water Conservation District, the Texas State Soil and Water Conservation Board, the USDA-Natural Resources Conservation Service, and the Texas AgriLife Extension Service.

Soil and Water Conservation Districts

By contacting the directors of the soil and water conservation district, a farmer or rancher can get assistance on all phases of conservation. Districts offer agricultural landowners or operators this technical assistance through coordination with the Natural Resources Conservation Service (NRCS), an agency of the United States Department of Agriculture (USDA). Through Memoranda of Understanding with USDA and NRCS, local SWCDs are able to furnish technical assistance to farmers and ranchers in the preparation of a complete soil and water conservation plan to meet each land unit's specific capabilities and needs.

The TSSWCB, the state agency charged with the overall responsibility of coordinating the SWCD programs in Texas, also makes technical assistance funds available to districts through a grant program. Personnel hired under this program are district employees who work cooperatively with NRCS employees to help agricultural landowners/operators plan and install conservation practices.

With water quality being a major issue of concern in Texas, the 73rd Legislature passed Senate Bill 503. This bill created the Water Quality Management Plan Program to provide agricultural and silvicultural (forestry) producers with an opportunity to comply with state water quality laws through traditional, voluntary, incentive-based programs.

Landowners and operators may request the development of a site-specific water quality management plan through local SWCDs. Plans include appropriate land treatment practices, production practices and management and technology measures to achieve a level of pollution prevention or abatement consistent with state water quality standards.

Districts also work with the USDA-Farm Service Agency, the Texas AgriLife Extension Service, Texas Forest Service, U.S. Forest Service and others when necessary to assist agricultural landowners/operators meet individual land use needs.

Texas State Soil and Water Conservation Board

The Texas State Soil and Water Conservation Board (TSSWCB) is a state agency that administers Texas' soil and water conservation law and coordinates conservation and pollution abatement programs throughout the State. Headquartered in Temple, Texas, the TSSWCB offers technical assistance to the State's 217 soil and water conservation districts (SWCDs). The TSSWCB is the lead Texas agency for planning, implementing, and managing programs and practices for abating agricultural and Silvicultural nonpoint source (NPS) pollution.

The primary means for achieving this is through the development of Water Quality Management Plans (WQMPs). A WQMP is a site-specific plan developed through and approved by soil and water conservation districts for agricultural or silvicultural lands. The plan includes appropriate land treatment practices, production practices, management measures, technologies or combinations thereof. The purpose of a WQMP is to achieve a level of pollution prevention or abatement determined by the TSSWCB, in consultation with local soil and water conservation districts, to be consistent with state water quality standards through five regional offices (Fig. 21) strategically located throughout the state, the TSSWCB provides local SWCDs and landowners assistance in developing WQMPs.

Natural Resources Conservation Service

The Natural Resources Conservation Service (NRCS) is an agency of the U.S. Department of Agriculture (USDA) which assists land owners and managers to improve and protect their soil, water and other natural resources. For decades, private landowners have voluntarily worked with NRCS specialists to prevent erosion, improve water quality and promote sustainable agriculture.

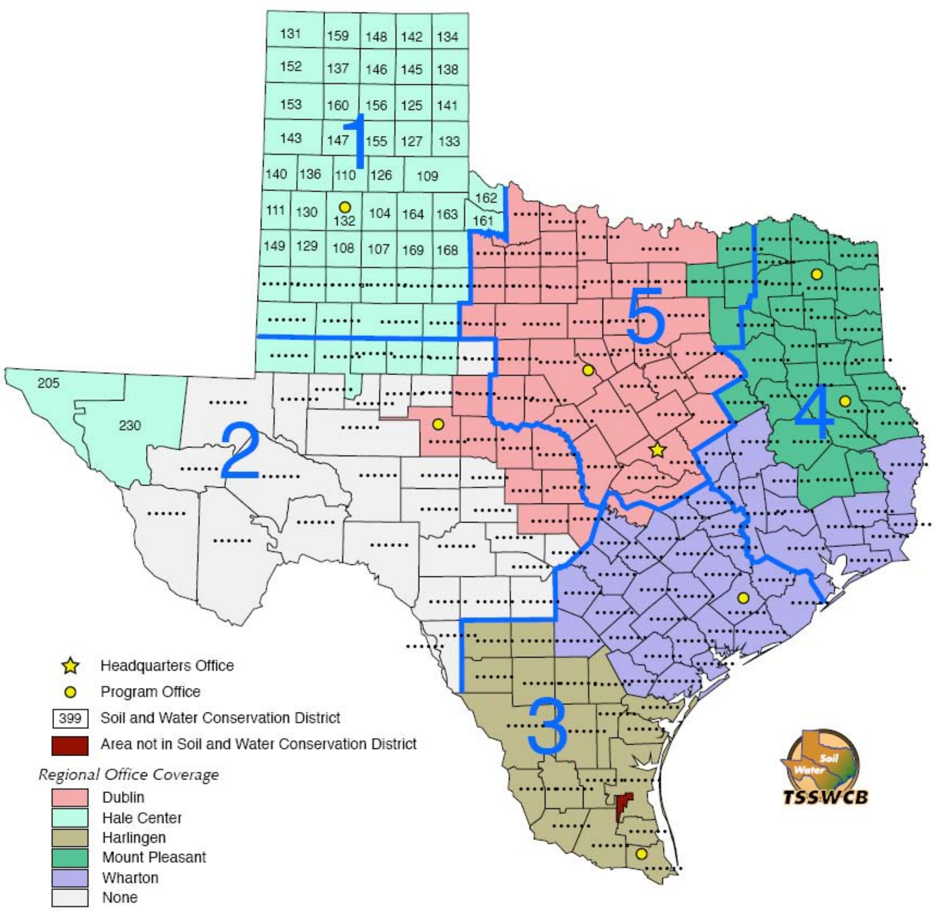

Figure 21. Map of the Texas State Soil and Water Conservation Board 5 regional offices. Illustration courtesy of the Texas State Soil and Water Conservation Board.

NRCS employs soil conservationists, rangeland management specialists, soil scientists, agronomists, biologists, engineers, geologists, engineers, and foresters. These experts help landowners develop conservation plans, create and restore wetlands and restore and manage other natural ecosystems.

Texas AgriLife Extension Service

The mission of the Texas AgriLife Extension Service is to serve Texans through providing community-based education. With a vast network of 250 county Extension offices, 616 Extension agents, and

343 subject-matter specialists, the expertise provided by AgriLife Extension is available to every resident in every Texas county. These specialists and agents are a great technical resource for agricultural producers throughout the state.

Sources of Financial Assistance for BMP Implementation

Financial assistance for implementing BMPs is primarily provided through the TSSWCB, NRCS, and USDA-Farm Services Agency (FSA).

Texas State Soil and Water Conservation Board

The TSSWCB provides cost-share funds to landowners through the Senate Bill 503 program and through the Clean Water Act Section 319(h) Grant Program for the implementation of WQMPs. Each year through the SB503 program, the TSSWCB provides over $2 million in assistance to landowners to implement BMPs in priority areas identified by the TSSWCB. Additionally, in specific project areas, the TSSWCB also provides cost-share funding for BMPs through the 319(h) program. Through these two programs, eligible landowners qualify for up to $15,000 in cost-share funding to implement their WQMP.

Natural Resources Conservation Service

The Natural Resources Conservation Service (NRCS) primary program for implementing BMPs is the Environmental Quality Incentives Program (EQIP).

EQIP is a voluntary conservation program that supports production agriculture and environmental quality. It provides farmers and ranchers with financial assistance for BMP implementation. It is designed to address both locally identified resource concerns and state priorities. The State Technical Advisory Committee recommends State Resource Concerns, while county work groups, composed of local SWCDs and others, set local priorities. In FY2009 the Texas allocation for EQIP was $62 million.

The amount of funding available for EQIP can vary from county to county. To be eligible for this program the person must be involved in livestock or agricultural production and develop a plan of operations. This plan defines the objective to be achieved by the conservation practice proposed and a schedule of practice implementation. Applications are then be ranked by environmental benefits achieved and the cost effectiveness of the proposed plan.

In addition to EQIP, there are several additional programs available from NRCS for BMP implementation including:

- Conservation Security Program (CSP)
- Grassland Reserve Program (GRP)
- Wetlands Reserve Program (WRP)
- Wildlife Habitat Incentives Program (WHIP)

CSP provides financial and technical assistance to promote conservation and natural resource improvement. GRP is a voluntary program that helps landowners and operators restore and protect grassland. WRP provides technical and financial support to help landowners with their wetland restoration efforts. WHIP provides financial incentives to develop habitat for fish and wildlife on private lands. For more information, see the NRCS website.

USDA – Farm Services Agency

The Farm Services Agency administers a number of programs that can assist in BMP implementation, including:

- Conservation Reserve Program (CRP)
- Conservation Reserve Enhancement Program (CREP)
- Source Water Protection Program

FSA's primary program for implementing BMPs is CRP. CRP provides annual rental payments and cost-share assistance to establish long-term, resource conserving covers on eligible farmland. This program helps agricultural producers safeguard environmentally sensitive land through practices that improve the quality of water, control soil erosion, and enhance wildlife habitat.

After enrollment, the FSA will pay an annual per acre rental rate and provide up to 50 percent cost share assistance for practices that accomplish the above goals. The portions of property to be submitted to the program will be under contract for 10 to 15 years and can not be grazed or farmed. To be eligible for the program agricultural producers must have owned or leased the land for one year prior to application. In addition, the land submitted for the program must be suitable for the following practices:

- Riparian Buffers
- Wildlife Habitat Buffers
- Wetland Buffers
- Filter Strips
- Wetland Restoration
- Grass Waterways
- Contour Grass Strips

In addition to CRP, FSA also administers CREP and the Source Water Protection Program. CREP is a voluntary land retirement program that helps ag producers protect environmentally sensitive land, decrease erosion, restore wildlife habitat, and safeguard ground and surface water. Source Water Protection Program helps prevent source water pollution through voluntary practices installed by producers at the local level.

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Additional Resources

Preparing for the Next Drought – SCS 2007 11

Testing You Soil: How to Collect and Send Samples – L-1793

Developing & Using a Forage System. – SCS-2003-08

Forage Establishment, Management, and Utilization Fundamentals – SCS-2003-07

Matching Enterprises to Resources – SCS-2003-05

Forages for Texas – SCS-2002-14

Conservation of Soil Resources on Lands Used for Grazing – SCS-2002-06

Forages: They're Good For Life. – SCS-2001-07

Texas Watershed Steward Handbook: A Water Resource Training Curriculum – B-6203

Rangeland Watershed Management for Texans: Are Your Pastures Healthy? – E-107

A Texas Field Guide to Evaluating Rangeland Stream & Riparian Health – B-6157

Grazing Land Stewardship: A Manual for Texas Landowners – B-6221

Alternatives for Cattle During the Drought: Moving Cattle off the Ranch – ASWeb-004

Destocking Strategies During Drought – ASWeb-016

Stocking Rate and Grazing Management – E-64

Water Quality: Its Relationship to Livestock – L-2374

Do You Have Enough Forage? – E-392

Stocking Rate Decisions – E-152

The Texas Cow-Calf and Stocker Beef Safety and Quality Assurance Handbook

Publications are available through the Texas AgriLife Extension Bookstore (https://agrilifebookstore.org/) or by contacting Dr. Larry Redmon (lredmon@ag.tamu.edu).

Lone Star Healthy Streams

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Extension publications can be found on the Web at http://agrilifebookstore.org
Visit the Texas AgriLife Extension Service at http://AgriLifeExtension.tamu.edu

Appendix C Lone Star Healthy Streams Certificate

Educational Credit Information

Certified Crop Advisors (CEU)

CEU ID#:

CEU Provider: Texas AgriLife Extension Service

Total Credits:

Subject: Soil & Water Management

TDA Pesticide License Holders (CEU)

CEU ID#:

CEU Provider: Texas AgriLife Extension Service

Total Credits:

Subject: General

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Appendix D LSHS Survey

LONE STAR HEALTHY STREAMS

AgriLIFE EXTENSION
Texas A&M System

Improving Lives. Improving Texas.

Lone Star Healthy Streams
Program Survey

We hope that you have enjoyed this program. Would you please take just a few moments to complete this survey? In doing so, you will help us make improvements to the program. THANK YOU!

1. For each item listed below, mark the ONE number in the left column that best describes your level of understanding BEFORE the program; and then mark the ONE number in the right column that best describes your level of understanding AFTER the program.

Poor	Fair	Good	Excellent
1	2	3	4

	BEFORE Program				AFTER Program			
	1	2	3	4	1	2	3	4
The Federal Clean Water Act requires specific water standards for each state, including Texas.	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ
A waterbody not meeting water quality standards (impaired waterbody) is placed on what is known as the 303(d) list.	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ
Once a waterbody is placed on the 303(d) list, a plan to improve the water quality is put in place known as a Total Maximum Daily Load (TMDL).	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ
E. coli are bacteria that cause both food-borne and water-borne illnesses.	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ
E. coli is an indicator organism for additional organisms that can cause water-borne illnesses.	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ
Water quality regarding bacteria is determined by testing for *E. coli*.	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ
There are many sources of bacteria that can impair a waterbody, including livestock.								
Riparian areas are environmentally sensitive areas along streams and rivers.	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ
There are Best Management Practices (BMPs) I can implement on my property to protect riparian areas.	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ
There are various sources of cost-share funds to assist my implementation of BMPs designed to protect riparian areas.	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ

2. Overall, how satisfied are you with this educational program activity?
   Θ Not at all   Θ Slightly   Θ Somewhat   Θ Mostly   Θ Completely

3. What did you like most about this educational program activity?

   ____

4. What did you like least about this educational program activity?

   ____

5. Would you recommend this particular educational program activity to others?
   Θ Yes Θ No

6. How likely are you to adopt one or more of the BMPs presented in today's program designed to improve water quality?
   Θ Likely Θ Not likel

Appendix E Draft Alternative Water Manuscript

Effects of an off stream watering facility on cattle behavior and in-stream *E. coli* levels

Abstract

Excessive levels of indicator bacteria are the leading cause of water quality impairment in Texas. Livestock with direct access to water bodies are identified as a significant source of these bacteria. To help address this, the effect of providing alternative off-stream watering facilities to reduce manure, and thus bacterial, deposition in or near surface waters was evaluated from July 2007 to July 2009 in Clear Fork of Plum Creek in central Texas. An upstream-downstream, pre-/post-treatment monitoring design was used with off-stream water being provided only during the second year of the project. Stream samples were analyzed semi-monthly for *E. coli* and turbidity, and flow was determined for each sample event. Cattle movement was tracked quarterly using global positioning system collars to assess the effect of providing alternative water on cattle behavior. The project found that when alternative off-stream water was provided, the amount of time cattle spent in the creek was reduced 43% from 3.0 to 1.7 minutes/animal unit/day. As a result of this, direct deposition of *E. coli* into Clear Fork of Plum Creek was estimated to be reduced from 1.11E+07 to 6.34E+06 cfu/animal unit/day. Observed pre- and post-treatment *E. coli* loads suggested similar reductions; however, this project could not conclusively attribute the observed *E. coli* loading reductions to providing alternative water because of the lack of statistical significance of these observations, the decrease in flow observed during the post-treatment period, and the observed increase in *E. coli* levels during the post-treatment period. A drought during the post-treatment period which reduced flows by 79% and influenced ranch management decisions to increase stocking rate 34% explain much, but not all, of the increase in *E. coli* levels observed. Other probable factors impacting the observed *E. coli* levels include natural variability, changes in fate and transport due to the drought, and potentially increased contributions from wildlife.

Finally, unlike previous studies, this project did not find turbidity to be a good predictor of *E. coli*. Thus, it was concluded that use of turbidity as an indicator must be determined on a case by case basis and used with caution.

Key Words

Alternative off-stream water—*E. coli*—GPS collars—cattle

Excessive levels of fecal indicator bacteria (i.e. *E. coli*, *Enterococcus*, and fecal coliforms) are the number one cause of water quality impairment in Texas. According to the Texas Commission on Environmental Quality (TCEQ) *2008 Water Quality Inventory and 303(d) List*, over half of the water quality impairments in Texas (295 of the 516 impairments) result from excessive levels of bacteria (TCEQ 2008a). Fecal indicator bacteria are common inhabitants of the intestines of all warm-blooded animals, including livestock. Livestock having direct access to water bodies are identified as significant sources of bacteria in numerous bacterial total maximum daily loads (TMDLs) (e.g. TCEQ 2007a, TCEQ 2007b).

Cattle are drawn to streams and adjacent riparian areas by water, shade, and the quality and variety of forage present (Kauffman and Krueger 1984). The length of time cattle spend in a stream, however, plays a significant role in fecal contamination (Mosley et al. 1999). When cattle have stream access, a portion of their fecal matter is deposited directly into the stream (Larsen et al. 1988) and can be a significant source of contamination. Gary et al. (1983) observed that cattle spent 5% of the day in or adjacent to the stream and 6.7-10.5% of defecations were deposited directly in the stream. Feces deposited in the stream have a greater impact on water quality than that deposited 0.6 m (2 feet) away from the stream. Larsen et al. (1994) found that manure deposited 0.6 m (2 feet) from a stream contributed 83% less bacteria and manure deposited 2.1 m (7 feet) from a stream contributed 95% less bacteria than that deposited directly in a stream.

Tiedemann et al. (1987) and Mosley et al. (1999) suggested animal access to streams had a greater impact on stream bacterial levels than stocking density. Thus, riparian protection is needed to reduce manure deposition in or near surface waters (Ball et al. 2002). Exclusion of livestock from riparian areas by fencing of streams is frequently recommended to reduce manure inputs to surface water (Godwin and Miner 1996; McIver 2004). Fencing of streams alone or in combination with other best management practices (BMPs) effectively reduces *E. coli* 37-46% (Meals 2004—37%; Meals 2001—46%), *enterococcus*

57% (Line 2003); and fecal coliform 30-94% (Hagedorn et al. 1999—94%; Line 2002—90%; Lombardo et al. 2000—70%; Line 2003—66%; Meals 2001—52%; Meals 2004—42%; Brenner 1996—41%; Brenner et al. 1994—30%; and Cook 1998—30%). However, this BMP is costly to install and maintain (Godwin and Miner 1996; Sheffield et al. 1997; Byers et al. 2005), results in loss of grazing area and ranching income, restricts access to reliable water sources, and may be inconvenient and impractical for many ranches. Thus, it is opposed by many ranchers (McIver 2004). Other concerns have recently been raised regarding the impact of increasing wildlife populations in fenced riparian zones, potentially negating *E. coli* loading reductions provided by restricting livestock access.

Another practice available to protect riparian areas and reduce manure deposition in or near surface waters is development of alternative watering facilities (FCA 1999; Tate et al. 2003; Byers et al. 2005). A permanent or portable off-stream water supply (e.g. trough) provides livestock another source of drinking water other than streams. They can be used alone or in conjunction with other practices to reduce the amount of time livestock spend near surface waters and in riparian areas. To achieve optimum uniformity of grazing and greatest use of alternative water sources, cattle should not have to travel more than 200-300 m to water (McIver 2004). They benefit livestock producers by improving grazing distribution, reducing herd health risks due to drinking or standing in contaminated water, decreasing herd injuries from cattle traversing steep or unstable stream banks, increasing water supply reliability during droughts, and increasing weight gains in beef cattle of 0.1 to 0.2 kg/day (0.2-0.4 lb/day) (Willms et al. 1994; Buchanan 1996; Porath 2002; Veira 2003; Wilms et al. 2002; and Dickard 1998).

Alternative off-stream water supplies also provide environmental benefits including reduced manure deposition and bacterial contamination of surface waters as well as reduce stream bank destabilization and erosion due to trampling and overgrazing of banks. Miner et al. (1992) visually observed that cattle spent 94% less time in an Oregon stream during winter when an off-stream watering facility was available, reducing the time cattle spent in the stream from 25.6 to 1.6 minutes/cow/day. Godwin and Miner (1996), using light beam counters, found that four cows together spent 15 minutes per day (i.e. 4.25 minutes/cow/day) within 4.5 m (14.7 feet) of an Oregon stream during summer when off-stream water was provided as compared to 60 minutes per day (i.e. 15 minutes/cow/day) within 4.5 m (14.7 feet) of the stream when no off-stream water was provided (75% reduction). Godwin and Miner (1996) deduced that under baseflow conditions, off-stream watering was nearly as effective fencing in reducing manure inputs to surface water thus reducing water quality impacts of grazing cattle at a reduced cost.

Clawson (1993), using a time-lapse camera, found that providing alternative water reduced stream use during summer from 4.7 minutes/ cow/day to 0.7 minutes/cow/day in Oregon (85% reduction).

Over a fourteen month period, Sheffield et al. (1997) visually observed that providing off-stream water reduced the time cattle spent drinking from a Virginia stream 89% from 6.7 to 0.7 minutes/cow/day. Additionally, the time cattle spent within 4.6 m (15 feet) of the stream was reduced 51% from 12.7 to 6.2 minutes/cow/day. As a result of the reductions in time cattle spent in and near streams, in-stream concentrations of fecal coliform were reduced by an average of 51%; however, results varied among sites. Statistically significant reductions in fecal coliform levels of 99%, 87%, and 57% were observed at three sites while a 53% increase (which was not statistically significant) was observed at one site.

Byers et al. (2005), using three Global Positioning System (GPS) collars, found that providing water troughs decreased the amount of time cattle spent within 12 m of a Georgia stream by 40% in March 2002, 96% in December 2002, and approximately 60% in July 2003. Although alternative water did not impact stormwater *E. coli* concentrations, the study found that median base flow *E. coli* loads decreased 95% in one pasture and 85% in another when water troughs were available. However, stream flow was 51% smaller when the troughs were available, thus impacting the loads.

With the exception of the study conducted by Byers et al. (2005), previous studies used light beam counters, visual observations, and time-lapse cameras to evaluate cattle behavior during daylight hours. Night time observations can be critical because cattle exhibit bimodal grazing patterns (early morning and evening) with certain breeds spending a greater portion of the night grazing as compared to day time (Pandey et al. 2009). Observation periods of these earlier studies were also generally of short duration, focusing on specific seasons. These studies also targeted the Pacific Northwest, Eastern and Southeastern U.S., regions where conditions are very different than much of Texas and much of the mid-section of the country where a majority of the cattle production is. Finally, most of these studies did not evaluate the impacts of off-stream water on *E. coli* levels (again, with the exception of Byers et al. 2005).

The objectives of this project were to better assess the effect of providing an off-stream watering facility (i.e. water trough) in reducing (a) the percent time cattle spend in a Central Texas stream and riparian zone, (b) the deposition of fecal matter in the stream and riparian zone and (c) the level of bacterial contamination of the stream. This information is needed by stakeholders, natural resource agencies, and others working to improve water quality in Texas not only to better understand the effectiveness of alternative water as a water quality BMP, but to populate and improve the predictive capabilities of water quality models being used in Texas for TMDLs and watershed protection plans with information on the percent time that cattle spend in streams and the amount of direct deposition results.

Materials and Methods

Site Description

This project was conducted at the 2S Ranch in Caldwell County, Texas near the community of Maxwell. This commercial cow-calf operation is bisected by the Clear Fork of Plum Creek. Although the drainage area above the ranch is only 26 km^2 (10 mi^2), the Clear Fork of Plum Creek is a perennial stream as a result of a number of springs located along it. The creek ranges in width from 0.3 to 0.6 m (1 to 2 feet) in some areas to 1.5 to 2.1 m (5 to 7 feet) in others and averages approximately 1.2 m (4 feet) wide. The average slope of the stream is 0.3% while the average slope perpendicular to the stream is 5.4%. Clear Fork of Plum Creek is a tributary of Plum Creek which is impaired by excessive levels of *E. coli,* listed on the 303(d) List as impaired, and the focus of watershed restoration efforts through development of a watershed protection plan.

The ranch is in the Texas Blackland Prairies Ecoregion (Omernik 1987) where annual precipitation averages 35 inches. The flood plain along the creek is dominated by Tinn Soils, a very deep, moderately well drained, very slowly permeable soil that formed in calcareous clayey alluvium. Upgradient of the Tinn soil is the Branyon clay which like the Tinn Soil is a very deep, moderately well drained, very slowly permeable soil. Finally, soils in the upland areas of the Ranch are comprised of Lewisville soils, a very deep, well drained, moderately permeable soil on slopes of 0 to 10 percent.

The predominant forage in the creek pasture is common bermudagrass (*Cynodon dactylon*). Vegetation in the three other pastures is WW-B Dahl Bluestem (*Bothriochloa bladhii*), Old World Bluestem [(*Bothriochloa* sp.); (*Dicanthium* sp.)], and native grasses. Typical riparian vegetation along the creek was limited to non-existent. Very few trees were present along the stream, thus little shade was available along the creek to draw cattle to the creek. The creek pasture has been in common bermudagrass for many years; however, most of the operation had been cropped until 2003 and converted to pastureland in 2004.

Pasture Management

Four pastures, ranging in size from 12 to 15 ha (30 to 37 acres) were grazed during the project. Cattle had complete and continuous access to the creek and creek pasture throughout the project. Cattle were allowed to rotationally graze the other pastures as needed. During the first year of the project, the pastures were stocked with 54 crossbred cows with calves and 2 bulls (56.7 animal units). During the second year of the project, the pastures were stocked with 72 cows with calves and 3 bulls (76 animal units). The stocking rate was increased in the second year as the cooperating cow-calf operation consolidated herds from two ranches in response to the severe drought, making it easier to feed, water, and care for the livestock until conditions improved. Water troughs supplying well water were present in all pastures but were turned off during the entire first year of the project (with the exception of two weeks in January 2008) forcing the cattle to water in the creek only. In January 2008, several calves became ill with bovine respiratory disease and the water troughs were activated for a period of two weeks then turned off again and they remained off until July 6, 2008. The troughs were then turned on for the second year of the project (treatment period) providing the cattle alternative sites to water. The distance between the water trough and stream in the creek pasture was approximately 137 m (150 yards).

Global Positioning System (GPS) Tracking of Cattle

Global Positioning System (GPS) and Geographic Information System (GIS) technology allow livestock behavior to be evaluated with greater spatial and temporal resolution. Animals can be tracked 24 hours a day using GPS receivers incorporated into collars worn by the animals (Pandey et al. 2009). Agouridis et al. (2004) evaluated GPS collars to determine their accuracy for applications pertaining to animal tracking in grazed watersheds and found that the collars were accurate within 4 to 5 m and thus acceptable for most cattle operational areas (Pandey et al 2009).

Each quarter throughout the 2 year project (Table 1), 6-8 randomly selected cows were collared with Lotek® GPS 3300LR collars (Lotek Wireless Inc., Newmarket, Ontario, Canada). The collar manufacturer reports that with differential correction applied, horizontal accuracies of position readings have errors less than 5 m. Positional readings were collected at a 5 minute fixed interval, providing up to 6,624 locations being recorded by each collar each quarter. Cattle movement was tracked for approximately 3 weeks (21-23 days) and then the collars removed.

Table 1. GPS monitoring dates.

Start Date	End Date	Treatment
7/4/07	7/25/07	No trough
10/3/07	10/25/07	No trough
1/11/08	2/2/08	Trough
4/4/08	4/26/08	No trough
9/19/08	10/9/08	Trough
11/7/08	11/29/08	Trough
2/5/09	2/27/09	Trough
4/10/09	5/2/09	Trough

The collars were then connected to the download unit and GPS Host software to download GPS location data and sensor data. The GPS collars were differentially corrected using data from the National Geodetic Survey (NGS), Continuously Operating Reference Stations (CORS) base-station nearest to the location of the trial for the day before the start of the trial through the day after the end of the trial. Differentially-corrected collar files were then combined with sensor data and converted to database (dbf) files for analysis using ArcGIS.

Data Analysis: GPS Collar Data

To analyze the positional readings collected from the GPS collars, the ArcView (ArcGIS 9, ArcMap Version 9.2, ESRI, Redlands, CA) software package was used. For each collar, the number of positional points in the stream (i.e. within 0.6 m of the midpoint of the stream) and within 4.6 m (15 feet) of the stream were determined using the “Select by Location” function. The percent time spent within each distance from the stream was determined by dividing the number of positional points within each buffer by the total number of positional readings taken. Percent time was then converted to minutes per day.

Estimation of bacteria deposition in the stream

To approximate the deposition of *E. coli* in the stream before and after alternative off-stream water was provided, the percent time spent by cattle in the stream as determined by the GPS collars was first multiplied by published fecal coliform production values (5.4E+09 cfu/AU/day—Metcalf and Eddy 1991) and then converted to *E. coli* concentrations by multiplying the result by 0.63 as EPA suggests (Hamilton et al. 2005).

In-Stream Sampling Procedures

Two sites, PC1 (29°53'35.81"N / 97°45'21.06"W)and PC2 (29°53'23.28"N / 97°45'2.67"W), located at the inflow and outflow of the Clear Fork of Plum Creek to the ranch, respectively, were monitored to assess the effectiveness of alternative off-stream water. These sites are approximately 0.8 km (0.5 mi) apart. Routine grab samples were collected and analyzed on a semi-monthly basis when water was flowing at both sampling sites. Water samples were collected directly from the stream, midway in the water column in visibly flowing water into sterile Whirl-Pak® bags. The bags were held upstream of the sampler and care was exercised to avoid contact with sediment and the surface micro layer of water. After collection, the samples were placed on ice in a cooler for transport to the lab where they were stored at 4°C until analysis.

Flow Calculation

Flow depth was measured bi-monthly in conjunction with water sample collection. Measurements were made in a 0.9 m (3 feet) corrugated metal culvert located at a stream crossing 0.16 km (0.1 mi.) below PC1 and 0.64 km (0.4 mi.) above PC2. Manning's equation (Grant 1991) was used to estimate the flow rate corresponding to each sampling event. The Manning roughness coefficient (**n**) was determined from field measurements of flow depth and velocity and compared to published values by Grant (1991) for corrugated metal subdrains. Slope (**S**) from PC1 to PC2 was determined using field evaluation of slope as well as elevations on Google Earth®. Area (**A**) and hydraulic radius (**R**) was obtained from published values (Grant 1991) based on the observed depth (**d**) in relation to the culvert depth (**D**).

Analytical Methods

Analysis of all water samples was conducted within 6 hours of collection. *E. coli* in water samples were isolated and enumerated using EPA Method 1603 (EPA 2002). If at the highest dilution, counts were greater than 200 colonies, then the count was reported as too numerous to count (**TNTC**). Results were reported as colony forming units (cfu) per 100 mL. Finally, beginning in February 2008 and continuing throughout the remainder of the study, turbidity was determined in water samples using a La Motte® Model 2008 Turbidity Meter and reported in Nephelometric Turbidity Units (**NTU**).

Statistical Analysis: Water Quality Data

The statistical software, Minitab (ver. 15, State College, Pa.: Minitab Inc.), was used for all statistical calculations. Basic statistics and graphical summaries of each dataset were created to evaluate means, medians, quartiles, confidence intervals, and normality (using Anderson-Darling Normality Test). As a majority of datasets were not normally distributed, they were all evaluated with nonparametric statistics. The Mann-Whitney statistical test was used to assess the differences in median (1) minutes cattle spent per day in and within 4.6 and 10.7 m (15 and 35 feet) of the creek; (2) flows; (3) *E. coli* concentrations; (4) *E. coli* loads; and (5) turbidities observed between sites and periods (pre- versus post-treatment). An alpha level of 0.05 was accepted as a nominal level of significance and results were considered statistically significant when a $p < 0.05$ was obtained. Regression analysis was used to evaluate the relationship between *E. coli* concentrations. Coefficients of determination values were used to evaluate the strength of regression equations for *E. coli* concentrations. Finally, analyses of covariance were developed using the Minitab General Linear Model, specifying the responses as PC2 turbidity, the model as the treatment period or calibration period, and the covariate as PC1 turbidity.

Evaluation of *E. coli* loads

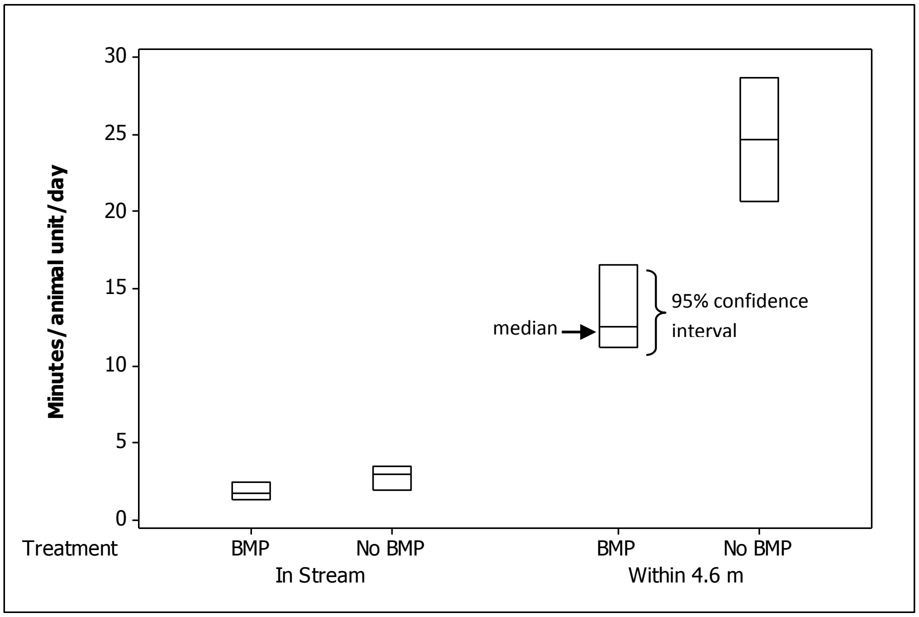
Flow rate at the time each grab sample was taken was expressed on a daily basis and then multiplied by the *E. coli* concentration in the grab sample to obtain a daily load for the upstream and downstream sites, PC1 and PC2, respectively. The daily load contributed by the treatment watershed (i.e. 2S Ranch) was then calculated by subtracting the upstream load from the downstream load (PC1 – PC2). Finally, this was converted to an animal unit basis by dividing the daily loads contributed by the treatment watershed by the number of animal units present in the treatment watershed during the respective period (i.e. 56.7 animal units during the pre-treatment period and 76.1 animal units during the post-treatment period).

Results and Discussion

GPS Tracking of Cattle

Comparison of the amount of time that cattle spent in and near the creek with and without alternative water available clearly indicates that providing alternative off-stream water reduces the amount of time cattle spent in the stream and within 4.6 m (15 feet) of the creek. Because shade along the riparian zone was limited, observed reductions were almost solely the result of cattle drinking from the alternative water supply and not the stream. Analysis of the GPS collar data (Table 2) indicated that providing alternative off-stream water significantly reduced the median amount of time that cattle spent in and near the creek ($p<0.01$).

Figure 3. Boxplot of median (and 95% confidence intervals) number of minutes per day that cattle spent in and near Clear Fork of Plum Creek with and without alternative off-stream water provided



The amount of time cattle spent within 4.5 m of the creek was reduced 52% from 25 to 12 minutes/AU/day when provided with off-stream water, compared to the 75% reduction from 15 to 4.25 minutes/AU/day found by Godwin and Miner (1996) and 51% reduction from 12.7 to 6.2 minutes/AU/day found by Sheffield et al. (1997). Although the percent reductions from this project were similar to those of Sheffield et al. (1997), the amount of time cattle spent near the stream varied substantially among the studies.

Table 2. Descriptive statistics of time (in minutes/day and percent of day) that cattle spent in and near Clear Fork of Plum Creek with and without alternative off-stream water provided.

Distance from creek	Statistic	Without Alt. Water min/day (%)	With Alt. Water min/day (%)	Percent Reduction
In-stream	Mean	3.5 (0.2%)	2.0 (0.1%)	
	sd	2.2 (0.1%)	1.2 (0.1%)	
	Median[a]	3.0 (0.2%)a	1.7 (0.1%)b	43%
	Max	10.5 (0.7%)	5.0 (0.3%)	
4.6 m (15 feet)	Mean	27 (1.9%)	15 (1.0%)	
	sd	12 (0.8%)	8 (0.6%)	
	Median[a]	25 (1.7%)a	12 (0.8%)b	52%
	Max	64 (4.4%)	44 (3.1%)	

Providing alternative off-stream water reduced stream use in this project from 3.0 to 1.7 minutes/AU/day, compared to reductions from 25.6 to 1.6 minutes/cow/day (Miner et al. 1992), 4.7 to

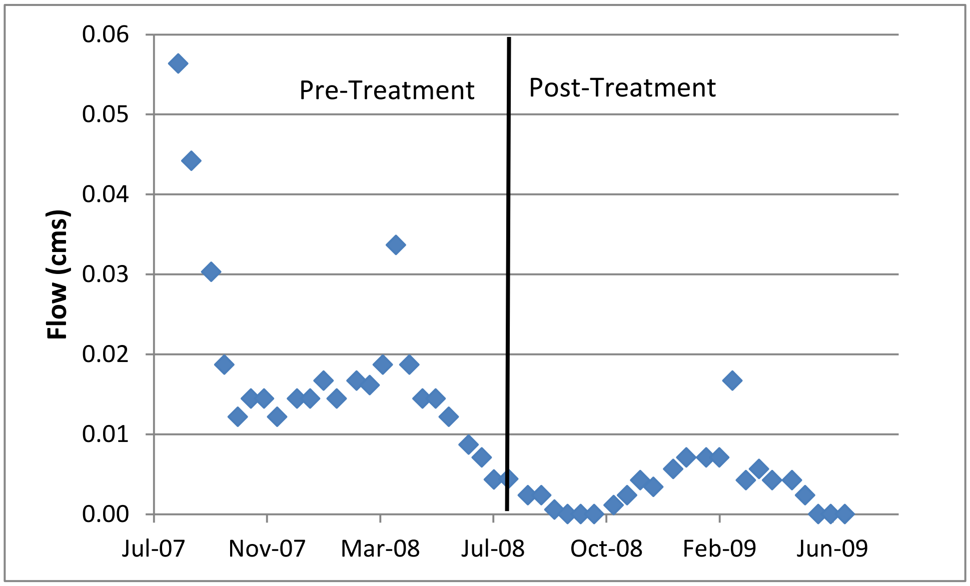
0.7 minutes/AU/day in Oregon (Clawson 1993), and 6.7 to 0.7 minutes/AU/day in Virginia (Sheffield et al. 1997). Based on the percent time cattle spent in the stream (as determined by the GPS collars), along with published fecal coliform loading rates (Metcalf and Eddy 1991) and the *E. coli* conversion factor suggested by EPA (Hamilton et al. 2005), it was estimated that the median daily deposition of *E. coli* in the treatment watershed was reduced from 1.11E+07 cfu/AU/day to 6.34E+06 cfu/AU/day when alternative water was provided.

Percent reductions in the time cattle spent in the stream observed by this project (43%) were significantly lower than those of previous studies (Miner et al. 1992—94%; Clawson 1993—85%; and Sheffield et al. 1997—89%). Additionally, the amount of time cattle spent in the stream varied substantially among the studies indicating the site specific nature of this measurement. As such, TMDL studies which utilize the percent time cattle spend in streams for assessing direct deposition rates would greatly benefit from GPS collars studies to validate models. In comparison to Sheffield et al. (1997) which found that cattle spent 6.7 minutes per day drinking from streams (when alternative water was not available), Clawson (1993) who found 4.7 minutes/cow/day, Miner et al. (1992) who found 25.6 minutes, and this project which found that cattle spend 3 minutes/day in-stream, it was estimated by Orange County TMDL stakeholders that, on average, the cattle drinking water from the bayous spend 10 minutes per day in the stream during June, July, August, or September, and five minutes per day in March, April, May, October, and November, and do not stand in the bayous to drink from December through February (TCEQ 2007a). Using these assumptions from the TMDL, cattle spend 5.4 minutes/day in the stream on average overall throughout the year. Although this estimate is not out of line with the findings of other studies, it is 80% higher than the findings of this project. Since the fecal deposition was assumed to be directly proportional to the time spent in the stream (TCEQ 2007a), if the true amount of time cattle spend in the streams in Orange County, Texas are more in line with the findings of this project, then the amount of bacterial loading allocated to direct deposition from cattle may have been significantly overestimated and could have serious implications for cattle producers.

Flow

The median streamflow observed during the post-treatment period (0.003 cubic meters per second — cms) was significantly lower ($p<0.001$) than that observed during the pre-treatment period (0.014 cms). In the spring of 2008, the region entered into a severe drought which continued throughout the remainder of the project (Figure 4).

Figure 4. Discharge (cms) measured in Clear Fork of Plum Creek, July 2007 through July 2009. Discharge measured on July 26, 2007 of 4.38 cms (154.83 cfs) is not shown.



As a result, during the second year of the project when alternative water was provided, flow was reduced 79% compared to those observed during the pre-treatment period (Table 3). In fact, flow ceased in the creek for three months during year 2 (mid-September through October 2008 and June 2009 until the end of the project).

Table 3. Descriptive statistics of discharge measurements (cms and cfs) in Clear Fork of Plum Creek, July 2007 through July 2009.

Statistic	Pre-Treatment cms (cfs)	Post-Treatment cms (cfs)
Mean	0.201 (7.08)	0.004 (0.13)
sd	0.891 (31.47)	0.004 (0.13)
Median[a]	0.014 (0.51)a	0.003 (0.10)b
Max	4.385 (154.83)	0.017 (0.59)

[a] Mann-Whitney Test ($p<0.001$)

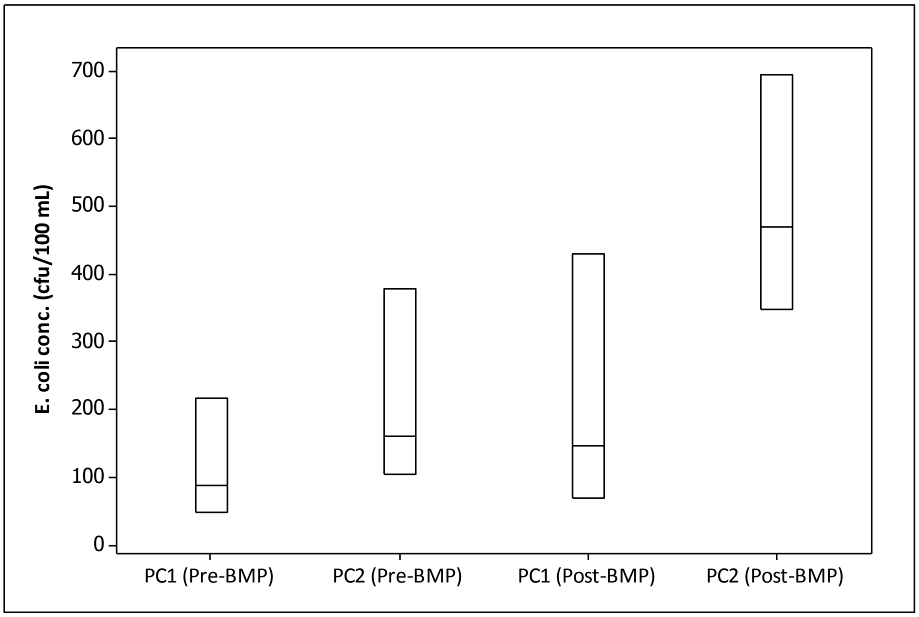
This drought not only impacted flow, but it also impacted ranch management decisions (resulting in the increased stocking rate during the post-treatment period), pasture condition, and ultimately in-stream *E. coli* levels and loading.

E. coli Levels

A total of 84 samples were collected from the two water quality stations (PC1 and PC2), of which 48 were collected during the pre-treatment period (July 2007 to July 2008) and 36 were during the post-treatment period (July 2008 to July 2009). Fewer samples were collected during the post- treatment period as a result of no flow being present in the creek during six of the sampling events.

E. coli levels at PC2 were significantly correlated with those at PC1 during both the pre- and post-treatment periods ($p<0.01$). Coefficient of determination values were moderate to high as well for both the pre-treatment ($r^2=0.58$) and post-treatment periods ($r^2=0.83$). *E. coli* levels increased between PC1 and PC2 during both the pre- and post-treatment periods (Figure 5). During the pre-treatment period, *E. coli* increased 73 cfu/100 mL from a median value of 88 cfu/100 mL at PC1 to 161 cfu/100 mL at PC2, approaching a statistically significant increase ($p=0.09$). During the post-treatment period, the increase was very pronounced, increasing by 323 cfu/100 mL from 147 cfu/100 mL at PC1 to 470 cfu/100 mL at PC2, a significant increase at $\alpha=0.05$ ($p=0.01$).

Figure 5. Boxplot of median (and 95% confidence intervals) *E. coli* concentrations at site PC1 and PC2 before and after alternative water was provided (i.e. Pre- and Post-BMP, respectively).



This pronounced increase during the post-treatment period was unexpected and inconsistent with the estimated 43% reduction in direct deposition of *E. coli* calculated based on the GPS collar data. The extreme drought which reduced flows by 79% and influenced ranch management decisions to increase stocking rate 34% provide a logical explanation for much of this increase. With more cattle having access to the creek and less flow to dilute any direct deposition, it would be expected that concentrations would increase, even with the decreased amount of time cattle spent in the stream during the post-treatment period. Based on the pre-treatment cattle numbers (56.7 AU), median flow (0.014 cms), and estimated median daily deposition of *E. coli* in the stream (1.11E+07 cfu/AU/day), it was calculated that direct deposition would contribute 52 cfu/100 mL to the median inflowing (PC1) concentration (88 cfu/100 mL) thus, inflowing *E. coli* and direct deposition together (140 cfu/100 mL) represent an estimated 87% of the median *E. coli* concentration observed at PC2 during the pre-treatment period (161 cfu/100 mL). Using the same method for the post-treatment period, it was calculated that direct deposition would contribute 186 cfu/100 mL to the median inflowing (PC1) concentration (147 cfu/100 mL) thus, inflowing *E. coli* and direct deposition (333 cfu/100 mL) represent an estimated 71% of the median *E. coli* concentration observed at PC2 during the pre-treatment period (470 cfu/100 mL).

This evaluation suggests that inflowing *E. coli* concentrations, direct deposition by cattle, and flow all contribute to the *E. coli* concentrations at PC2; however, they do not fully explain the concentrations observed. Approximately 13% of the *E. coli* during the pre-treatment period and 29% during the post-treatment period are unaccounted for. At least a portion of this likely results from the variability observed in the *E. coli* concentrations. *E. coli* concentrations were highly variable, with standard deviations greatly exceeding mean *E. coli* concentrations (

Table 4). Natural variability in *E. coli* concentrations resulting from the complex nature of bacterial deposition, survival, and transport is likely a significant factor in determining the observed *E. coli* concentrations (Harmel et al. 2010). Due to the drought and resulting increased stocking rate, declining range condition, and reduced flows during the post-treatment period, significant changes in the fate and transport of *E. coli* occurred making comparisons of the pre- and post-treatment periods difficult.

Table 4. Descriptive statistics of *E. coli* concentrations (cfu/100 mL) in Clear Fork of Plum Creek at PC1 and PC2, July 2007 through July 2009

Site	Statistic	Pre-Treatment (cfu/100 mL)	Post-Treatment (cfu/100 mL)
PC1 (control)	Mean	365	552
	sd	689	1305
	Median[a]	89	147
	Max	2600	5700
PC2 (treatment)	Mean	427	1249
	sd	704	2315
	Median[b]	161	470
	Max	3300	8100

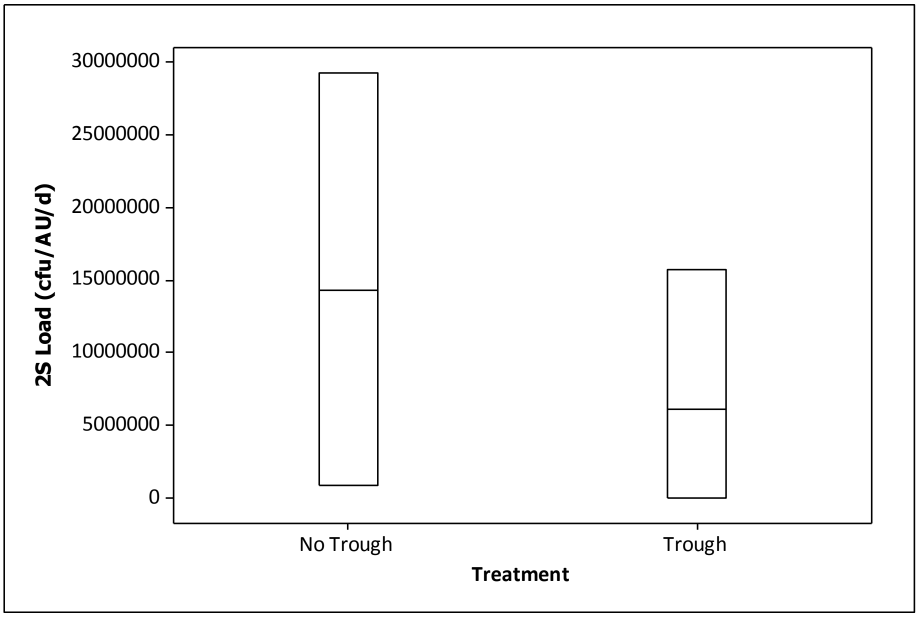
Measurement uncertainty may have also contributed to data variability. McCarthy et al. (2008) found that combined uncertainty in discrete *E. coli* samples ranged from 15 to 67% and averaged 33%. However, because the field technician, collection methods, lab analyst, and lab methods used were consistent throughout the project, this impact is considered nominal.

Finally, although not quantified, increased use of the creek by wildlife during the drought could have also impacted *E. coli* concentrations during the post-treatment period. It is logical that wildlife would increasingly use the creek as other water sources in the area were depleted. Thus, even though use of the stream by cattle as documented by the GPS collars decreased significantly when alternative water was provided, wildlife use increases could have potentially contributed to the resulting overall increase in *E. coli* concentrations.

E. coli Loading

Contrary to the *E. coli* concentrations results, *E. coli* loading (cfu/AU/day) was substantially lower during the post-treatment period (Figure 6). The median post-treatment *E. coli* load (6.15E+06 cfu/AU/day) was 57% lower than that observed during the pre-treatment period (1.44E+07 cfu/AU/d); however, the observed difference was not statistically significant ($p=0.47$).

Figure 6. Boxplot displaying medians and 95% confidence intervals of observed in-stream *E. coli* loading (cfu/AU/day) for the pre- and post-treatment periods (i.e. no trough and trough, respectively).



Due to the variability in the loading observed during the pre-treatment period, a 99% change in loading or greater would have been needed to observe a significant difference in the pre- and post-treatment loadings. Despite this, these results are remarkably similar to the estimated pre- and post-treatment *E. coli* deposition in the stream of 1.11E+07 and 6.34E+06 cfu/AU/d, respectively, calculated using the GPS collar data and published fecal coliform data.

Even though observed *E. coli* loading and those estimated using GPS collar data are remarkably similar and both indicate reductions of more than 40%, this project cannot conclusively attribute *E. coli* loading reductions to providing alternative water because of the lack of statistical significance of these observations, the significant decrease in flow observed during the post-treatment period, and the observed increase in *E. coli* levels during the post-treatment period.

Turbidity

Median turbidity levels (Table 5) were typically 40% higher at PC1 than at PC2 indicating that turbidity generally improved as the creek flowed through the treatment watershed; however, only during the pre-treatment period were median turbidity levels significantly lower at PC2. Turbidity levels flowing into the treatment watershed played a greater role in determining the levels at PC2 during the post-treatment period. During the post-treatment period, turbidity at PC1 and PC2 were significantly related ($p=0.01$; $r^2=36\%$), unlike the pre-treatment period when turbidities at PC1 and PC2 were not related

($p=0.98$, $r^2=0\%$). Finally, an analysis of covariance between the pre-treatment and post-treatment periods indicated that there was no significant treatment effect of providing alternative water on turbidity ($p=0.93$).

Table 5. Descriptive statistics of turbidity (NTU) measured at PC1 and PC2 during the pre- and post-treatment periods.

Period	Statistic	PC1 (control)	PC2 (treatment)
Pre-Treatment	Mean	35	17
	sd	20	8
	Median[a]	29a	16b
	Max	62	31
Post-Treatment	Mean	14	12
	sd	11	13
	Median[b]	10a	6a
	Max	43	47

[a] Mann-Whitney Test ($p<0.01$)

[b] Mann-Whitney Test ($p=0.19$)

Turbidity was primarily measured to evaluate its use as a predictor of *E. coli* concentration; however, regression analysis results indicated that turbidity was not a good predictor of *E. coli* concentrations in Clear Fork of Plum Creek ($p=0.51$; $r^2=1\%$). This is in contrast to the findings of Huey and Meyer (2010) who found that turbidity was an effective indicator of *E. coli* in the upper Pecos River basin in New Mexico. Additionally, Collins (2003) developed a statistical model to determine median *E. coli* concentrations based on turbidity which explained 70% of the observed *E. coli* variance. Similarly, Brady et al. (2009) found that a model based on turbidity and rainfall performed well at correctly predicting *E. coli* concentrations (81% correct responses) in the Cuyahoga River, Ohio. Thus, turbidity does have utility as a predictor in some watersheds; however, this must be determined on a case by case basis and used with caution.

Summary and Conclusions

Use of GPS collars was found to be a very useful tool, one which would benefit not only future BMP evaluations, but would also benefit TMDL studies which utilize the percent time cattle spend in streams for assessing direct deposition rates. GPS collar studies could be used to quickly validate models allowing them to more accurately predict *E. coli* loading. In this project, GPS collars indicated that the amount of time cattle spent in the stream could be reduced 43% from 3.0 to 1.7 minutes/animal unit/day by providing alternative off-stream water. As a result of this, direct deposition of *E. coli* into Clear Fork of Plum Creek was estimated to be reduced from 1.11E+07 to 6.34E+06 cfu/animal unit/day. Observed pre- and post-treatment *E. coli* loads suggested similar reductions; however, this project could not conclusively attribute the observed *E. coli* loading reductions to providing alternative water because of the lack of statistical significance of these observations, the decrease in flow observed during the post-treatment period, and the observed increase in *E. coli* levels during the post-treatment period. A drought during the post-treatment period which reduced flows by 79% and influenced ranch management decisions to increase stocking rate 34% explain much, but not all, of the increase in *E. coli* levels observed. Other probable factors impacting the observed *E. coli* levels include natural variability, changes in fate and transport due to the drought, and potentially increased contributions from wildlife.

Although this project did not provide conclusive evidence of reduced *E. coli* levels resulting from providing alternative off-stream water supplies, this practice is still highly recommended as a result of the significant reductions observed in the time cattle spent in and near the stream, the 51% reduction in fecal coliform documented by Sheffield et al. (1997), and the 85 to 95% decrease in median baseflow *E. coli* load found by Byers et al. (2005). These reductions are comparable to those provided by fencing of streams which reduces *E. coli* 37-46% (Meals 2004; Meals 2001) and fecal coliform 30-94% (Hagedorn et al. 1999; Line 2002; Lombardo et al. 2000; Line 2003; Meals 2001; Meals 2004; Brenner 1996; Brenner et al. 1994; and Cook 1998). Further, this project supports McIver (2004) which noted that alternative water supplies alone will not achieve water quality improvements unless it is implemented in conjunction with good grazing management (i.e. balance stocking rate with available forage, evenly distribute grazing, avoid grazing during vulnerable periods, and provide ample rest after grazing). As a result of the severe drought, these principles were not adhered and water quality improvements were not observed.

Finally, unlike others, this project did not find turbidity to be a good predictor of *E. coli*. Thus, use of turbidity as an indicator must be assessed on a case by case basis and used with caution.

Acknowledgements

This evaluation and demonstration of alternative water supplies was funded by the Texas State Soil and Water Conservation Board with Clean Water Act, Section 319(h) funding from the Environmental Protection Agency. I would like to thank Bill and Doris Steubing for allowing us access to their ranch and working with us for 2 years as we gathered cattle 16 times over the course of the project, Dr. Bob Lyons for all his expertise with the GPS collars, Garrett Norman for collecting the water samples rain or shine throughout the project, and Heidi Mjelde for keeping the lab supplied with agar plates and buffer solution for all the analyses.

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Appendix F Draft Grazing Management Manuscript

Assessment of cattle grazing effects on *E. coli* runoff

Abstract

Runoff of *E. coli* and other fecal indicator bacteria from grazing lands has been identified as a significant source of bacterial contamination in need of reductions to improve water quality. Development of best management practices to address these bacterial issues is critical to the success of watershed restoration efforts. The effect of grazing management was evaluated to assess its effectiveness as a best management practice. *E. coli* levels in runoff from grazed and ungrazed rangeland, improved pasture, and native prairie sites were monitored from November 2007 through October 2010.

The project found that rotational grazing, if timed appropriately, was a very effective practice for reducing *E. coli* runoff. The impact of grazing timing in relation to runoff event was much more significant than the impact of level of grazing (i.e. moderately stocked or heavy stocked) or stocking rate. When runoff occurred more than two weeks following grazing, *E. coli* levels in runoff were decreased more than 88%. As a result of these findings, it is recommended that creek pastures and other hydrologically connected pastures be grazed during periods when runoff is less likely (e.g. summer and winter in much of Texas) and upland sites be grazed during rainy seasons when runoff is more likely to occur.

Background levels were considerable and relatively consistent among sites, with median levels ranging from 3,500 to 5,500 cfu/100 mL. These levels should be considered when applying water quality models to develop total maximum daily loads and other efforts. Impacts of wildlife and other non-domesticated animals on *E. coli* runoff were also significant, being responsible for over 80% of the loading in 2009 at three sites. Finally, it was observed that over 90% of the samples exceeded Texas Water Quality Standards for *E. coli*. In light of this and other findings of this project, it is recommended that exemptions from the current standards be made for storm flows and wildlife, or additional research be conducted to accurately define bacterial quality for runoff and establish practical water quality standards.

Key Words

Grazing management—*E. coli*—cattle—stocking rate—runoff

Livestock grazing on pasture and rangeland is frequently identified as a source of bacteria requiring reductions to improve surface water quality (TCEQ 2007, TCEQ 2008b). Runoff of bacteria deposited with manure onto land surfaces have resulted in the observation of direct relationships between the presence of cattle and increased fecal coliform levels (Tiedemann et al. 1987). In New Zealand, elevated *E. coli* concentrations have been observed in streams flowing through grazed pastures (Donnison et al. 2004). The Environmental Protection Agency (EPA 2001) reports fecal coliform levels in runoff from grazed pastures range from 1.2E+02 to 1.3E+06 organisms/100 mL, an order of magnitude or more higher than background levels (1.5E+01 to 4.5E+05 organisms/100 mL). Fecal coliform levels in runoff from grazed pasture in south-central Nebraska were 5 to 10 times higher than levels in runoff from ungrazed areas (Doran and Linn 1979, Doran et al. 1981). In Colorado, the presence of cattle increased in-stream fecal coliform concentrations by 1.6 to 12.5 times background levels (Gary et al. 1983).

Contamination of streams can arise through direct deposition of feces into streams, surface runoff, and subsurface flows. Surface runoff is a key process for delivery of *E. coli* to streams (Collins et al. 2005). Development and implementation of appropriate best management practices (BMPs) to reduce bacterial loadings from grazing lands are critical to the success of water resource improvement and protection efforts in impaired waterbodies throughout Texas. Excessive levels of fecal indicator bacteria (i.e. *E. coli*, *Enterococcus*, and fecal coliforms) are the number one cause of water quality impairment in Texas. Fecal indicator bacteria, which are common inhabitants of the intestines of all warm-blooded animals, are responsible for over half of the water quality impairments in Texas (295 of the 516 impairments (TCEQ 2008a).

E. coli levels in beef cattle feces on grazed pastures are high, ranging from 1.0E+05 to 7.9E+05 cfu/gram wet weight. Grazing beef cattle excrete from 28.4 kg (62.6 pounds) to 32.0 kg (70.5 pounds) wet weight per animal per day (McDowell et al. 2008). Resulting deposition rates on an animal unit basis thus range from 2.8E+09 to 4.2E+10 cfu/AU/d. These levels vary daily as well as with livestock type, diet, and season (Oliver et al. 2010), with significantly lower levels excreted in the winter (McDowell et al. 2008).

Within two days of deposition however, cow pats form a well-defined crust which keeps the interior moist. Once formed, leaching losses are lowered to less than 1%. Subsequent rainfall can, however, rehydrate the cow pat and stimulate regrowth of *E. coli* (Sinton et al. 2007).

Substantial quantities of *E. coli* may also accumulate in the soil. Oliver et al. (2010) detected *E. coli* levels ranging from below detection to 10^6 cfu/g dry soil between cow pats on grazed sites which served as an additional chronic source of *E. coli* in runoff.

The extent and severity to which bacteria from grazing lands affect water quality is generally a function of (1) the number and size of cattle in the pasture, (2) the location of fecal deposits in relation to waterbodies, (3) site characteristics affecting adsorption and runoff, and (4) bacterial survivability between time of fecal deposition and runoff events (Larsen et al. 1994).

Use of the correct stocking rate is the most important consideration in grazing management (Redmon 2002; NRCS 2007). The number and size of cattle (i.e. animal units) in a given pasture has an obvious impact on the quantity of manure produced and thus the quantity of bacteria deposited on the land surface or into the stream. As the number of animal units (454.5 kg live weight) on a given amount of land over a certain period of time (i.e. stocking rate) increases, the quantity of feces, and thus bacteria deposited on the given tract of land, increases. A number of studies have found that, as grazing intensity increases, in-stream coliform levels increase as well (Larsen et al. 1994; Gary et al. 1983). However, observed fecal coliform levels in runoff vary (Table 6).

Table 6. Geometric mean values for fecal coliform concentrations (cfu/100 mL) in runoff from ungrazed and grazed pastures and corresponding annual stocking rates and grazing days (in animal unit days per hectare—AUD/ha and animal unit days per acre—AUD/ac).

Site	Reference	Stocking Rate[1] ha/AUY (ac/AUY)	Grazing – AUD/ha (AUD/ac)	Fecal coliform (cfu/100 mL)
Ungrazed pasture	Doran et al. 1981	0.0	0.0	6.6E+03
Grazed pasture	Doran et al. 1981	1.2 (2.9)	308 (124)	5.7E+04
Ungrazed pasture	Robbins et al. 1972	0.0	0.0	1.0E+04
Grazed pasture	Robbins et al. 1972	0.5 (1.2)	773 (313)	3.0E+04
Grazed pasture	Edwards et al. 1997	0.9 (2.3)	386 (156)	3.7E+03
Grazed pasture	Edwards et al. 1997	0.9 (2.3)	386 (156)	2.7E+04
Grazed pasture	Edwards et al. 1997	1.2 (3.0)	300 (121)	5.5E+04
Grazed pasture	Edwards et al. 1997	3.1 (7.7)	117 (48)	8.7E+03

[1] Stocking rate in hectares per animal unit year and acres per animal unit year

[2] FC - fecal coliform colony forming units per 100 mL

The location of fecal deposition relative to major runoff contributing areas (e.g. variable source areas, riparian areas, etc.) is an important factor determining potential for *E. coli* in cow pats to be transported downstream (Tate et al. 2003). Larsen et al. (1994) found that manure deposited 0.6 m (2 feet) from a stream contributed 83% less bacteria and manure deposited 2.1 m (7 feet) from a stream contributed 95% less bacteria than that deposited directly in a stream. Manure deposited throughout the pasture can result in approximately 0.4 to 2.0% of a pasture being covered in fecal deposits annually. However, cow pat distribution in pastures is not uniform and is dependent on complex, interacting environmental and management factors (Tate et al. 2003). Much of the feces are concentrated in congregation areas such as near watering facilities, fence lines, gates, and bedding areas. Runoff from these areas can carry viable bacteria from the cow pats into nearby streams (Larsen et al. 1994).

Variability in bacterial concentrations in runoff may result from the characteristics of the initial site of deposition including soil type, slope, drainage patterns, and management (FCA 1999). Ferguson et al. (2003) suggests that soil type strongly impacts immobilization of bacteria from surface runoff. However, Soupir and Mostaghimi (2011) recently found that greater than 95% of *E. coli* are transported unattached to other particles indicating that this may not be as important a factor as initially considered. More important is the hydrology of the site (Larsen et al. 1994) which is affected by soil type. Runoff and transport of microbes would be expected to be higher on Hydrologic Soil Group D soils due to the increased runoff from these soil types. Both rainfall depth and intensity have been found to be important to the release of pathogens from fecal matter and transport to surface water (Ferguson et al. 2003). However, because bacteria are living organisms and their transport is complex and impacted by adsorption, straining (i.e. filtration), interception, entrapment, and sedimentation, bacterial levels are difficult to simulate using routine hydrologic models. In addition, bacterial levels in runoff and streams are greatly affected by their survival and potential re-growth in the environment.

Finally, the timing of fecal deposition relative to runoff events greatly impacts the potential for *E. coli* in cow pats to be transported downstream (Tate et al. 2003). *E. coli* populations in soil and manure generally exhibit progressive decline which is typically described using first order kinetics. *E. coli* die-off rates of 0.06/day have been observed in cow pats in the UK and New Zealand (Oliver et al. 2010; Sinton et al. 2007). However, their fate is not accurately predictable under complex natural conditions. If nutrients and energy sources are available and key abiotic conditions are favorable, *E. coli* can survive and even grow in open environments. However, under fluctuating natural conditions, *E. coli* growth and survival can be disparate (Van Elsas et al. 2011). Recent studies show initial increases in *E. coli* concentrations (1 to 1.5 orders of magnitude), typically in the first 6 to 10 days following deposition, followed by a decline (Sinton et al. 2007; Van Kessel et al. 2007; Oliver et al. 2010) once moisture levels fall below 70% to 75%. Even in the decline phase, bacterial populations in cow pats remain metabolically active providing the potential for continued growth should conditions become favorable (Thelin and Gifford 1983). Because cow pats contain needed nutrients, *E. coli* can persist in cowpats as long as water and temperature are suitable (Sinton et al. 2007). As a result, the potential for bacterial contamination of waterbodies by rainfall runoff can exist for long periods after cattle are removed from a site (Thelin and Gifford 1983; Larsen et al. 1994). *E. coli* has been observed to survive 30-365 days in soil, 10-182 days in cattle manure, 99 days in grass, and 35 days in water depending on the chemical, physical, and biological composition of feces, soil, and water it was deposited in (Crane and Moore 1986, University of Wisconsin 2007a&b). Not only can *E. coli* persist in cow pats for long periods, but it can remain as high as 10^4 cfu/g five months after deposition. Sinton et al. (2007) determined that the time to achieve a 90% decrease (T_{90}) in *E. coli* levels in cow pats ranged from 38 to 66 days, depending on season with *E. coli* being more persistent during Spring, Summer, and Fall and less persistent in the Winter. As a result of this persistence, in-stream fecal coliform levels may remain elevated for up to 9 months following cattle removal (Tiedemann et al. 1988).

Nevertheless, risk of pollution is greatest immediately after deposition of manure. Thelin and Gifford (1983) found that fecal coliform concentrations in cow pats less than five days old released greater than 1.0E+06 cfu/100 mL whereas 30 day old cow pats released 4.0E+04 cfu/100 mL (96% less) indicating that downstream water quality is at least partially dependent on days since grazing ceased. If runoff occurs the day of fecal deposition, 58 to 90% of the fecal coliform in the manure may be transported in the runoff (Crane et al. 1983, Coyne et al. 1995). Similarly, *E. coli* levels in runoff in pastures grazed by sheep may range from 10^5 to 10^6 cfu/100 mL, while levels in runoff occurring 75 days after grazing ranged from 10^3 to 10^4 (Collins et al. 2005). Conversely, if weather conditions are dry and deposition is on well-drained soils, bacterial runoff is greatly reduced (Ogden et al. 2001).

Finally, season appears to play an important role as *E. coli* excretion rates are typically lower in the winter (McDowell et al. 2008), as is the persistence of *E. coli* (Sinton et al. 2007) likely explaining the observation by Edwards et al. (1997) that levels of fecal coliforms and fecal streptococci in runoff from four pastures in Northwest Arkansas were higher in warmer months.

A number of practices have been identified to reduce bacterial runoff from grazing lands. The primary focus of these practices is to maintain adequate ground cover in order to improve the filtering capacity of the vegetation and enhance infiltration of rainfall and runoff (NRCS 2007). This in turn minimizes erosion and runoff (FCA 1999) and thus pollutant runoff problems (Ball et al. 2002). Healthy pastures have higher infiltration rates, which promote soil filtration and the removal of bacteria during soil passage by sorption/ desorption, inactivation, and predation (Ferguson et al. 2003).

Proper grazing management is essential to maintaining adequate ground cover as well as minimizing livestock concentration areas and as such is critical to addressing bacterial loading from grazing lands (NRCS 2007). Proper grazing management includes (1) balancing animal demand with available forage, (2) distributing grazing evenly, (3) avoiding grazing during vulnerable periods, and (4) providing ample rest after grazing (Fitch et al. 2003). Through careful planning of the duration, frequency, intensity, and season of grazing near surface waters, forages can be maintained or improved while also providing water quality benefits (Larsen et al. 1994) and reducing soil erosion.

Watershed scale *E. coli* runoff data is greatly needed to support ongoing and future TMDL and watershed planning activities and models. Further, data is needed on background runoff levels, levels in runoff from grazed sites with vary levels and intensity of grazing, and impacts of practices such as Prescribed Grazing on *E. coli* runoff. Published data on *E. coli* runoff from grazed pastures is currently sparse (McDowell et al. 2008) with much of the existing data being derived from laboratory experiments and in-stream monitoring of grazed watersheds. However, laboratory derived data is not sufficient for development of accurate models at the farm and watershed scale (Oliver et al. 2010) and monitoring of streams does not allow the discrimination of surface runoff, subsurface flows, direct deposition, and resuspension of sediment bound *E. coli* (Collins et al. 2005). The objective of this project is to assess *E. coli* concentrations and loads in runoff at the small watershed scale from grazed and ungrazed pastures and assess the effect of grazing, both in terms of stocking rate (ha/animal unit) and level of grazing (e.g. moderate grazing, heavy grazing), on *E. coli* levels in runoff.

Materials and Methods

Site Descriptions

Assessment of the effect of grazing on *E. coli* levels in runoff took place at 7 separate sites (

Table 7) located at the (1) USDA-Agricultural Research Service (ARS) Watersheds near Riesel, (2) Welder Wildlife Foundation near Sinton, and (3) Texas A&M University (TAMU), Department of Animal Science, Beef Cattle Systems Center located west of College Station, along the banks of the Brazos River.

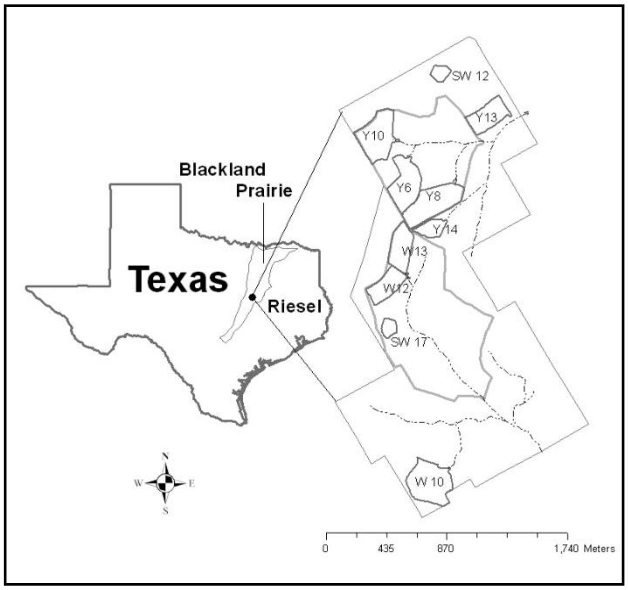
Table 7. Sample Sites

Site	Lat/Long	Site Description
WWR1	28° 6'55.97"N / 97°21'20.82"W	Ungrazed Rangeland
WWR3	28° 6'52.60"N / 97°21'13.83"W	Moderately Stocked Rangeland
SW12	31° 28’48”N / 96° 52’59”W	Ungrazed Native Prairie
SW17	31° 27’45”N / 96° 53’14”W	Moderately Stocked Bermudagrass
BB1	30° 31'44.3"N / 96°24'58.3"W	Ungrazed Tifton 85 Bermudagrass
BB2	30° 31'47.5"N / 96°24'57.7"W	Moderately Stocked Tifton 85 Bermudagrass
BB3	30° 31'47.7"N / 96°24'57.9"W	Heavy Stocked Tifton 85 Bermudagrass

USDA-ARS Watersheds near Riesel, Texas

The USDA-ARS Grassland, Soil and Water Research Laboratory in Riesel, TX, has been one of the most intensively monitored hydrological research sites in the country since establishment in the 1930s (Harmel et al. 2007). It is located in the Blackland Prairie region on the border of Falls and McLennan counties (Figure 7). Houston Black clay soils dominate the region. This soil is very slowly permeable when wet; however, preferential flow associated with soil cracks contributes to high infiltration rates when the soil was dry.

Figure 7. Sample sites at Riesel.



Mean annual rainfall is approximately 36 inches. Thirteen runoff stations are in operation on the research site to monitor sub-watersheds under both pasture and cropland management. Two 1.2 ha sites were used to evaluate grazing management, SW12 and SW17. The average slope of SW12 is 3.8%, while slope averages 1.8% at SW17.

Welder Wildlife Foundation near Sinton, Texas

The Rob and Bessie Welder Wildlife Foundation is located on a 3,156 ha (7,800-acre) native wildlife refuge 8 miles north of Sinton, Texas, in the Coastal Bend region of the state (Figure 8). The Welder is in the Copano Bay watershed, site of an ongoing bacterial TMDL. Three 1 ha (2.4-ac) watershed sites had previously been established to monitor runoff by the Texas A&M University Rangeland Ecology and Management Department in 2000 to study the effects of shrub management on water quality and quantity on Coastal Bend rangeland. However, the berms on site WWR2 failed preventing data collection during this project.

Figure 8. Welder Wildlife Refuge Sites.

The Welder is typical of South Texas rangelands. It is located in the transition zone between the Gulf Prairies and Marshes and the South Texas Plains and contains many plants of tropical or subtropical origin. The Welder has never been cultivated and has historically been managed for livestock (Stewart 2003). The watershed sites are located on chaparral-mixed grass communities on the east and west sides of Paloma draw, approximately 4 miles from the foundation headquarters. Victoria clay (0-1% slopes) underlay the upper quarter to third of the watershed sites and Monteola clay (5-8% slopes) underlay the remainder. Both soils are classified as Hydrologic Soil Group D soils.

Texas A&M University, Department of Animal Science, Beef Cattle Systems Center

The final site for the evaluation of the effects of grazing management on bacterial runoff was the Texas A&M University, Department of Animal Science Beef Cattle Systems Center located west of College

Station on the Brazos River. This site was used primarily for row crop production prior to initiation of this project. In October 2007, berms were constructed around three 1-ha watershed sites (Figure 9) and slope modified so that each site would drain to the watershed outlet. Following berm construction, all sites were sprigged with Tifton 85 bermudagrass. The three watershed sites are under a ½-mile center pivot irrigation system affording the opportunity to irrigate. However, due to the expense of irrigating, it was only used on a limited basis, primarily for establishing the Tifton 85 on the watershed sites and elsewhere in the pasture under the pivot.

Figure 9. Beef Cattle Systems Center sampling sites.

These sites are located in the East Central Texas Plains Floodplains and Low Terraces ecoregion (Omernik 1987). Annual precipitation averages 40 inches. Soils within the project area are comprised of Belk clay, a heavier-textured alluvial soil (Hydrologic Soil Group D) found along the Brazos River. Measured slope averages 0.2%.

Pasture Management

Three different treatments were evaluated — ungrazed, moderately stocked, and heavy stocked (double the stocking rate of the moderately stocked treatment). All sites were fenced so that cattle grazing could be controlled. Ungrazed sites included SW12, WWR1, and BB1. Site SW12 is notable in that this ungrazed native prairie reference site has not been stocked since the Riesel Research Center was established in 1937 (Harmel et al. 2006). WWR1 represented ungrazed brushy rangeland. Finally, BB1 represented ungrazed improved pasture; however, the electric fence went down briefly on March 11, 2009, November 13, 2009 and February 1, 2010 allowing limited cattle access to the site.

Moderately stocked sites included SW17, WWR3, and BB2 and only site BB3 was heavy stocked. Both BB2 and SW17 were moderately grazed bermudagrass sites. The stocked sites were not stocked continuously; instead, over the course of the project, six to seven grazing treatments at each site (Table

10). Additionally, at sites BB2 and BB3, electric fences went down on February 1-8, 2010; however minimal grazing occurred on the sites during this time. Grass height was monitored monthly to determine grazing timing. These grazing treatments allowed the evaluation of the impact of a variety of stocking rates on *E. coli* runoff.

Table 8. Grazing Treatments.

Location	Site	Start	End	Stocking Rate (AU/ha)[1]	Stocking Rate (AUD/ha)[2]	Stocking Rate ha/AUY (ac/AUY)[3]
Riesel	SW17	9/12/07	11/14/07	1.1	70	2.6 (6.4)
	SW17	2/25/08	6/2/08	1.1	109	1.7 (4.1)
	SW17	11/5/08	4/21/09	1.1	185	1.6 (3.9)
	SW17	5/1/09	6/3/09	1.1	37	1.7 (4.1)
	SW17	7/15/09	11/6/09	1.1	126	1.1 (2.6)
	SW17	5/3/10	5/24/10	1.1	23	2.3 (5.6)
	SW17	7/19/10	8/27/10	1.1	43	2.5 (6.2)
Welder	WWR3	12/1/07	2/13/08	0.4	31	11.6 (28.7)
	WWR3	4/18/08	4/28/08	2.6	26	6.4 (15.7)
	WWR3	10/20/08	10/25/08	2.9	15	5.1 (12.5)
	WWR3	4/27/09	5/1/09	3.4	14	11.7 (29.0)
	WWR3	6/21/10	6/22/10	2.6	3	140.9 (348.0)
	WWR3	9/1/10	9/11/10	2.6	26	12.8 (31.6)
BCSC	BB2	1/12/09	1/16/09	4.0	16	22.8 (56.3)
	BB2	5/22/09	6/5/09	6.1	79	3.8 (9.5)
	BB2	8/7/09	8/8/09	6.4	6	3.6 (8.9)
	BB2	8/12/09	8/19/09	6.4	46	2.5 (6.1)
	BB2	11/12/09	11/17/09	18.4	90	1.5 (3.8)
	BB2[4]	2/1/10	2/8/10	2.5	17	1.5 (3.8)
	BB2	6/21/10	7/2/10	17.7	194	1.7 (4.3)
	BB3	1/12/09	1/16/09	8.0	32	11.4 (28.2)
	BB3	5/22/09	6/5/09	13.4	175	1.8 (4.4)
	BB3	8/7/09	8/8/09	12.8	13	1.7 (4.1)
	BB3	8/12/09	8/19/09	12.8	92	1.2 (2.9)
	BB3	11/12/09	11/17/09	36.8	180	0.7 (1.8)
	BB3[4]	2/1/10	2/8/10	2.5	17	0.8 (1.9)
	BB3	6/21/10	7/2/10	31.7	346	1.0 (2.5)

[1] Animal units per hectare

[2] Animal unit days per hectare

[3] Annual stocking rate in hectares per animal unit and acres per animal unit

[4] Electric fences went down allowing cattle access

Edge of Field Sampling Procedures

Flow-weighted composite edge of field samples from the 7 watershed sites were collected using ISCO 6712 full-size portable samplers with single bottle configuration into sterile polyethylene 4-gallon round bottles. Flow from each watershed site was measured with ISCO 730 Module bubble flow meters. Flow data were downloaded at least monthly using an ISCO 581 Rapid Transfer Device (RTD). BB1, BB2, BB3, WWR1, and WWR3 were equipped with berms and 90^{o} v-notch weirs to aid in collection and measurement of runoff, while SW12 and SW17 were monitored using 0.9 m H-flumes. Runoff was monitored for a period of 3 years, from November 2007 through October 2010, at WWR1, WWR3, SW12, and SW17. Runoff at sites BB1, BB2, and BB3 was monitored for a period of 2 years, from November 2008 through October 2010. The ISCO samplers at sites WWR1, WWR3, BB2, and BB3 enable when the water level exceeds 6 mm (0.02 foot) and then collects 50 mL for every 4.2 m^3 (150 cubic feet) of runoff. The ISCO sampler at BB1 enables when the water level exceeds 6 mm (0.02 foot) and then collects 25 mL for every 2.1 m^3 (75 cubic feet) of runoff. All ISCO samplers were programmed to rinse sample tubing with ambient water prior to collection of each samples. Following each event, samples were retrieved as soon as possible (typically within 24 hours) from the ISCO samplers and placed on ice in a cooler for transport to the lab where they were stored at 4^{o}C until analysis.

Analytical Methods

Analysis of all water samples was conducted within 6 hours of collection. *E. coli* in water samples were isolated and enumerated using EPA Method 1603 (EPA 2006). If at the highest dilution, counts were greater than 200 colonies, then the count was reported as too numerous to count (TNTC). Results were reported as colony forming units (cfu) per 100 mL. Finally, beginning in February 2008 and continuing throughout the remainder of the project, turbidity was determined in water samples using a La Motte® Model 2008 Turbidity Meter and reported in Nephelometric Turbidity Units (NTU).

Statistical Analysis

The statistical software, Minitab (ver. 15, State College, Pa.: Minitab Inc.), was used for all statistical calculations. Basic statistics and graphical summaries of each dataset were created to evaluate means, medians, quartiles, confidence intervals, and normality (using Anderson-Darling Normality Test). As a majority of datasets were not normally distributed, all were evaluated with nonparametric statistics. The Mann-Whitney statistical test was used to assess differences in median concentrations and loads observed between sites and treatments. An alpha level of 0.05 was accepted as a nominal level of significance and results were considered statistically significant when a $p < 0.05$ was obtained.

Results and Discussion

Comparison of E. coli Concentrations among Sites

E. coli concentrations were measured in 127 water samples collected from the seven sites over the three year project. Observations varied greatly with standard deviations exceeding mean values at most sites (Table 11). When *E. coli* concentration data from all years at each site are combined and evaluated, only at Riesel is the effect of grazing on median levels in runoff indicated. Median *E. coli* concentrations at the ungrazed SW12 were 67% lower than those observed at the moderately grazed SW17 (p=0.03). No significant differences were observed in median *E. coli* concentrations between sites at either the Beef Cattle Systems Center or the Welder Wildlife Refuge.

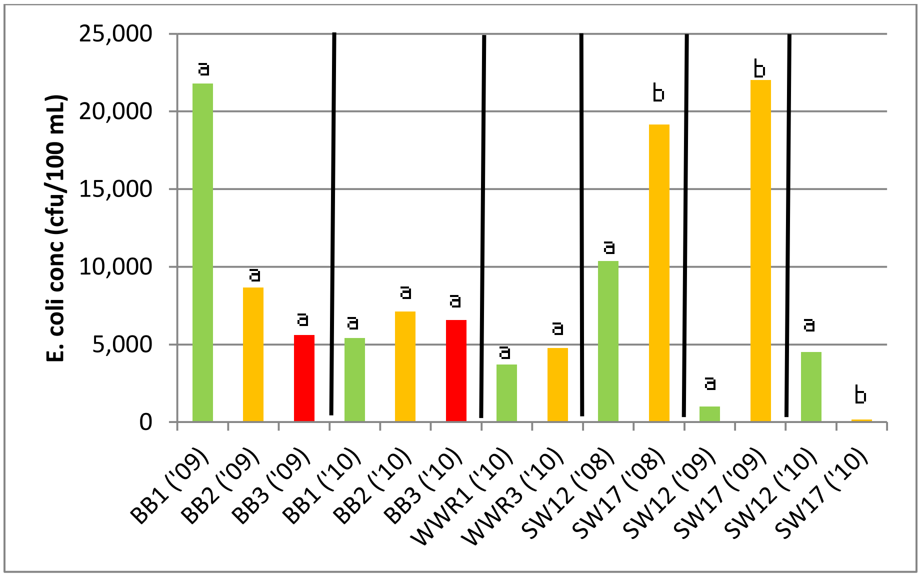
Table 9. Summary statistics for *E. coli* concentration data (cfu/100 mL).

Location	Site	Grazing	Mean	SD	Min.	Q1	Median[1]	Q3	Max.
BCSC	BB1	Ungrazed	27,083	62,494	410	2,250	7,600a	22,900	261,000
	BB2	Mod.	20,210	42,379	980	2,281	7,100a	15,107	181,000
	BB3	Heavy	62,469	170,689	140	2,100	5,591a	24,000	800,000
Welder	WWR1	Ungrazed	6,286	9,241	330	640	3,700a	6,480	30,000
	WWR3	Mod.	4,475	3,288	330	1,298	4,750a	7,145	10,300
Riesel	SW12	Ungrazed	5,932	5,737	110	1,200	4,450a	9,775	21,000
	SW17	Mod.	51,548	161,587	20	1,003	13,500b	27,750	800,000

[1] Median values followed by the same letter are not significantly different (α=0.05)

To better assess the effects of grazing at each site, the annual statistics for each site were evaluated (**Error! Reference source not found.**). This assessment revealed considerable spatial and temporal ariability in the median annual *E. coli* concentrations at both grazed and ungrazed sites. However, as with the combined data for each site, only at the Riesel location (sites SW12 and SW17) were significant differences in median annual *E. coli* concentrations between grazed and ungrazed sites observed. Interestingly, the highest and lowest median annual concentrations were observed at the moderately grazed SW17. Median *E. coli* concentrations at the ungrazed SW12 were 46% lower than those at the grazed SW17 during 2008 (p=0.01) and 95% lower in 2009 (p=0.00). Conversely, the median annual *E. coli* concentration at the grazed SW17 was significantly (96%) lower than those at SW12 in 2010 (p=0.03). This demonstrates the extreme temporal variability observed with *E. coli* concentrations. Secondly, it is noteworthy that the second highest median annual *E. coli* concentration was observed at the ungrazed BB1 during 2009.

Figure 10. Median annual *E. coli* concentrations (cfu/100 mL). Bars with the same letter above them are not significantly different (α=0.05)



Impact of non-domesticated animals

As previously stated, *E. coli* levels at BB1 were inexplicably high in 2009. This was, in fact, the case at all BCSC sites during October 2009 (Table 10). At the ungrazed BB1, median *E. coli* concentrations increased an order of magnitude and the maximum observed increased almost three orders of magnitude over levels observed throughout the rest of the project. At the two grazed sites, median concentrations increased half an order of magnitude and maximum concentrations were approximately an order of magnitude higher than those observed during similar destocked periods throughout the rest of the project. There was no ongoing grazing during this period and there had not been any since early-August two months earlier. Because *E. coli* concentrations in the first runoff event in October at both grazed sites were comparable to those observed during other ungrazed periods and because maximum concentrations were not observed until the fourth runoff event in October, it does not appear that the increase could be attributed to the August 2009 grazing treatment. Although wildlife and other non-domesticated animal activity were not documented at the sites during this period, it offers the only plausible explanation. Possible sources include feral hogs which are common along the Brazos River floodplain and frequently seen at the BCSC and adjacent TAMU Research Farm. Another possible source is migratory birds. However, as previously stated, neither was documented. The only fact that is documented is that no grazing or cattle access to the sites occurred during this time period. Thus, this suggests that sources other than grazing livestock can have a tremendous impact on *E. coli* runoff from grazing lands.

Table 10. Comparison of median and maximum *E. coli* concentrations (cfu/100 mL) at BCSC sites during October 2009 to those observed during other ungrazed periods.

Site	Stat	October 2009	Excluding Oct 2009 & grazed periods
BB1	Median[1]	49,926a	4,400b
	Max	261,000	9800
BB2	Median[1]	23,935a	4,150b
	Max	181,000	12,200
BB3	Median[1]	15,000a	3,500b
	Max	172,500	24,000

[1] Median values followed by the same letter are not significantly different (α=0.05)

Impact of Cattle Presence during Rainfall Event

Throughout the project, all sites were rotationally grazed, meaning cattle were not on the sites year-round. This project revealed that runoff events occurring while cattle were actively grazing and within two weeks of the cattle being removed (period referred to as “stocked”) generally resulted in the highest *E. coli* levels in runoff from the grazed sites. By two weeks following removal of cattle from a site, *E. coli* levels in runoff decreased substantially and after approximately 30 days, *E. coli* values had declined to background levels. This decline was best observed at BB3 (Table 11) where *E. coli* levels declined from 800,000 cfu/100 mL when cattle were actively grazing to 4,400 cfu/ml 35 days after cattle were removed. However, similar observations were made at BB2 and SW17.

Table 11. *E. coli* levels measured at BB3 during and following grazing from November 12 to 17, 2009.

Date	*E. coli* Conc. (cfu/100 mL)	Runoff Occurred:
11/16/09	800,000	Cattle actively grazing
11/21/09	223,750	4 days after cattle removed
11/29/09	87,000	12 days after cattle removed
12/1/09	13,300	14 days after cattle removed
12/22/09	4,400	35 days after cattle removed

E. coli concentrations were significantly higher when BB2 (p=0.03), BB3 (p<0.01), and SW17 (p<0.01) were stocked (**Error! Reference source not found.**) than when they were destocked. At only WWR3 was his relationship not observed (p=0.06). However, this can be easily explained by the very limited grazing that occurred prior to the three runoff events at WWR3 while it was stocked. Due to a very severe drought during 2008 and 2009, this site had not been grazed for over a year and following this drought, it was only lightly grazed for a very short duration (i.e. three animal unit days (AUD) prior to the first event and 33 AUD prior to the other two events).

Table 12. Comparison of *E. coli* levels at grazed sites when runoff occurred during or within 2 weeks of grazing (Stocked) and more than 2 weeks after grazing (Destocked).

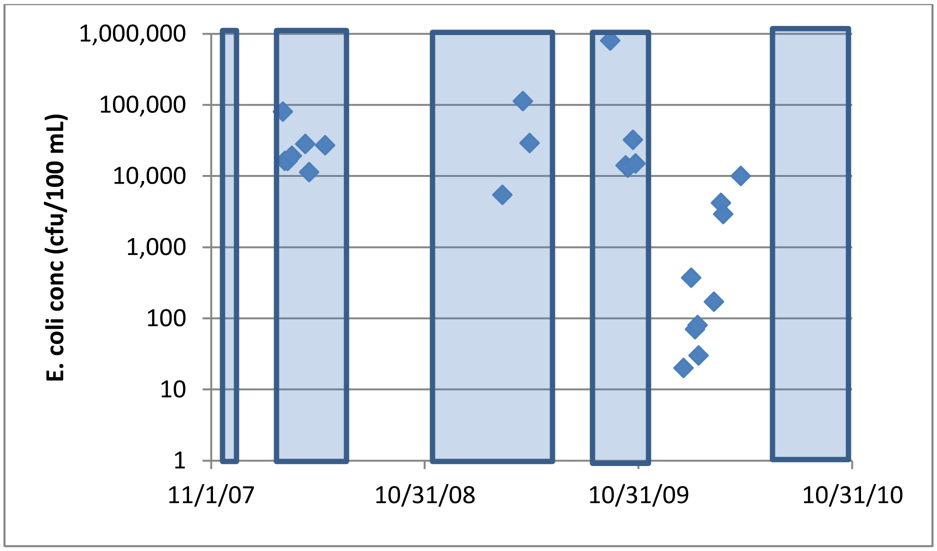
	BB2[1]		BB3[1]		WWR3		SW17	
	Destocked	Stocked	Destocked	Stocked	Destocked	Stocked	Destocked	Stocked
Mean	5,084	34,400	5,112	281,013	5,737	1,530	1,982	81,287
SD	3,810	33,375	6,165	356,809	3,100	1,107	3,370	200,904
Median[2]	4,150a	34,400b	3,500a	155,375b	5,500a	1,600a	170a	19,150b
Geomean	3,686	25,028	2,637	119,965	4,167	1,175	309	27,667
n	12	2	14	4	7	3	9	15

[1] Data from October 2009 not included in analysis.

[2] Median values followed by the same letter are not significantly different (α=0.05)

Results from SW17 are particularly noteworthy. Coincidentally, during 2008 and 2009, every runoff event occurred while cattle were actively grazing the site except one which occurred less than two weeks of cattle being rotated to another pasture (**Error! Reference source not found.**). In 2010, again by oincidence, every runoff event occurred while the site was destocked. This resulted in the *E. coli* concentrations at SW17 being significantly higher than those at the ungrazed SW12 in 2008 and 2009 and then SW17 levels being significantly lower than SW12 in 2010 as discussed earlier and shown in Figure 10. This was not planned, but it was very fortuitous as it offers insight into the effectiveness of rotational grazing as a management strategy for reducing *E. coli* runoff; and more importantly the significance of timing of grazing in relation to runoff events.

Figure 11. Comparison of timing of grazing (shaded areas) and *E. coli* concentrations at SW17.



Striking reductions of 88% at BB2, 98% at BB3, and 99% at SW17 in *E. coli* concentrations were observed when the sites were destocked at the time runoff occurred, thus demonstrating the importance of timing of grazing on bacterial levels. Similar results have been found in studies on manure application. Lewis et al. (2010) found that fecal coliform concentrations and loads in runoff occurring more than two weeks after application of dairy manure were 80% lower than those occurring within two weeks of application. Meals and Braun (2006) found that *E. coli* levels in runoff from plots receiving 30 day old dairy manure were 97% lower than those receiving fresh manure.

This suggests that creek pastures and other hydrologically critical areas would benefit from rotational grazing with grazing being deferred on such pastures during rainy periods in preference of upland hydrologically disconnected sites. More data is needed to confirm this finding and evaluate the impacts of this practice on a watershed scale. Additionally, work is needed to assess the impacts of continuous grazing on runoff. Previous work by Sovell et al. (2000) already showed that in stream fecal coliform levels were consistently higher at continuously stocked sites than at rotationally stocked sites in southeastern Minnesota.

Assessment of Background E. coli Levels

As briefly referenced in the previous section, a relatively consistent "background" level of *E. coli* in runoff was observed at all sites. Once those *E. coli* concentrations observed during October 2009 at BCSC (attributed to wildlife) and those attributed to grazing events were removed, the remaining concentrations at all sites were remarkably similar (Table 15) with means ranging from 5,000 to 6,000 cfu/100 mL and median values ranging from 3,500 to 5,500 cfu/100 mL. With the exception of SW17, background *E. coli* concentrations were not significantly different among sites.

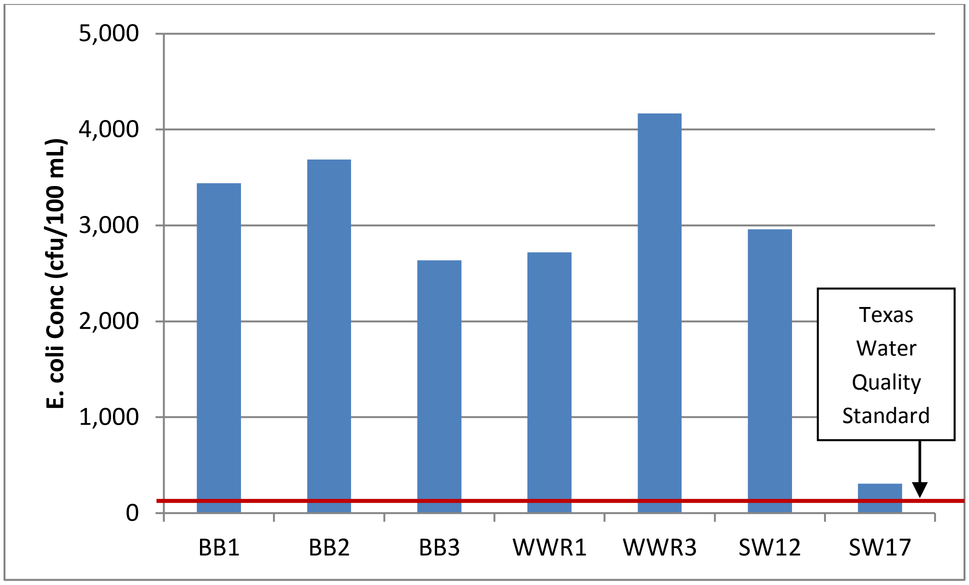
Table 13. Background E. coli levels observed at all sites.

	BB1[1]	BB2[1]	BB3[1]	WWR1	WWR3[2]	SW12	SW17[2]
Mean	4,890	5,084	5,112	6,286	5,737	5,932	1,982
SD	3,461	3,810	6,165	9,241	3,100	5,737	3,370
Median[3]	4,400a	4,150a	3,500a	3,700a	5,500a	4,450a	170b
Geomean	3,442	3,686	2,637	2,720	4,167	2,960	309

[1] Concentrations from October 2009 and those attributed to grazing events removed.
[2] Concentrations attributed to grazing events removed.
[3] Median values followed by the same letter are not significantly different (α=0.05)

There are a range of possible sources for this background *E. coli* from rodent, bird, and other wildlife populations to indigent *E. coli* populations residing in the soil. Regardless, these background *E. coli* concentrations should be taken into account when developing total maximum daily loads and watershed protection plans, conducting the modeling to support these activities, and most importantly, when applying water quality standards to storm flow (Figure 12). Current water quality models being used for assessing bacterial loads do not take into account background levels, attributing *E. coli* loads to a relatively limited list of possible sources (e.g. human, deer, cattle, feral hogs). As such, these models are potentially over-allocating loads and thus load reductions to these categories while not taking into consideration background levels.

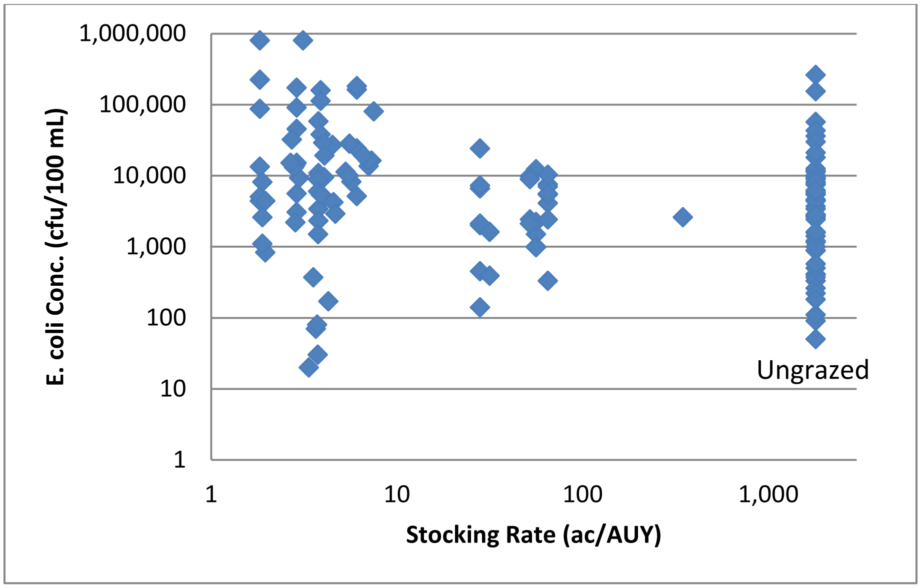
Figure 12. Comparison of geometric mean values for background *E. coli* concentrations observed in rural runoff to those required by Texas Water Quality Standards (geometric mean = 126 cfu/100 mL).



Comparison of Stocking Rate (SR) and E. coli Concentration

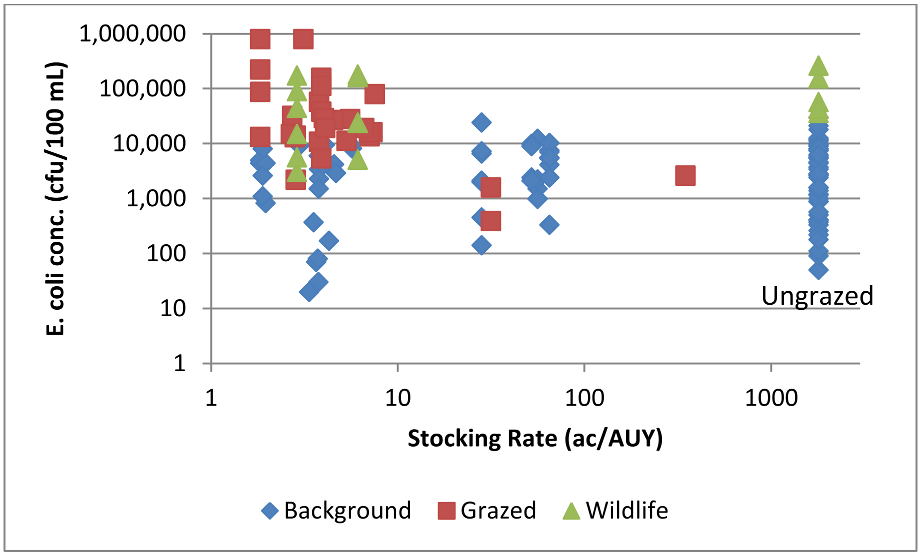
Stocking rates varied substantially at each of the grazed sites throughout the project (see Table 8). To determine if stocking rate impacted E. coli concentration, the annual stocking rate was compared to the *E. coli* concentration for each event (Figure 13). The annual stocking rate (i.e. the average stocking rate for the twelve month immediately preceding the runoff event) was selected for this comparison as it is most commonly used in grazing recommendations as well as modeling exercises to evaluate *E. coli* loadings. Initial evaluation of this data suggests a general increasing trend in *E. coli* concentrations with increasing stocking rate.

Figure 13. Comparison of annual stocking rate (acres/animal unit year) to *E. coli* concentration in runoff.



However, when data are evaluated in the context of cattle presence during runoff event, background levels, and wildlife dominated events (Figure 14) as discussed in the previous sections, it becomes apparent that cattle presence during the runoff event is the dominant factor with stocking rate having a lesser effect. In general, highest *E. coli* concentrations were observed when the annual stocking rate was less than four acres per animal unit; however, with the exception of when the stocking rate was 30 acres per animal unit or greater, no significant differences were observed between stocking rates of 2 to 8 acres per animal unit. When the stocking rate was 30 acres per annual unit year or greater, *E. coli* levels were significantly lower than those observed at stocking rates of 2 to 8 acres per animal unit year; and they did not exceed background levels (based on only three observations). Thus, based on this data, pastures stocked heavier than eight acres per animal unit should be the focus of initial implementation efforts when addressing bacterial impairments.

Figure 14. Comparison of annual stocking rate to *E. coli* concentrations associated with background, grazed or recently grazed, and wildlife dominated conditions.



E. coli loading

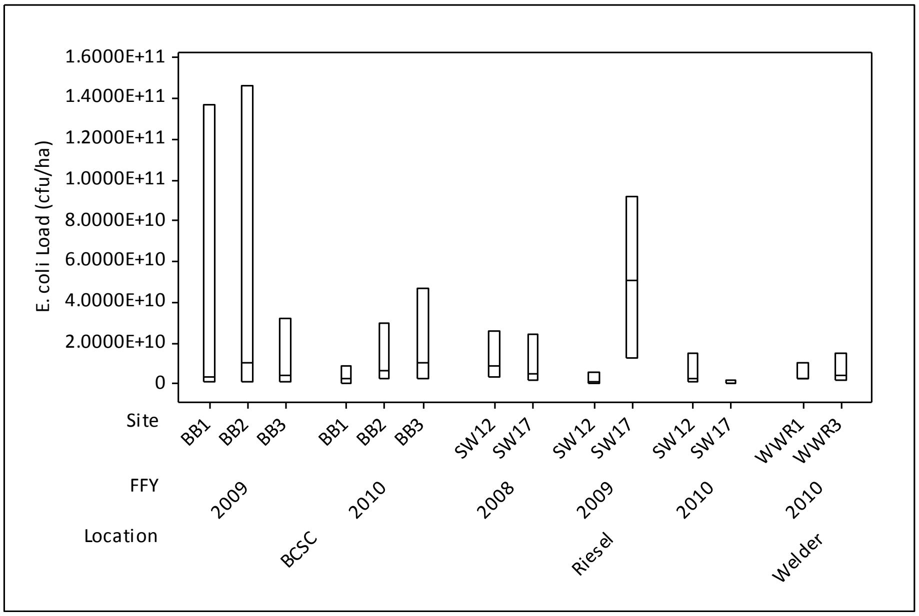
Annual *E. coli* loading from ungrazed sites generally ranged from 4.0 to 8.0E+10 cfu/ha while annual loading from actively grazed sites generally ranged from 8.0 to 40.0E+10 cfu/ha (**Error! Reference ource not found.**). Exceptions were observed at SW17 in 2010 and the BCSC sites in 2009 due to the effects of wildlife or other non-domesticated animals previously discussed. The effects of wildlife or other non-domesticated animals on the annual loadings at the BCSC in 2009 are conspicuous (contributing 80 to 99% of the load in 2009), especially when compared to the level of grazing in 2010 and corresponding loading values in 2010.

Table 14. Annual *E. coli* loading and corresponding amount of grazing annually (in animal unit days per hectare).

		AUD/ha			*E. coli* load (cfu/ha)		
Location	**Site**	2008	2009	2010	2008	2009	2010
BCSC	BB1		0	17		6.17E+11	5.02E+10
	BB2		148	302		7.89E+11	1.46E+11
	BB3		311	543		3.02E+11	4.08E+11
Welder	WWR1	0	0	0			4.19E+10
	WWR3	83	16	33			8.14E+10
Riesel	SW12	0	0	0	6.96E+10	5.89E+10	8.14E+10
	SW17	128	354	75	8.35E+10	4.14E+11	7.22E+09

Assessment of median event loads for *E. coli* at each site in 2008, 2009, and 2010 reveals considerable spatial and temporal variability with significant differences in median event loads only being observed at the Beef Cattle Systems Center in 2010 and Riesel in 2008 and 2010 (Figure 15). Median event loads at the ungrazed BB1 were 80% lower in 2010 than those observed at the heavy stocked BB3 ($p=0.04$) and 67% lower than those at the moderately grazed BB2 ($p=0.09$). However, no significant difference was observed between the median loads at BB2 and BB3 in 2010. Loading at Riesel was interesting in that in 2008, there was no significant difference observed between SW12 and SW17; in 2009, loading at SW17 was significantly greater than those at SW12 ($p<0.01$); and finally, in 2010, loading at the ungrazed SW12 were significantly greater than those at the grazed SW17 ($p=0.01$). Only at the Welder Wildlife Refuge were no significant differences observed in median *E. coli* loads.

Figure 15. Boxplot of median event loads and corresponding 95% confidence intervals for *E. coli*.



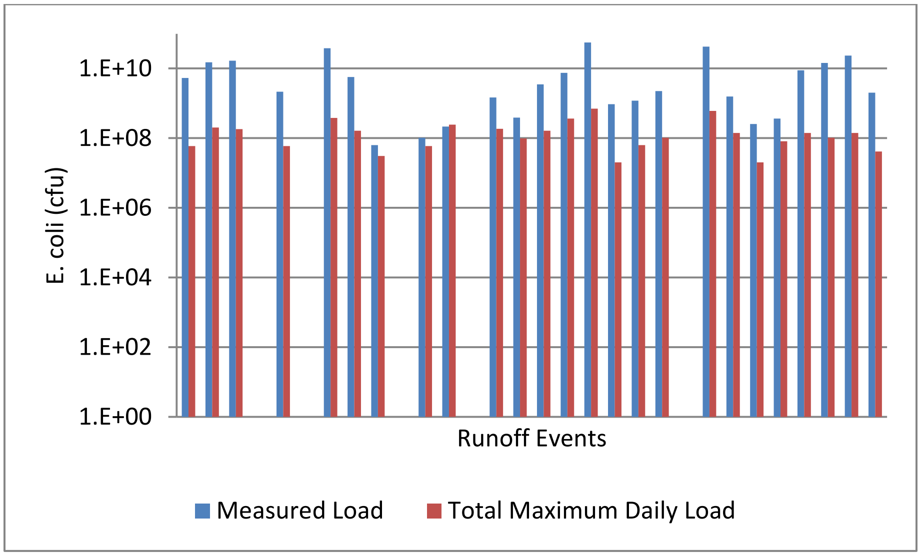
Comparison of E. coli Concentrations and Loads to Texas Water Quality Standards

E. coli levels in 114 of the 127 samples collected (90%) exceeded the single sample maximum for *E. coli* in water (394 cfu/100 mL) listed in the Texas Water Quality Standards. Further, *E. coli* levels at all sites exceeded the geometric mean (126 cfu/100 mL) listed in the Texas Water Quality Standards by over an order of magnitude. These results are similar to Edwards et al. (1997) who found that fecal coliform levels in runoff from four pastures in northwest Arkansas exceeded water quality standards 70-89% of the time.

It is especially noteworthy that even runoff from the ungrazed BB1, WWR1, and SW12 exceeded the single sample maximum in 88-100% of the samples. This is not uncommon as Doran and Linn (1979) also found that bacteria (total and fecal coliforms) in runoff from ungrazed pastures in eastern Nebraska exceeded water quality standards. Although these water quality standards apply only to surface waters (e.g. streams and lakes) and not edge-of-field runoff as described here, this project does expose the impracticality of applying the existing water quality standards to runoff events. Water quality in streams draining rural watersheds are frequently cited as exceeding water quality criteria for bacteria at some frequency, even when agricultural activities are at a minimum and BMPs are not needed. Further, many studies have found that runoff even after implementation of BMPs may not achieve water quality standards (Clausen and Meals 1989, Fajardo et al. 2001, Dickey and Vanderholm 1981, Coyne et al. 1995, Walker et al. 1990). As such, it is recommended that exemptions from the current standards be made for runoff or storm flows or, as Dickey and Vanderholm recommended in 1981, that additional research be conducted to accurately define bacterial quality for runoff and establish practical stream water quality standards.

This re-evaluation of the water quality standards is of utmost importance as total maximum daily loads are currently being established in hundreds of watersheds across Texas and thousands across the U.S. at a great cost. An assessment of the loading reduction that would be needed at the ungrazed native prairie site (SW12) revealed that a 98% load reduction would be mandated for that watershed to decrease *E. coli* loads the almost two orders of magnitude needed to achieve existing water quality standards (Figure 16). Assessment of the other six sites yielded similar results (data not shown). Attempting to achieve current standards during storm events is an insurmountable goal and not a judicious use of resources.

Figure 16. Comparison of measured *E. coli* loads and loads needed to comply with Texas Water Quality Standards at an ungrazed native prairie reference site (SW12), November 2007 through October 2008.



Summary and Conclusions

This project found rotational grazing to be an effective practice for reducing *E. coli* runoff. When runoff occurred more than two weeks following grazing, *E. coli* levels in runoff were decreased from 88 to 99%. As a result of these findings, it is recommended that creek pastures and other hydrologically connected pastures be grazed during periods when runoff is less likely (e.g. summer and winter in much of Texas) and upland sites be grazed during rainy seasons when runoff is more likely to occur. Further research is recommended to evaluate the impact of this practice on a watershed scale.

The impact of grazing timing in relation to runoff event was much more significant than the impact of level of grazing (i.e. moderately stocked or heavy stocked) or stocking rate. No significant differences were observed between *E. coli* runoff from moderate or heavy stocked pastures. Highest *E. coli* concentrations were generally observed when runoff occurred within two weeks of grazing and the annual stocking rate was less than four acres per animal unit; however, no significant differences were observed between stocking rates of 2 to 8 acres per animal unit for these events. When the stocking rate was 30 acres per annual unit or greater (and runoff occurred within two weeks of them being grazed), *E. coli* levels were significantly lower and did not exceed background levels. Additional research is needed to evaluate runoff from severely overgrazed sites as well as sites that are continuously grazed as runoff conditions from these may be significantly different than those observed by this project.

Background levels were considerable and relatively consistent among all sites, with median levels typically ranging from 3,500 to 5,500 cfu/100 mL. Most existing water quality models and thus total maximum daily loads and other watershed plans do not take background *E. coli* levels into account. Background levels should be considered when applying these models to prevent over-allocating loads and loading reductions to other sources.

This project also demonstrated the significant impact that wildlife and other non-domesticated animals can have on runoff from grazing lands. As observed at all Beef Cattle Systems Center sites in October 2009, median concentrations increased approximately an order of magnitude. Loading from these sources during this period was responsible for 80% to 99% of the total loading in 2009.

Finally, these results support the need to revise water quality standards as they apply to storm flow conditions. Ninety percent of runoff samples exceeded Texas Water Quality Standards, even at ungrazed sites. Although these water quality standards apply only to surface waters (e.g. streams and lakes) and not edge-of-field runoff as described here, this project does expose the impracticality of applying the existing water quality standards to runoff events, especially in runoff dominated streams. Background levels need to be considered as well as the significant impacts of wildlife and other non-domesticated animals. As such, it is recommended that exemptions from the current standards be made for storm flows and wildlife or additional research be conducted to accurately define bacterial quality for runoff and establish practical stream water quality standards.

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Appendix G Data Collected

Welder Wildlife Refuge *E. coli*, Flow, and Loading Data

Date	WWR1 - Ungrazed			WWR3 - Moderately Grazed		
	E. coli (cfu/100 ml)	Flow (cf)	Load	E. coli (cfu/100 ml)	Flow (cf)	Load
11/20/09	3700	6355	6.66E+09	4100	8910	1.03E+10
11/21/09	5500	8617	1.34E+10	7500	12081	2.57E+10
12/1/09	30000	228	1.94E+09	5400	808	1.23E+09
12/17/09			0.00E+00	330	311	2.90E+07
1/15/10	7460	5299	1.12E+10	7027	6351	1.26E+10
2/5/10	880	618	1.54E+08	10300	1480	4.32E+09
2/11/10	5500	1200	1.87E+09	5500	2415	3.76E+09
7/1/10	400	20407	2.31E+09	2600	26248	1.93E+10
9/19/10	330	18920	1.77E+09	390	24064	2.66E+09
9/23/10	2800	3312	2.63E+09	1600	3196	1.45E+09
Average	6286	64955	4.19E+10	4475	85864	8.14E+10
SD	9241			3288		
Geomean	2720			2850		
Site Mean	2280			3348		
Median	3700			4750		
Annual Load (#/ac)			**1.70E+10**			**3.30E+10**

Riesel *E. coli*, Flow, and Loading Data

Date	SW12				SW17			
	E. coli (cfu/100 ml)	*Flow (cf)*	*Load (cfu)*	*Load (cfu/ha)*	*E. coli* (cfu/100 ml)	*Flow (cf)*	*Load (cfu)*	*Load (cfu/ha)*
3/3/08			0.00E+00	0.00E+00	80000	52	1.18E+09	9.83E+08
3/6/08	11250	1666	5.31E+09	4.42E+09	16200	1136	5.21E+09	4.34E+09
3/11/08	9450	5666	1.52E+10	1.26E+10	16250	1696	7.80E+09	6.50E+09
3/18/08	11750	5066	1.69E+10	1.40E+10	19150	2826	1.53E+10	1.28E+10
4/10/08			0.00E+00	0.00E+00	28000	505	4.00E+09	3.33E+09
4/10/08	4600	1666	2.17E+09	1.81E+09			0.00E+00	0.00E+00
4/17/08			0.00E+00	0.00E+00	11300	566	1.81E+09	1.51E+09
5/14/08	12550	10766	3.83E+10	3.19E+10	27000	8486	6.49E+10	5.41E+10
5/15/08	4450	4566	5.75E+09	4.79E+09			0.00E+00	0.00E+00
3/13/09	260	865	6.37E+07	5.31E+07	5400	1311	2.00E+09	1.67E+09
4/17/09			0.00E+00	0.00E+00	113000	3396	1.09E+11	9.06E+10
4/18/09	220	1666	1.04E+08	8.65E+07			0.00E+00	0.00E+00
4/28/09	110	6866	2.14E+08	1.78E+08	29000	5096	4.18E+10	3.49E+10
9/13/09			0.00E+00	0.00E+00	800000	566	1.28E+11	1.07E+11
10/9/09	1000	5166	1.46E+09	1.22E+09	14000	3966	1.57E+10	1.31E+10
10/11/09	500	2766	3.92E+08	3.26E+08			0.00E+00	0.00E+00
10/13/09	2700	4566	3.49E+09	2.91E+09	13000	7916	2.91E+10	2.43E+10
10/22/09	2600	10166	7.48E+09	6.24E+09	32000	10186	9.23E+10	7.69E+10
10/26/09	10100	19766	5.65E+10	4.71E+10	15000	18676	7.93E+10	6.61E+10
10/30/09	5900	566	9.46E+08	7.88E+08			0.00E+00	0.00E+00
11/21/09	2400	1766	1.20E+09	1.00E+09			0.00E+00	0.00E+00
1/16/10	2800	2865	2.27E+09	1.89E+09			0.00E+00	0.00E+00
1/16/10			0.00E+00	0.00E+00	20	1058	5.99E+06	4.99E+06
1/29/10	8900	16966	4.28E+10	3.56E+10	370	14706	1.54E+09	1.28E+09
2/5/10	1400	3966	1.57E+09	1.31E+09	70	3966	7.86E+07	6.55E+07
2/9/10	1600	566	2.56E+08	2.14E+08	80	1126	2.55E+07	2.13E+07
2/11/10	570	2266	3.66E+08	3.05E+08	30	4526	3.84E+07	3.20E+07
3/9/10	8000	3966	8.98E+09	7.49E+09	170	2266	1.09E+08	9.09E+07
3/21/10	18000	2866	1.46E+10	1.22E+10	4200	566	6.73E+08	5.61E+08
3/25/10	21000	3966	2.36E+10	1.97E+10	2900	1696	1.39E+09	1.16E+09
4/24/10	6200	1166	2.05E+09	1.71E+09	10000	1696	4.80E+09	4.00E+09
Average	5932	122147	2.52E+11	2.10E+11	51548	97985	6.06E+11	5.05E+11
SD	5737				161587			
Geomean	2960				5129			
Median	4450				13500			
Site Mean	7281			6068	21844			18203
Annual Load (#/ac)			2.83E+10				6.76E+10	

2S Data (Year 1)

Date	2S flow (cfs)	Days since rain	PC1			PC2			2S *E. coli* Load (cfu/d)	# of AU	2S *E. coli* Load (cfu/AU/d)
			E. coli (cfu/100mL)	Turb. (NTU)	*E. coli* Load (cfu/d)	*E. coli* (cfu/100mL)	Turb. (NTU)	*E. coli* Load (cfu/d)			
7/26/07	154.83	0	1220		4.62E+12	920		3.48E+12	-1.14E+12	57	-2.00E+10
8/2/07	1.99	4	50		2.43E+09	70		3.41E+09	9.74E+08	57	1.72E+07
8/16/07	1.56	0	2300		8.78E+10	3300		1.26E+11	3.82E+10	57	6.73E+08
9/6/07	1.07	2	320		8.38E+09	880		2.30E+10	1.47E+10	57	2.59E+08
9/20/07	0.66	1	40		6.46E+08	110		1.78E+09	1.13E+09	57	1.99E+07
10/4/07	0.43	9	17		1.75E+08	287		3.02E+09	2.84E+09	57	5.01E+07
10/18/07	0.51	10	80		9.98E+08	27		3.33E+08	-6.65E+08	57	-1.17E+07
11/1/07	0.51	10	30		3.74E+08	55		6.86E+08	3.12E+08	57	5.50E+06
11/15/07	0.43	24	213		2.24E+09	162		1.70E+09	-5.37E+08	57	-9.46E+06
12/6/07	0.51	10	73		9.05E+08	200		2.50E+09	1.59E+09	57	2.81E+07
12/20/07	0.51	5	31		3.87E+08	35		4.37E+08	4.99E+07	57	8.80E+05
1/3/08	0.59	19	17		2.45E+08	104		1.50E+09	1.26E+09	57	2.21E+07
1/17/08	0.51	2	87		1.09E+09	111		1.39E+09	2.99E+08	57	5.28E+06
2/7/08	0.59	13	21	5	3.03E+08	23	5	3.32E+08	2.89E+07	57	5.09E+05
2/21/08	0.57	5	230	19	3.21E+09	420	16	5.86E+09	2.65E+09	57	4.67E+07
3/6/08	0.66	0	35	23	5.57E+08	125	12	2.02E+09	1.46E+09	57	2.58E+07
3/20/08	1.19	2	340	21	9.89E+09	295	29	8.58E+09	-1.31E+09	57	-2.31E+07
4/3/08	0.66	4	81	35	1.31E+09	103	24	1.66E+09	3.55E+08	57	6.27E+06
4/17/08	0.51	14	170	34	2.12E+09	1475	19	1.84E+10	1.63E+10	57	2.87E+08
5/1/08	0.51	5	210	60	2.62E+09	370	31	4.62E+09	2.00E+09	57	3.52E+07
5/15/08	0.43	1	182	18	1.91E+09	83	21	8.68E+08	-1.05E+09	57	-1.85E+07
6/5/08	0.31	23	90	61	6.75E+08	430	9	3.23E+09	2.55E+09	57	4.50E+07
6/19/08	0.25	13	2600	57	1.60E+10	160	12	9.82E+08	-1.50E+10	57	-2.64E+08
7/2/08	0.15	30	325	62	1.22E+09	500	8	1.87E+09	6.55E+08	57	1.16E+07

2S Data (Year 2)

Date	2S flow (cfs)	Days since rain	PC1			PC2			2S *E. coli* Load (cfu/d)	# of AU	2S *E. coli* Load (cfu/AU/d)
			E. coli (cfu/100mL)	Turb. (NTU)	*E. coli* Load (cfu/d)	*E. coli* (cfu/100mL)	Turb. (NTU)	*E. coli* Load (cfu/d)			
7/17/08	0.16	9	410	23	1.57E+09	465	16	1.78E+09	2.10E+08	76	2.77E+06
8/7/08	0.08	14	320	17	6.58E+08	400	12	8.22E+08	1.64E+08	76	2.16E+06
8/21/08	0.08	2	490	30	1.01E+09	1075	6	2.21E+09	1.20E+09	76	1.58E+07
9/4/08	0.02	7	745	27	3.65E+08	93	6	4.55E+07	-3.19E+08	76	-4.20E+06
9/18/08	0.00	5			0.00E+00			0.00E+00	0.00E+00	76	0.00E+00
10/2/08	0.00	21			0.00E+00			0.00E+00	0.00E+00	76	0.00E+00
10/16/08	0.00	1			0.00E+00			0.00E+00	0.00E+00	76	0.00E+00
11/6/08	0.04	0	150	8	1.47E+08	845	5	8.27E+08	6.80E+08	76	8.95E+06
11/20/08	0.08	16	145	4	2.97E+08	450	3	9.25E+08	6.28E+08	76	8.26E+06
12/4/08	0.15	32	43	4	1.58E+08	475	2	1.74E+09	1.59E+09	76	2.09E+07
12/18/08	0.12	10	400	3	1.17E+09	120	2	3.52E+08	-8.22E+08	76	-1.08E+07
1/8/09	0.20	2	106	4	5.19E+08	56	2	2.74E+08	-2.45E+08	76	-3.22E+06
1/22/09	0.25	16	30	2	1.81E+08	530	1	3.25E+09	3.07E+09	76	4.04E+07
2/12/09	0.25	2	450	9	2.76E+09	500	7	3.07E+09	3.07E+08	76	4.04E+06
2/26/09	0.25	16	62	10	3.77E+08	810	8	4.97E+09	4.59E+09	76	6.04E+07
3/12/09	0.59	0	5700	18	8.23E+10	8100	14	1.17E+11	3.46E+10	76	4.56E+08
3/26/09	0.15	12	20	10	7.34E+07	268	13	9.84E+08	9.10E+08	76	1.20E+07
4/9/09	0.20	7	36	5	1.76E+08	280	5	1.37E+09	1.19E+09	76	1.57E+07
4/23/09	0.15	5	660	18	2.42E+09	7000	31	2.57E+10	2.33E+10	76	3.06E+08
5/14/09	0.15	17	78	21	2.86E+08	600	47	2.20E+09	1.92E+09	76	2.52E+07
5/28/09	0.08	4	100	43	2.06E+08	410	34	8.43E+08	6.37E+08	76	8.38E+06
6/11/09	0.00	8			0.00E+00			0.00E+00	0.00E+00	76	0.00E+00
6/24/09	0.00	24			0.00E+00			0.00E+00	0.00E+00	76	0.00E+00
7/9/09	0.00	2			0.00E+00			0.00E+00	0.00E+00	76	0.00E+00

2S GPS Collar Data

GPS Number	Sample Period	Total Points	Corrected Tot Pts	Points in each buffer In-stream	15 ft	25 ft	35 ft	50 ft	% time within each buffer In-stream	15 ft	25 ft	35 ft	50 ft	BMP
1276	Jul-07	6336	6252	13	93	148	266	433	0.2%	1.5%	2.4%	4.3%	6.9%	None
1909	Jul-07	6336	6183	8	63	122	205	356	0.1%	1.0%	2.0%	3.3%	5.8%	None
1910	Jul-07	6335	6211	8	88	168	260	412	0.1%	1.4%	2.7%	4.2%	6.6%	None
380	Jul-07	6336	6242	8	70	146	217	308	0.1%	1.1%	2.3%	3.5%	4.9%	None
88	Jul-07	6336	6314	46	279	424	506	649	0.7%	4.4%	6.7%	8.0%	10.3%	None
Mean	**Jul-07**	**6336**		**17**	**119**	**202**	**291**	**432**	**0.3%**	**1.9%**	**3.2%**	**4.6%**	**6.9%**	
Std Dev	**Jul-07**			**17**	**91**	**125**	**123**	**131**	**0.3%**	**1.4%**	**2.0%**	**1.9%**	**2.0%**	
1276	Oct-07	6446	6327	7	89	145	211	307	0.1%	1.4%	2.3%	3.3%	4.9%	None
1909	Oct-07	6446	6321	11	128	212	287	383	0.2%	2.0%	3.4%	4.5%	6.1%	None
1910	Oct-07	6446	6294	15	103	191	288	440	0.2%	1.6%	3.0%	4.6%	7.0%	None
1951	Oct-07	6446	6267	15	112	195	297	458	0.2%	1.8%	3.1%	4.7%	7.3%	None
1952	Oct-07	6446	6326	9	106	199	289	421	0.1%	1.7%	3.1%	4.6%	6.7%	None
380	Oct-07	6446	6388	13	112	186	256	354	0.2%	1.8%	2.9%	4.0%	5.5%	None
88	Oct-07	6446	6351	26	120	183	265	369	0.4%	1.9%	2.9%	4.2%	5.8%	None
Mean	**Oct-07**	**6446**		**14**	**110**	**187**	**270**	**390**	**0.2%**	**1.7%**	**3.0%**	**4.3%**	**6.2%**	
Std Dev	**Oct-07**			**6**	**13**	**21**	**30**	**53**	**0.1%**	**0.2%**	**0.3%**	**0.5%**	**0.9%**	
1909	Jan-08	6621	6538	4	25	39	60	88	0.1%	0.4%	0.6%	0.9%	1.3%	Trough
1910	Jan-08	6624	6482	3	18	27	40	53	0.0%	0.3%	0.4%	0.6%	0.8%	Trough
1951	Jan-08	6624	6541	4	51	74	108	173	0.1%	0.8%	1.1%	1.7%	2.6%	Trough
1952	Jan-08	6624	6555	3	22	43	66	107	0.0%	0.3%	0.7%	1.0%	1.6%	Trough
87	Jan-08	6624	4448	4	41	70	89	126	0.1%	0.9%	1.6%	2.0%	2.8%	Trough
Mean	**Jan-08**	**6623**		**4**	**31**	**51**	**73**	**109**	**0.1%**	**0.5%**	**0.9%**	**1.2%**	**1.9%**	
Std Dev	**Jan-08**			**1**	**14**	**20**	**26**	**45**	**0.0%**	**0.3%**	**0.5%**	**0.6%**	**0.9%**	

GPS Number	Sample Period	Total Points	Corrected Tot Pts	Points in each buffer In-stream	15 ft	25 ft	35 ft	50 ft	% time within each buffer In-stream	15 ft	25 ft	35 ft	50 ft	BMP
1276	Apr-08	6624	6460	13	101	179	274	487	0.2%	1.6%	2.8%	4.2%	7.5%	None
1909	Apr-08	6621	6422	25	159	263	373	572	0.4%	2.5%	4.1%	5.8%	8.9%	None
1910	Apr-08	6620	6197	5	64	115	205	343	0.1%	1.0%	1.9%	3.3%	5.5%	None
1951	Apr-08	6624	6434	7	69	121	196	334	0.1%	1.1%	1.9%	3.0%	5.2%	None
1952	Apr-08	6624	6485	15	135	254	380	590	0.2%	2.1%	3.9%	5.9%	9.1%	None
380	Apr-08	6624	6454	21	172	249	360	505	0.3%	2.7%	3.9%	5.6%	7.8%	None
87	Apr-08	6623	4836	21	168	280	409	552	0.4%	3.5%	5.8%	8.5%	11.4%	None
88	Apr-08	6621	6460	15	122	217	370	636	0.2%	1.9%	3.4%	5.7%	9.8%	None
Mean	**Apr-08**	**6623**		**15**	**124**	**210**	**321**	**502**	**0.3%**	**2.0%**	**3.4%**	**5.3%**	**8.2%**	
Std Dev	**Apr-08**			**7**	**43**	**64**	**84**	**111**	**0.1%**	**0.8%**	**1.3%**	**1.7%**	**2.1%**	
1276	Sep-08	6048	6011	21	183	271	357	507	0.3%	3.0%	4.5%	5.9%	8.4%	Trough
1909	Sep-08	6048	5958	7	43	69	106	154	0.1%	0.7%	1.2%	1.8%	2.6%	Trough
1910	Sep-08	6048	5839	15	111	161	233	310	0.3%	1.9%	2.8%	4.0%	5.3%	Trough
1951	Sep-08	6048	5906	12	98	164	246	330	0.2%	1.7%	2.8%	4.2%	5.6%	Trough
1952	Sep-08	6048	5975	7	84	138	202	295	0.1%	1.4%	2.3%	3.4%	4.9%	Trough
380	Sep-08	6048	5992	5	43	67	98	169	0.1%	0.7%	1.1%	1.6%	2.8%	Trough
87	Sep-08	6048	4639	8	38	86	129	196	0.2%	0.8%	1.9%	2.8%	4.2%	Trough
88	Sep-08	6048	5940	5	38	71	97	144	0.1%	0.6%	1.2%	1.6%	2.4%	Trough
Mean	**Sep-08**	**6048**		**10**	**80**	**128**	**184**	**263**	**0.2%**	**1.4%**	**2.2%**	**3.2%**	**4.5%**	
Std Dev	**Sep-08**			**6**	**51**	**71**	**93**	**123**	**0.1%**	**0.8%**	**1.2%**	**1.5%**	**2.0%**	
1276	Nov-08	6624	6576	8	50	86	115	174	0.1%	0.8%	1.3%	1.7%	2.6%	Trough
1909	Nov-08	6624	6562	2	52	85	121	176	0.0%	0.8%	1.3%	1.8%	2.7%	Trough
1910	Nov-08	6624	6481	12	71	128	165	227	0.2%	1.1%	2.0%	2.5%	3.5%	Trough
1951	Nov-08	1622	1613	0	9	18	27	40	0.0%	0.6%	1.1%	1.7%	2.5%	Trough
1952	Nov-08	6624	6578	4	37	56	80	133	0.1%	0.6%	0.9%	1.2%	2.0%	Trough
380	Nov-08	6624	6583	7	52	85	128	203	0.1%	0.8%	1.3%	1.9%	3.1%	Trough
87	Nov-08	6624	4831	3	43	87	127	216	0.1%	0.9%	1.8%	2.6%	4.5%	Trough
88	Nov-08	6625	6576	8	57	85	112	146	0.1%	0.9%	1.3%	1.7%	2.2%	Trough
Mean	**Nov-08**	**5999**		**6**	**46**	**79**	**109**	**164**	**0.1%**	**0.8%**	**1.4%**	**1.9%**	**2.9%**	
Std Dev	**Nov-08**			**4**	**18**	**31**	**41**	**60**	**0.1%**	**0.2%**	**0.4%**	**0.5%**	**0.8%**	

GPS Number	Sample Period	Total Points	Corrected Tot Pts	Points in each buffer In-stream	15 ft	25 ft	35 ft	50 ft	% time within each buffer In-stream	15 ft	25 ft	35 ft	50 ft	BMP
1276	Feb-09	6624	6599	11	59	98	128	160	0.2%	0.9%	1.5%	1.9%	2.4%	Trough
1909	Feb-09	6624	6585	7	55	76	90	109	0.1%	0.8%	1.2%	1.4%	1.7%	Trough
1910	Feb-09	6624	6534	14	81	149	217	309	0.2%	1.2%	2.3%	3.3%	4.7%	Trough
1951	Feb-09	6624	6597	4	52	80	97	131	0.1%	0.8%	1.2%	1.5%	2.0%	Trough
1952	Feb-09	6624	6603	9	76	109	133	158	0.1%	1.2%	1.7%	2.0%	2.4%	Trough
380	Feb-09	6624	6593	10	51	78	104	155	0.2%	0.8%	1.2%	1.6%	2.4%	Trough
87	Feb-09	6624	4721	9	42	60	75	87	0.2%	0.9%	1.3%	1.6%	1.8%	Trough
88	Feb-09	6624	6607	7	40	63	70	91	0.1%	0.6%	1.0%	1.1%	1.4%	Trough
Mean	**Feb-09**	**6624**		**9**	**57**	**89**	**114**	**150**	**0.1%**	**0.9%**	**1.4%**	**1.8%**	**2.3%**	
Std Dev	**Feb-09**			**3**	**15**	**29**	**47**	**71**	**0.1%**	**0.2%**	**0.4%**	**0.7%**	**1.0%**	
1276	Apr-09	6624	6507	4	45	90	153	247	0.1%	0.7%	1.4%	2.4%	3.8%	Trough
1909	Apr-09	6624	6547	19	103	161	234	346	0.3%	1.6%	2.5%	3.6%	5.3%	Trough
1910	Apr-09	6624	6401	6	77	139	220	327	0.1%	1.2%	2.2%	3.4%	5.1%	Trough
1951	Apr-09	6624	6509	16	85	155	251	407	0.2%	1.3%	2.4%	3.9%	6.3%	Trough
1952	Apr-09	2773	2694	7	32	50	75	117	0.3%	1.2%	1.9%	2.8%	4.3%	Trough
380	Apr-09	6624	6538	13	127	187	256	359	0.2%	1.9%	2.9%	3.9%	5.5%	Trough
87	Apr-09	6624	4986	13	89	148	212	287	0.3%	1.8%	3.0%	4.3%	5.8%	Trough
88	Apr-09	6624	6516	11	100	176	250	379	0.2%	1.5%	2.7%	3.8%	5.8%	Trough
Mean	**Apr-09**	**6143**		**11**	**82**	**138**	**206**	**309**	**0.2%**	**1.4%**	**2.3%**	**3.5%**	**5.2%**	
Std Dev	**Apr-09**			**5**	**31**	**46**	**63**	**92**	**0.1%**	**0.4%**	**0.5%**	**0.6%**	**0.8%**	

AllBac Data

Site	Sample Type	Event Date	Filter vol. (mL)	Extraction Date	Elution vol. (uL)	Lid No.	qPCR Date	Template vol. (uL)	AllBac (copies/rxn)	AllBac (copies/L)	AllBac %R	qPCR AllBac Fecal Conc	AllBac Fecal Conc (mg/L)
BB1	Grab	3/25/09	10	7/24/09	100	5	1/13/11	5	6.76E+02	1.35E+06	102%	65	0.65
BB1	ISCO	4/17/09	20	7/25/09	100	19	1/13/11	5	2.15E+03	2.15E+06	81%	134	0.67
BB1	ISCO	4/18/09	30	7/25/09	100	24	1/13/11	5	2.41E+04	1.61E+07	86%	646	2.15
BB1	ISCO	4/28/09	20	7/24/09	100	13	1/13/11	5	1.32E+03	1.32E+06	85%	98	0.49
BB1	ISCO	10/4/09	10	10/1/10	100	82	1/12/11	5	3.42E+04	6.84E+07	106%	650	6.50
BB1	ISCO	10/9/09	30	10/1/10	100	87	1/12/11	5	1.98E+04	1.32E+07	101%	476	1.59
BB1	ISCO	10/13/09	30	10/1/10	100	74	1/12/11	5	1.43E+04	9.53E+06	98%	372	1.24
BB1	Grab	10/26/09	30	10/2/10	100	90	1/11/11	5	1.11E+05	7.43E+07	98%	549	1.83
BB1	ISCO	10/26/09	30	10/2/10	100	93	1/13/11	5	1.42E+04	9.44E+06	100%	376	1.25
BB1	ISCO	11/21/09	20	10/1/10	100	79	1/12/11	5	3.58E+03	3.58E+06	108%	180	0.90
BB1	ISCO	12/1/09	20	10/1/10	100	71	1/12/11	5	2.52E+03	2.52E+06	98%	118	0.59
BB1	ISCO	1/16/10	25	9/23/10	100	53	1/14/11	5	1.76E+04	1.41E+07	98%	443	1.77
BB1	ISCO	1/29/10	25	9/23/10	100	56	1/12/11	5	7.83E+03	6.27E+06	104%	211	0.84
BB1	ISCO	2/4/10	20	1/31/11	200	124	2/2/11	5	1.48E+03	2.96E+06	100%	18	0.18
BB2	Grab	3/25/09	10	7/24/09	100	6	1/13/11	5	4.25E+02	8.50E+05	95%	48	0.48
BB2	ISCO	3/25/09	10	7/24/09	100	8	1/13/11	5	1.86E+02	3.72E+05	97%	29	0.29
BB2	ISCO	4/17/09	20	7/25/09	100	20	1/13/11	5	8.27E+02	8.27E+05	103%	75	0.37

Site	Sample Type	Event Date	Filter vol. (mL)	Extraction Date	Elution vol. (uL)	Lid No.	qPCR Date	Template vol. (uL)	AllBac (copies/rxn)	AllBac (copies/L)	AllBac %R	qPCR AllBac Fecal Conc	AllBac Fecal Conc (mg/L)
BB2	ISCO	4/18/09	30	7/25/09	100	25	1/13/11	5	8.93E+03	5.95E+06	93%	342	1.14
BB2	ISCO	4/28/09	20	7/24/09	100	14	1/13/11	5	1.02E+03	1.02E+06	94%	83	0.42
BB2	ISCO	10/4/09	20	10/1/10	100	83	1/12/11	5	4.37E+03	4.37E+06	99%	201	1.01
BB2	ISCO	10/4/09	30	10/1/10	100	85	1/12/11	5	6.45E+03	4.30E+06	105%	252	0.84
BB2	ISCO	10/9/09	30	10/1/10	100	88	1/13/11	5	1.60E+04	1.07E+07	103%	401	1.34
BB2	ISCO	10/13/09	30	10/1/10	100	75	1/12/11	5	9.01E+03	6.01E+06	89%	274	0.91
BB2	Grab	10/26/09	30	10/2/10	100	91	1/11/11	5	2.36E+04	1.58E+07	100%	182	0.61
BB2	ISCO	10/26/09	30	10/2/10	100	94	1/13/11	5	5.45E+03	3.63E+06	98%	221	0.74
BB2	ISCO	11/21/09	30	10/1/10	100	80	1/12/11	5	4.23E+04	2.82E+07	99%	733	2.44
BB2	ISCO	12/1/09	20	10/1/10	100	72	1/12/11	5	5.12E+03	5.12E+06	97%	189	0.94
BB2	ISCO	1/16/10	25	9/23/10	50	54	10/8/10	1	4.50E+03	9.00E+06	74%	298	0.60
BB2	ISCO	1/29/10	25	9/23/10	100	57	1/12/11	5	2.55E+03	2.04E+06	96%	116	0.47
BB2	ISCO	2/4/10	20	1/31/11	200	125	2/2/11	5	1.79E+03	3.57E+06	99%	21	0.21
BB2	ISCO	2/8/10	10	9/18/10	50	51	10/8/10	1	8.73E+02	4.36E+06	97%	81	0.40
BB3	Grab	3/13/09	20	7/24/09	100	2	1/13/11	5	2.93E+03	2.93E+06	101%	162	0.81
BB3	Grab	3/25/09	10	7/24/09	100	7	1/10/11	5	7.47E+02	1.49E+06	97%	33	0.33
BB3	ISCO	3/25/09	10	7/24/09	100	9	1/13/11	5	4.20E+02	8.40E+05	96%	48	0.48
BB3	Grab	3/27/09	20	7/25/09	100	18	1/13/11	5	1.17E+04	1.17E+07	86%	388	1.94
BB3	ISCO	4/17/09	20	7/25/09	100	21	1/13/11	5	7.46E+02	7.46E+05	103%	70	0.35

Site	Sample Type	Event Date	Filter vol. (mL)	Extraction Date	Elution vol. (uL)	Lid No.	qPCR Date	Template vol. (uL)	AllBac (copies/rxn)	AllBac (copies/L)	AllBac %R	qPCR AllBac Fecal Conc	AllBac Fecal Conc (mg/L)
BB3	ISCO	4/18/09	30	7/25/09	100	26	1/13/11	5	6.33E+03	4.22E+06	97%	275	0.92
BB3	ISCO	4/28/09	20	7/24/09	100	15	1/13/11	5	8.59E+02	8.59E+05	90%	75	0.38
BB3	ISCO	10/4/09	40	10/1/10	100	86	1/12/11	5	6.71E+03	3.35E+06	99%	258	0.64
BB3	ISCO	10/4/09	25	10/1/10	100	84	1/12/11	5	4.13E+03	3.30E+06	103%	195	0.78
BB3	ISCO	10/9/09	30	10/1/10	100	89	1/13/11	5	7.14E+03	4.76E+06	100%	257	0.86
BB3	ISCO	10/13/09	30	10/1/10	100	76	1/12/11	5	5.49E+03	3.66E+06	95%	198	0.66
BB3	Grab	10/26/09	30	10/2/10	100	92	1/11/11	5	3.42E+04	2.28E+07	97%	237	0.79
BB3	ISCO	10/26/09	30	10/2/10	100	95	1/13/11	5	4.45E+03	2.97E+06	98%	198	0.66
BB3	ISCO	11/16/09	20	10/1/10	100	66	1/12/11	5	3.52E+06	3.52E+09	-59%	14,126	70.63
BB3	ISCO	11/21/09	30	10/1/10	100	81	1/12/11	5	1.44E+05	9.60E+07	85%	1,473	4.91
BB3	ISCO	11/29/09	20	10/1/10	100	59	1/12/11	5	5.12E+04	5.12E+07	105%	568	2.84
BB3	ISCO	12/1/09	20	10/1/10	100	73	1/12/11	5	1.07E+04	1.07E+07	96%	307	1.54
BB3	ISCO	1/16/10	25	9/23/10	100	55	1/12/11	5	1.69E+04	1.35E+07	112%	316	1.27
BB3	ISCO	1/29/10	25	9/23/10	100	58	1/12/11	5	4.16E+03	3.33E+06	98%	151	0.60
BB3	ISCO	2/4/10	15	9/18/10	50	50	10/8/10	1	4.62E+03	1.54E+07	94%	304	1.01
BB3	ISCO	2/8/10	15	9/18/10	50	52	10/8/10	1	6.40E+02	2.13E+06	100%	63	0.21
SW12	Grab	3/3/08	50	10/11/10	200	113	2/2/11	5	8.21E+03	6.57E+06	89%	80	0.32
SW12	ISCO	3/6/08	50	2/19/09	100	38	1/14/11	5	2.35E+04	9.38E+06	113%	190	0.38
SW12	Grab	3/10/08	50	10/11/10	200	115	2/2/11	5	2.62E+03	2.10E+06	90%	39	0.16

Site	Sample Type	Event Date	Filter vol. (mL)	Extraction Date	Elution vol. (uL)	Lid No.	qPCR Date	Template vol. (uL)	AllBac (copies/rxn)	AllBac (copies/L)	AllBac %R	qPCR AllBac Fecal Conc	AllBac Fecal Conc (mg/L)
SW12	ISCO	3/10/08	50	2/19/09	100	42	1/14/11	5	4.04E+04	1.62E+07	104%	168	0.34
SW12	ISCO	3/18/08	50	2/19/09	100	44	1/14/11	5	1.46E+04	5.84E+06	92%	133	0.27
SW12	Grab	4/10/08	50	7/24/09	100	1	1/10/11	5	2.65E+04	1.06E+07	97%	369	0.74
SW12	ISCO	4/10/08	50	2/26/09	100	28	1/13/11	5	8.31E+03	3.32E+06	97%	327	0.65
SW12	ISCO	5/14/08	100	2/26/09	100	32	1/13/11	5	1.87E+04	3.74E+06	93%	549	0.55
SW12	ISCO	5/15/08	99.75	1/31/11	200	123	2/2/11	5	2.57E+04	1.03E+07	107%	269	0.54
SW12	Grab	3/13/09	50	7/24/09	100	3	1/10/11	5	1.65E+04	6.61E+06	104%	268	0.54
SW12	ISCO	4/17/09	40	7/25/09	100	22	1/13/11	5	4.78E+04	2.39E+07	91%	1,000	2.50
SW12	Grab	4/18/09	100	7/24/09	100	10	1/10/11	5	1.76E+04	3.52E+06	93%	280	0.28
SW12	ISCO	4/28/09	50	1/31/11	200	121	2/2/11	5	1.12E+03	8.92E+05	77%	11	0.05
SW12	Grab	10/9/09	25	10/3/10	100	101	1/11/11	5	1.02E+04	8.17E+06	99%	100	0.40
SW12	ISCO	10/9/09	25	10/3/10	100	99	1/13/11	5	2.61E+03	2.09E+06	99%	147	0.59
SW12	ISCO	10/11/09	25	10/11/10	100	117	1/14/11	5	5.56E+03	4.45E+06	113%	116	0.46
SW12	ISCO	10/13/09	25	10/11/10	100	118	1/14/11	5	2.09E+03	1.68E+06	108%	37	0.15
SW12	ISCO	10/22/09	25	10/3/10	50	108	1/7/11	5	1.04E+04	4.18E+06	97%		
SW12	ISCO	10/26/09	25	10/3/10	50	110	1/7/11	5	4.15E+03	1.66E+06	84%		
SW12	ISCO	10/30/09	25	10/3/10	50	112	1/7/11	5	2.02E+04	8.09E+06	116%		
SW12	ISCO	1/16/10	25	10/3/10	100	106	1/13/11	5	8.92E+02	7.13E+05	98%	81	0.32
SW17	Grab	3/3/08	50	10/11/10	200	114	2/2/11	5	1.15E+05	9.16E+07	87%	1,050	4.20

Site	Sample Type	Event Date	Filter vol. (mL)	Extraction Date	Elution vol. (uL)	Lid No.	qPCR Date	Template vol. (uL)	AllBac (copies/rxn)	AllBac (copies/L)	AllBac %R	qPCR AllBac Fecal Conc	AllBac Fecal Conc (mg/L)
SW17	ISCO	3/6/08	50	2/19/09	200	39	2/2/11	5	3.09E+04	2.47E+07	94%	291	1.17
SW17	Grab	3/10/08	50	10/11/10	100	116	1/14/11	5	2.46E+04	9.82E+06	94%	655	1.31
SW17	ISCO	3/10/08	50	2/19/09	200	43	2/2/11	5	1.40E+04	1.12E+07	96%	134	0.54
SW17	ISCO	3/18/08	50	2/19/09	100	45	1/14/11	5	4.34E+04	1.74E+07	90%	271	0.54
SW17	Grab	4/10/08	50	2/26/09	100	29	1/11/11	5	1.31E+05	5.22E+07	96%	614	1.23
SW17	ISCO	4/18/08	30	2/26/09	100	31	1/13/11	5	1.48E+05	9.88E+07	92%	2,060	6.87
SW17	ISCO	5/14/08	30	1/31/11	200	122	2/2/11	5	1.18E+05	1.58E+08	98%	1,152	7.68
SW17	Grab	3/13/09	50	7/24/09	200	4	2/2/11	5	2.58E+05	2.06E+08	97%	2,320	9.28
SW17	ISCO	4/17/09	40	7/25/09	100	23	1/13/11	5	1.63E+05	8.16E+07	89%	2,191	5.48
SW17	Grab	4/18/09	40	7/24/09	100	11	1/10/11	5	1.59E+05	7.96E+07	85%	1,246	3.11
SW17	ISCO	4/28/09	49	7/25/09	100	27	1/13/11	5	6.52E+03	2.66E+06	88%	280	0.57
SW17	Grab	10/9/09	25	10/3/10	100	102	1/11/11	5	1.54E+05	1.23E+08	106%	692	2.77
SW17	ISCO	10/9/09	25	10/3/10	100	100	1/13/11	5	1.62E+04	1.30E+07	95%	404	1.62
SW17	ISCO	10/13/09	25	10/11/10	100	119	1/14/11	5	1.34E+04	1.07E+07	93%	323	1.29
SW17	ISCO	10/22/09	25	10/3/10	250	109	1/14/11	5	5.25E+04	1.05E+08	75%	1,587	15.87
SW17	ISCO	10/26/09	50	1/31/11	200	126	2/2/11	5	1.98E+04	1.58E+07	99%	209	0.84
SW17	Grab	1/16/10	25	10/3/10	100	107	1/11/11	5	1.25E+04	9.99E+06	121%	115	0.46
WWR1	Grab	10/26/09	30	10/2/10	100	98	1/11/11	5	4.32E+03	2.88E+06	82%	55	0.18
WWR1	ISCO	11/20/09	30	10/1/10	100	67	1/12/11	5	4.60E+03	3.07E+06	98%	176	0.59

Site	Sample Type	Event Date	Filter vol. (mL)	Extraction Date	Elution vol. (uL)	Lid No.	qPCR Date	Template vol. (uL)	AllBac (copies/rxn)	AllBac (copies/L)	AllBac %R	qPCR AllBac Fecal Conc	AllBac Fecal Conc (mg/L)
WWR1	ISCO	11/21/09	30	10/1/10	100	77	1/12/11	5	8.26E+03	5.50E+06	116%	290	0.97
WWR1	ISCO	12/1/09	20	10/1/10	100	60	1/12/11	5	1.32E+04	1.32E+07	82%	278	1.39
WWR1	ISCO	1/15/10	25	1/31/11	200	128	2/2/11	5	8.07E+02	1.29E+06	80%	10	0.08
WWR1	ISCO	1/16/10	25	1/31/11	200	130	2/2/11	5	3.58E+02	5.73E+05	85%	5	0.04
WWR1	ISCO	2/3/10	30	9/18/10	100	46	1/14/11	5	3.61E+03	2.41E+06	84%	70	0.23
WWR2	Grab	10/26/09	30	10/2/10	100	96	1/11/11	5	4.15E+03	2.76E+06	87%	53	0.18
WWR2	ISCO	11/20/09	18	10/1/10	100	68	1/12/11	5	1.68E+03	1.87E+06	46%	91	0.50
WWR2	ISCO	11/21/09	20	10/1/10	100	78	1/12/11	5	8.99E+02	8.99E+05	111%	82	0.41
WWR3	Grab	10/26/09	30	10/2/10	100	97	1/11/11	5	1.28E+04	8.52E+06	82%	118	0.39
WWR3	ISCO	11/20/09	30	10/1/10	100	69	1/12/11	5	5.22E+02	3.48E+05	78%	54	0.18
WWR3	ISCO	11/21/09	30	10/1/10	100	70	1/12/11	5	9.68E+02	6.45E+05	94%	63	0.21
WWR3	ISCO	12/1/09	30	1/31/11	200	127	2/2/11	5	7.88E+02	1.05E+06	75%	10	0.06
WWR3	ISCO	1/15/10	25	1/31/11	200	129	2/2/11	5	4.71E+02	7.53E+05	79%	8	0.06
WWR3	ISCO	1/16/10	25	1/31/11	200	131	2/2/11	5	1.70E+03	2.72E+06	83%	20	0.16
WWR3	ISCO	2/3/10	20	1/31/11	200	132	2/2/11	5	2.60E+02	5.21E+05	42%	3	0.03

BoBac Data

Site	Sample Type	Event Date	Filter vol. (mL)	Extraction Date	Elution vol. (uL)	Lid No.	qPCR Date	Template vol. (uL)	BoBac (copies/rxn)	BoBac (copies/L)	BoBac %R	qPCR BoBac Fecal Conc	BoBac Fecal Conc (mg/L)
BB1	Grab	3/25/09	10	7/24/09	100	5	1/17/11	5	1.31E+01	2.63E+04	94%	1	0.01
BB1	ISCO	4/17/09	20	7/25/09	100	19	1/17/11	5	4.15E+00	4.15E+03	71%	0	0.00
BB1	ISCO	4/18/09	30	7/25/09	100	24	1/17/11	5	1.82E+01	1.22E+04	80%	2	0.01
BB1	ISCO	4/28/09	20	7/24/09	100	13	1/17/11	5	5.14E+00	5.14E+03	78%	0	0.00
BB1	ISCO	10/4/09	10	10/1/10	100	82	1/22/11	5	4.47E+00	8.94E+03	103%	1	0.01
BB1	ISCO	10/9/09	30	10/1/10	100	87	1/22/11	5	6.41E+00	4.27E+03	87%	1	0.00
BB1	ISCO	10/13/09	30	10/1/10	100	74	1/22/11	5	2.92E+01	1.95E+04	93%	2	0.01
BB1	Grab	10/26/09	30	10/2/10	100	90	1/16/11	5	3.66E+00	2.44E+03	84%	0	0.00
BB1	ISCO	10/26/09	30	10/2/10	100	93	1/22/11	5	3.85E+00	2.57E+03	100%	0	0.00
BB1	ISCO	11/21/09	20	10/1/10	100	79	1/22/11	5	1.73E+02	1.73E+05	92%	10	0.05
BB1	ISCO	12/1/09	20	10/1/10	100	71	1/22/11	5	1.28E+02	1.28E+05	87%	8	0.04
BB1	ISCO	1/16/10	25	9/23/10	100	53	1/23/11	5	1.34E+02	1.07E+05	92%	32	0.13
BB1	ISCO	1/29/10	25	9/23/10	100	56	1/23/11	5	6.93E+01	5.54E+04	97%	9	0.04
BB1	ISCO	2/4/10	20	1/31/11	100	124	2/1/11	5	8.35E+02	8.35E+05	86%	67	0.33
BB2	Grab	3/25/09	10	7/24/09	100	6	1/17/11	5	9.80E+00	1.96E+04	83%	1	0.01
BB2	ISCO	3/25/09	10	7/24/09	100	8	1/17/11	5	2.62E+00	5.23E+03	87%	0	0.00
BB2	ISCO	4/17/09	20	7/25/09	100	20	1/17/11	5	2.95E+00	2.95E+03	90%	0	0.00
BB2	ISCO	4/18/09	30	7/25/09	100	25	1/17/11	5	1.20E+01	8.02E+03	91%	1	0.00
BB2	ISCO	4/28/09	20	7/24/09	100	14	1/17/11	5	3.28E-01	3.28E+02	90%	0	0.00
BB2	ISCO	10/4/09	30	10/1/10	100	85	1/22/11	5	2.20E+01	1.47E+04	101%	2	0.01
BB2	ISCO	10/4/09	20	10/1/10	100	83	1/22/11	5	2.48E+00	2.48E+03	115%	0	0.00
BB2	ISCO	10/9/09	30	10/1/10	100	88	1/22/11	5	2.83E+01	1.89E+04	97%	3	0.01
BB2	ISCO	10/13/09	30	10/1/10	100	75	1/22/11	5	1.75E+01	1.17E+04	82%	1	0.00
BB2	Grab	10/26/09	30	10/2/10	100	91	1/16/11	5	1.26E+01	8.41E+03	91%	1	0.00
BB2	ISCO	10/26/09	30	10/2/10	100	94	1/23/11	5	4.50E+00	3.00E+03	77%	2	0.01
BB2	ISCO	11/21/09	30	10/1/10	100	80	1/22/11	5	1.13E+04	7.54E+06	110%	679	2.26
BB2	ISCO	12/1/09	20	10/1/10	100	72	1/22/11	5	1.68E+03	1.68E+06	87%	82	0.41

Site	Sample Type	Event Date	Filter vol. (mL)	Extraction Date	Elution vol. (uL)	Lid No.	qPCR Date	Template vol. (uL)	BoBac (copies/rxn)	BoBac (copies/L)	BoBac %R	qPCR BoBac Fecal Conc	BoBac Fecal Conc (mg/L)
BB2	ISCO	1/16/10	25	9/23/10	100	54	2/5/11	5	1.16E+02	9.29E+04	223%	17	0.07
BB2	ISCO	1/29/10	25	9/23/10	100	57	1/23/11	5	9.93E+01	7.94E+04	98%	13	0.05
BB2	ISCO	2/4/10	20	1/31/11	100	125	2/1/11	5	1.04E+03	1.04E+06	86%	83	0.41
BB2	ISCO	2/8/10	10	9/18/10	100	51	2/3/11	5	4.89E+02	9.79E+05	96%	27	0.27
BB3	Grab	3/13/09	20	7/24/09	100	2	1/17/11	5	1.49E+01	1.49E+04	130%	1	0.00
BB3	Grab	3/25/09	10	7/24/09	100	7	1/16/11	5	5.62E+00	1.12E+04	118%	0	0.00
BB3	ISCO	3/25/09	10	7/24/09	100	9	1/17/11	5	3.49E+00	6.98E+03	79%	0	0.00
BB3	Grab	3/27/09	20	7/25/09	100	18	1/17/11	5	2.92E+00	2.92E+03	71%	0	0.00
BB3	ISCO	4/17/09	20	7/25/09	100	21	1/17/11	5	5.26E+00	5.26E+03	91%	1	0.00
BB3	ISCO	4/18/09	30	7/25/09	100	26	1/17/11	5	3.78E+00	2.52E+03	107%	0	0.00
BB3	ISCO	4/28/09	20	7/24/09	100	15	1/17/11	5	3.68E+00	3.68E+03	82%	0	0.00
BB3	ISCO	10/4/09	40	10/1/10	100	86	1/22/11	5	1.73E+01	8.63E+03	107%	2	0.00
BB3	ISCO	10/4/09	25	10/1/10	100	84	1/22/11	5	1.16E+01	9.26E+03	109%	1	0.01
BB3	ISCO	10/9/09	30	10/1/10	100	89	1/22/11	5	9.59E+00	6.40E+03	93%	1	0.00
BB3	ISCO	10/13/09	30	10/1/10	100	76	1/22/11	5	1.09E+01	7.26E+03	94%	1	0.00
BB3	Grab	10/26/09	30	10/2/10	100	92	1/14/11	5	1.87E+01	1.25E+04	82%	23	0.08
BB3	ISCO	10/26/09	30	10/2/10	100	95	1/23/11	5	2.25E+01	1.50E+04	100%	8	0.03
BB3	ISCO	11/16/09	20	10/1/10	100	66	1/18/11	5	6.68E+05	6.68E+08	141%	25,645	128.22
BB3	ISCO	11/21/09	30	10/1/10	100	81	1/22/11	5	3.36E+04	2.24E+07	112%	1,836	6.12
BB3	ISCO	11/29/09	20	10/1/10	100	59	1/23/11	5	4.82E+03	4.82E+06	93%	528	2.64
BB3	ISCO	12/1/09	20	10/1/10	100	73	1/22/11	5	3.68E+03	3.68E+06	98%	169	0.84
BB3	ISCO	1/16/10	25	9/23/10	100	55	1/23/11	5	4.01E+02	3.21E+05	105%	50	0.20
BB3	ISCO	1/29/10	25	9/23/10	100	58	1/23/11	5	1.13E+02	9.07E+04	99%	28	0.11
BB3	ISCO	2/4/10	15	9/18/10	100	50	1/23/11	5	2.21E+03	2.94E+06	97%	286	1.91
BB3	ISCO	2/8/10	15	9/18/10	100	52	2/5/11	5	2.05E+02	2.73E+05	122%	16	0.10
SW12	Grab	3/3/08	50	10/11/10	100	113	1/23/11	5	3.05E+00	1.22E+03	85%	0	0.00
SW12	ISCO	3/6/08	50	2/19/09	100	38	1/17/11	5	4.96E+00	1.98E+03	78%	0	0.00
SW12	Grab	3/10/08	50	10/11/10	100	115	1/23/11	5	1.73E+00	6.93E+02	88%	0	0.00
SW12	ISCO	3/10/08	50	2/19/09	100	42	1/17/11	5	5.32E+00	2.13E+03	70%	1	0.00

Site	Sample Type	Event Date	Filter vol. (mL)	Extraction Date	Elution vol. (uL)	Lid No.	qPCR Date	Template vol. (uL)	BoBac (copies/rxn)	BoBac (copies/L)	BoBac %R	qPCR BoBac Fecal Conc	BoBac Fecal Conc (mg/L)
SW12	ISCO	3/18/08	50	2/19/09	100	44	1/17/11	5	3.69E+00	1.48E+03	112%	0	0.00
SW12	Grab	4/10/08	50	7/24/09	100	1	1/16/11	5	2.41E+00	9.62E+02	106%	0	0.00
SW12	ISCO	4/10/08	50	2/26/09	100	28	1/17/11	5	1.97E+02	7.87E+04	103%	18	0.04
SW12	ISCO	5/14/08	100	2/26/09	100	32	1/17/11	5	4.00E+00	7.99E+02	106%	0	0.00
SW12	ISCO	5/15/08	99.75	1/31/11	100	123	2/1/11	5	4.27E+00	8.56E+02	72%	0	0.00
SW12	Grab	3/13/09	50	7/24/09	100	3	1/16/11	5	6.19E+00	2.47E+03	112%	0	0.00
SW12	ISCO	4/17/09	40	7/25/09	100	22	1/17/11	5	3.66E+00	1.83E+03	86%	0	0.00
SW12	Grab	4/18/09	100	7/24/09	100	10	1/16/11	5	4.54E+00	9.09E+02	100%	0	0.00
SW12	ISCO	4/28/09	50	1/31/11	200	121	2/3/11	5	7.27E+00	5.81E+03	81%	0	0.00
SW12	Grab	10/9/09	25	10/3/10	100	101	1/23/11	5	6.43E+00	5.15E+03	103%	3	0.01
SW12	ISCO	10/9/09	25	10/3/10	100	99	1/22/11	5	7.75E-01	6.20E+02	97%	0	0.00
SW12	ISCO	10/11/09	25	10/11/10	100	117	1/23/11	5	2.93E+00	2.34E+03	94%	0	0.00
SW12	ISCO	10/13/09	25	10/11/10	100	118	1/23/11	5	2.28E+00	1.83E+03	98%	0	0.00
SW12	ISCO	10/22/09	25	10/3/10	250	108	1/22/11	5	2.86E+00	5.72E+03	73%	1	0.01
SW12	ISCO	10/26/09	25	10/3/10	250	110	1/22/11	5	5.45E+01	1.09E+05	107%	8	0.08
SW12	ISCO	10/30/09	25	10/3/10	250	112	1/23/11	5	7.19E+00	1.44E+04	93%	1	0.01
SW12	ISCO	1/16/10	25	10/3/10	100	106	1/22/11	5	4.44E+00	3.55E+03	126%	1	0.00
SW17	Grab	3/3/08	50	10/11/10	100	114	1/23/11	5	3.09E+04	1.24E+07	93%	3,046	6.09
SW17	ISCO	3/6/08	50	2/19/09	100	39	1/17/11	5	1.56E+04	6.25E+06	92%	1,164	2.33
SW17	Grab	3/10/08	50	10/11/10	100	116	1/23/11	5	3.01E+03	1.20E+06	90%	336	0.67
SW17	ISCO	3/10/08	50	2/19/09	100	43	1/17/11	5	3.60E+03	1.44E+06	86%	283	0.57
SW17	ISCO	3/18/08	50	2/19/09	100	45	1/17/11	5	4.04E+03	1.62E+06	115%	317	0.63
SW17	Grab	4/10/08	50	2/26/09	100	29	1/17/11	5	6.10E+03	2.44E+06	127%	455	0.91
SW17	ISCO	4/18/08	30	2/26/09	100	31	1/17/11	5	5.67E+04	3.78E+07	114%	4,024	13.41
SW17	ISCO	5/14/08	30	1/31/11	100	122	2/1/11	5	3.76E+04	2.51E+07	86%	2,939	9.80
SW17	Grab	3/13/09	50	7/24/09	100	4	1/16/11	5	1.28E+05	5.12E+07	126%	11,765	23.53
SW17	ISCO	4/17/09	40	7/25/09	100	23	1/17/11	5	5.23E+04	2.62E+07	101%	3,427	8.57
SW17	Grab	4/18/09	40	7/24/09	100	11	1/16/11	5	1.96E+04	9.81E+06	101%	1,690	4.22
SW17	ISCO	4/28/09	49	7/25/09	100	27	1/17/11	5	4.77E+02	1.95E+05	96%	42	0.08

Site	Sample Type	Event Date	Filter vol. (mL)	Extraction Date	Elution vol. (uL)	Lid No.	qPCR Date	Template vol. (uL)	BoBac (copies/rxn)	BoBac (copies/L)	BoBac %R	qPCR BoBac Fecal Conc	BoBac Fecal Conc (mg/L)
SW17	Grab	10/9/09	25	10/3/10	100	102	1/16/11	5	1.11E+04	8.87E+06	NA	936	3.74
SW17	ISCO	10/9/09	25	10/3/10	100	100	1/22/11	5	9.93E+03	7.94E+06	87%	440	1.76
SW17	ISCO	10/13/09	25	10/11/10	100	119	1/23/11	5	2.05E+03	1.64E+06	95%	234	0.94
SW17	ISCO	10/22/09	25	10/3/10	250	109	1/22/11	5	5.88E+04	1.18E+08	107%	1,674	16.74
SW17	ISCO	10/26/09	50	1/31/11	200	126	2/3/11	5	4.08E+03	3.27E+06	92%	266	1.07
SW17	Grab	1/16/10	25	10/3/10	100	107	2/1/11	5	7.20E+01	5.76E+04	43%	2	0.01
WWR1	Grab	10/26/09	30	10/2/10	100	98	1/16/11	5	2.68E+00	1.79E+03	66%	0	0.00
WWR1	ISCO	11/20/09	30	10/1/10	100	67	1/23/11	5	2.70E+02	1.80E+05	93%	55	0.18
WWR1	ISCO	11/21/09	30	10/1/10	100	77	1/22/11	5	5.00E+02	3.33E+05	84%	27	0.09
WWR1	ISCO	12/1/09	20	10/1/10	100	60	1/23/11	5	1.33E+02	1.33E+05	72%	32	0.16
WWR1	ISCO	1/15/10	25	1/31/11	200	128	2/3/11	5	2.74E+00	4.38E+03	63%	0	0.00
WWR1	ISCO	1/16/10	25	1/31/11	200	130	2/3/11	5	1.33E+00	2.12E+03	67%	0	0.00
WWR1	ISCO	2/3/10	30	9/18/10	100	46	1/17/11	5	7.12E+01	4.75E+04	35%	7	0.02
WWR2	Grab	10/26/09	30	10/2/10	100	96	1/14/11	5	4.10E+01	2.73E+04	84%	50	0.17
WWR2	ISCO	11/20/09	18	10/1/10	100	68	2/1/11	5	7.99E+01	8.87E+04	19%	2	0.01
WWR2	ISCO	11/21/09	20	10/1/10	100	78	1/23/11	5	2.75E+00	2.75E+03	58%	1	0.01
WWR3	Grab	10/26/09	30	10/2/10	100	97	1/16/11	5	3.85E+01	2.56E+04	60%	3	0.01
WWR3	ISCO	11/20/09	30	10/1/10	100	69	1/22/11	5	6.40E+01	4.27E+04	69%	4	0.01
WWR3	ISCO	11/21/09	30	10/1/10	100	70	1/22/11	5	7.64E+01	5.09E+04	94%	5	0.02
WWR3	ISCO	12/1/09	30	1/31/11	200	127	2/3/11	5	2.49E+01	3.32E+04	55%	1	0.01
WWR3	ISCO	1/15/10	25	1/31/11	200	129	2/3/11	5	3.92E+00	6.27E+03	61%	0	0.00
WWR3	ISCO	1/16/10	25	1/31/11	200	131	2/3/11	5	1.12E+00	1.79E+03	68%	0	0.00
WWR3	ISCO	2/3/10	20	1/31/11	200	132	2/3/11	5	2.73E+00	5.47E+03	23%	0	0.00