Stream Corridor Riparian Area Restoration

Compiled by:

Oklahoma Conservation Commission

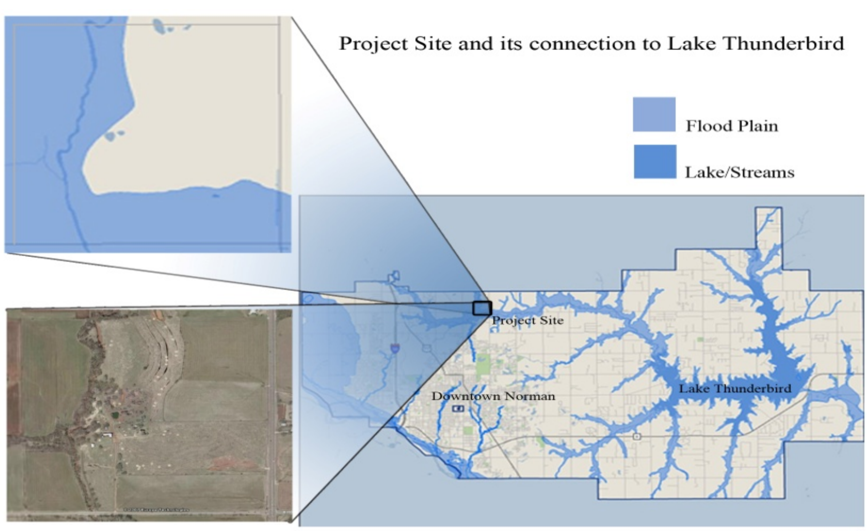
As required by:
EPA FY 2003 104(b)(3) Wetlands
CD976400-01-0, Project 2

September 2008
Draft Final Report

Introduction
Past and current land use activities in both urban and rural watersheds have resulted in the loss of critical riparian wetland acreage. Often, riparian corridors are nonexistent due to urban encroachment, livestock mismanagement, and/or tillage practices. These practices result in streams that are isolated from the myriad of economic and environmental benefits associated with functioning forested riparian wetland areas. These flood prone areas are an integral component for improving water quality, maintaining and protecting the streamside environment and providing wildlife habitat.

Protecting and restoring riparian wetland areas has become a national effort. From the Office of the President to the state level, a new relationship has developed with regard to the manner in which this resource is viewed. The State of Oklahoma has addressed this issue in its Comprehensive Wetlands Management Plan. Several of the 12 specific objectives in the Management Plan discuss the importance of restoration, enhancement and the integration of conservation practices in riparian wetland areas. In fact, municipalities have recognized the importance and benefits these systems can provide to their communities. The City of Norman (City) expressed interest in protecting riparian and/or wetland areas through various incentives and educational efforts, which prompted the development of this project.

This project specifically addressed City owned property located in the Lake Thunderbird Watershed. A substantial portion of the City's water supply comes from Lake Thunderbird; so protecting the water quality is of foremost importance. Lake Thunderbird was created when the Bureau of Reclamation impounded the Little River. Historically the land use in the watershed was agriculture, but urban sprawl and commercial development have become more important as of late. Consequently, there are segments of the river and its tributaries that have lost the forested riparian wetland area and no longer benefit from its associated attributes. The City is interested in restoring the forested riparian wetlands along their streams to capitalize on the benefits that these areas provide. The City realizes that the restoration of the bottomland hardwood forests that once were wide spread through the Little River and its tributaries could improve overall quality of the lake.



Project Goals

Riparian wetland area restoration:

Develop a plan to restore and enhance over one-half mile of forest riparian wetlands (both banks) on the North Fork Creek tributary to the Little River. Reestablish a native and locally indigenous bottomland hardwood forest and other associated attributes of a forested riparian wetland area. Install best management practices in the forested riparian wetland area by reestablishing between 6 to 15 acres of hardwood forest in the riparian area. This equates to 50 to 100 feet of riparian “buffer” on either side of the tributary.

Educational opportunities:

Provide educational opportunities for the City in terms of planning and development as well as focusing attention on the importance of these areas for environmental and economical benefits. Provide students experiential opportunities in the creation, maintenance and function of riparian wetland areas. This area would be made available to universities, public and private schools, the agricultural community, and other groups for research, education, and hands on learning opportunities.

Project Site

This property was originally purchased by the City in 2003 for a new 2.5- 4.5 MGD Wastewater Treatment Plan (WWTP). Those plans have since been shelved. The project site is situated northwest of the intersection of 12th Ave. NE and Franklin Road. Total site area is approximately 160 acres. The site is bordered by Franklin Road on the south, 12th Ave NE. on the east and agricultural farm lands on the west and north. The property can be described as the Southeast Quarter of Section 5, Township 9N, Range 2W of the Indian Meridian, Cleveland County, Oklahoma.

Approximately one half of the site is located within the 100-year floodplain. These areas compose approximately 80 acres located in the southern one third and western one third of the property. The floodplain designation is zone A or areas of flooding during the 100-year event with an undetermined flood hazard factor.

Based on the aerial photography review, the property appears to have been used for agricultural/cattle purposes in addition to mineral exploration and extraction. The properties located immediately adjacent to the north, south, east and west of the subject parcel are also described as agricultural/cattle production. One occupied residence is located along the north property boundary. Three oil wells were known to have been drilled, only one of which is currently operating.

Project Activities
After the purchase of the project site, the City leased the property to a farmer for cattle and haying. Cattle activity along a stream degrades the riparian vegetation and the stability of streambanks. The first action for this project was to remove the cattle from the riparian area of the stream. Since no riparian fencing was available, the cattle were completely removed from the property. The lessee was able to continue haying 100 feet from either side of the stream. Soon after this was done, the University of Oklahoma Big Event, a large volunteer event, volunteers came out to the site to clean up trash and various debris and items that had accumulated over the years on the old homestead.

After removing the cattle and initial site clean-up, a restoration plan was developed for the stream corridor riparian area. The plan (Appendix B) calls for the development of a riparian area consisting of three zones projecting out from the stream to a distance of approximately 100 feet. Zone 1 (~5 acres) consists of the first 15-30 feet closest to the stream and is comprised of native riparian tree species to central Oklahoma. This zone is the most important for stabilizing the streambank and riparian area. Zone 2 (~18 acres) is an intermediate zone consisting of a mixture of native trees and shrubs ranging from 60-110 feet wide where active management may take place. Its purpose is to provide the necessary contact time and carbon energy resource for buffering to occur, as well as long term storage of nutrients in the forested areas. Zone 3 (~60 acres) consists of native grass species and is designed for runoff control and provides sediment filtering, nutrient uptake, and the space necessary to convert concentrated flow to uniform, shallow sheet flow.

City staff prepared the area for planting by digging holes with a bobcat equipped with an auger. About 80 volunteers from the University of Oklahoma Big Event helped again at the site by planting trees in the holes dug by the City. A combination of ball and burlap and containerized trees and shrubs were planted in the holes, and bare root trees were planted near the stream. Native grasses were planted along the outer edge of the riparian corridor. A list of the variety of native tree, shrub, and grass species that were planted throughout the riparian corridor can be found in the restoration plan (Appendix B). After the trees were planted a trail was constructed along the riparian corridor using mulch from the City's compost facility.

Educational Opportunities

This project provided opportunities to educate different audiences on the importance and benefits of properly functioning riparian corridors. Riparian information from the Project WET curriculum was presented to primary and secondary school teachers, so they can provide students with experiential learning opportunities on the function of riparian wetland areas. In addition, this project and riparian corridors information were presented to City staff and the City's Environmental Concerns Advisory Board in terms of planning and development as well as focusing attention on the importance of these areas for environmental and economical benefits. Also, "Stream and Riparian Ecosystem Rehabilitation" was taught in a course, Ecological Engineering Science, at the University of Oklahoma School of Civil Engineering and Environmental Science. The importance of riparian systems and concepts of rehabilitating dysfunctional areas using ecological applications were conveyed to the students. Additionally, the project area was utilized by two undergraduate researchers to study interactions between streams and their riparian areas. All of the supporting documentation for these educational opportunities can be found in Appendix C.

Future Plans

Some of the future plans for the project site include the connection of the riparian corridor to the City of Norman greenbelt system that runs through the city. This will provide recreational and learning opportunities for the public to experience riparian wetland ecosystems. In addition, some ideas have been floated by City staff to use the existing barn on the property as a visitor center. The structure could then be utilized for displaying educational material regarding riparian systems, and it could also be used as an outdoor classroom for area teachers.

APPENDIX A
(Project Workplan)

Project 2

Agency: Oklahoma Conservation Commission
In Cooperation with:
Oklahoma's Office of the Secretary of Environment
City of Norman
University of Oklahoma
Cleveland County Conservation District
Natural Resource Conservation Service

Title: **Stream Corridor Riparian Area Restoration**

Background:

Past and current land use activities in both urban and rural watersheds have resulted in the loss of critical riparian wetland acreage. Often, riparian corridors are nonexistent due to urban encroachment, livestock mismanagement, and/or tillage practices. This results in streams that are isolated from the myriad of economic and environmental benefits associated with functioning forested riparian wetland areas. These flood prone areas are an integral component for improving water quality, maintaining and protecting the streamside environment and providing wildlife habitat.

Protecting and restoring riparian wetland areas has become a national effort. From the Office of the President to the state level, a new relationship has developed with regard to the manner in which this resource is viewed. The State of Oklahoma has addressed this issue in its Comprehensive Wetlands Management Plan. Several of the 12 specific objectives in the Management Plan discuss the importance of restoration, enhancement and the integration of conservation practices in riparian wetland areas. In fact, even municipalities recognize the importance and benefits associated with these systems. The City of Norman (City), has recently expressed interest in protecting riparian and/or wetland areas through various incentives and educational efforts.

This project would specifically address City owned property located in the Lake Thunderbird Watershed. A substantial portion of the City's water supply comes from Lake Thunderbird; so protecting the water quality is of foremost importance. Lake Thunderbird was created when the Bureau of Reclamation impounded the Little River. Historically the land use in the watershed was agriculture, but urban sprawl and commercial development have become more important as of late. Consequently, there are segments of the river and its tributaries that have lost the forested riparian wetland area and no longer benefit from the associated attributes. The City is interested in restoring the forested riparian wetlands along their streams to capitalize on the benefits that these areas provide. The City realizes that the restoration of the bottomland hardwood forests that once were wide spread through the Little River and its tributaries could improve overall quality of the lake.

Goals:

1. Riparian Wetland Area Restoration
    a. Restore and enhance over one-half mile of forested riparian wetlands (both banks) on a tributary of the Little River.
    b. Reestablish a native and locally indigenous bottomland hardwood forest and other associated attributes of a forested riparian wetland area.
    c. Install best management practices in the forested riparian wetland area.

2. Educational Opportunities
    a. Provide educational opportunities for the City in terms of planning and development as well as focusing attention on the importance of these areas for environmental and economic benefits.
    b. Provide students experiential opportunities in the creation, maintenance and function of riparian wetland areas. This area would be made available to universities, public and private schools, the agricultural community, and other groups for research, education, and hands-on learning opportunities.

Measures of Success:

1) Reestablishing between 6 to 15 acres of hardwood forest in the riparian area. This equates to 50 to 100 feet of riparian "buffer" on either side of the tributary.
2) Incorporating educational and experiential opportunities for students and the public in the design and implementation of the restoration effort. The design and implementation will specifically involve input and effort from the City, university students, and primary and secondary school age children.
3) Educating City planners and local officials on the importance and benefits of riparian areas (10 - 15 city employees and officials).

Workplan:

October 2003 through September 2008

***Task 1*:** **Educational Outreach**

Educational seminars will be held to relate the importance of riparian wetland areas and need for them within urban and rural environments. At least three presentations will be specifically designed and directed to appropriate audiences, which could include: (a) City planners, officials and other pertinent people; (b) university level students; (c) primary and secondary students; and (d) private landowners and citizens. Each seminar will be age and education level appropriate as well as relevant to the interest of audience. The OCC and University of Oklahoma will conduct the seminars with input and participation from the Conservation District, NRCS and the City. The restoration effort on the City property will be incorporated into the presentations to provide a tangible example of overall goal.

Milestone Date: September 2008
Deliverable: Letter report detailing the attendance, agenda and practical educational materials

Costs: $12,000 ($9,000 federal*)*

***Task 2*:** **Development of the Restoration Plan**

A restoration and enhancement plan for restoring this riparian wetland system will be developed by the City and the University of Oklahoma, under the auspices of the OCC with input from NRCS. This would include: hydrologic evaluation, species selection and planting design, minor earthwork plans, and other activities.

Milestone Date: September 2008
Deliverable: Detailed plans and engineering drawings of the implementation plan along with a narrative description of the overall design
Costs: $10,000 ($7,500 federal)

***Task 3*:** **Implementation of the Restoration Plan**

Based on the design generated and approved by EPA, the plan will be implemented through the use of volunteers, City employees and contracted labor. The implementation will be incorporated into the educational experience. Implementation will involve vegetative planting, minor earthwork, and other ancillary activities. The earthwork would include the creation of small berms to increase the retention of water and provide microtopography. These activities would establish bottomland hardwood forested wetlands with a mosaic of habitats that would support both terrestrial and aquatic vegetative species.

Milestone Date: September 2008
Deliverable: Letter report detailing the effort along with photo documentation of pre and post construction
Costs: $25,240 ($18,930 federal)

***Task 4*:** **Quarterly and Final Reports**

Milestone Date: December 2003 through September 2008
Deliverable: Quarterly reports will be written to provide an update on the status of the project. A final report will be submitted to EPA, which summarizes all the activities associated with this project as well as a section that documents the utility of this effort and the lesson learned in restoring bottomland hardwoods within an urban/rural environment.
Costs: $4,000 ($3,000 federal)

Budget Categories:

	Federal	*State*	*Total*
Personnel	$10,000	$3,333	$13,333
Fringe Benefits	$2,000	$667	$2,667
Equipment	$0	$0	$0
Travel	$530	$177	$707
Supplies	$4,000	$1,333	$5,333
Contracting	$19,500	$6,500	$26,000
Total Direct Charges	$36,030	$12,010	$48,040
Indirect Charges @ 20%	$2,400	$800	$3,200
Total	*$38,430*	*$12,810*	*$51,240*

Personnel:

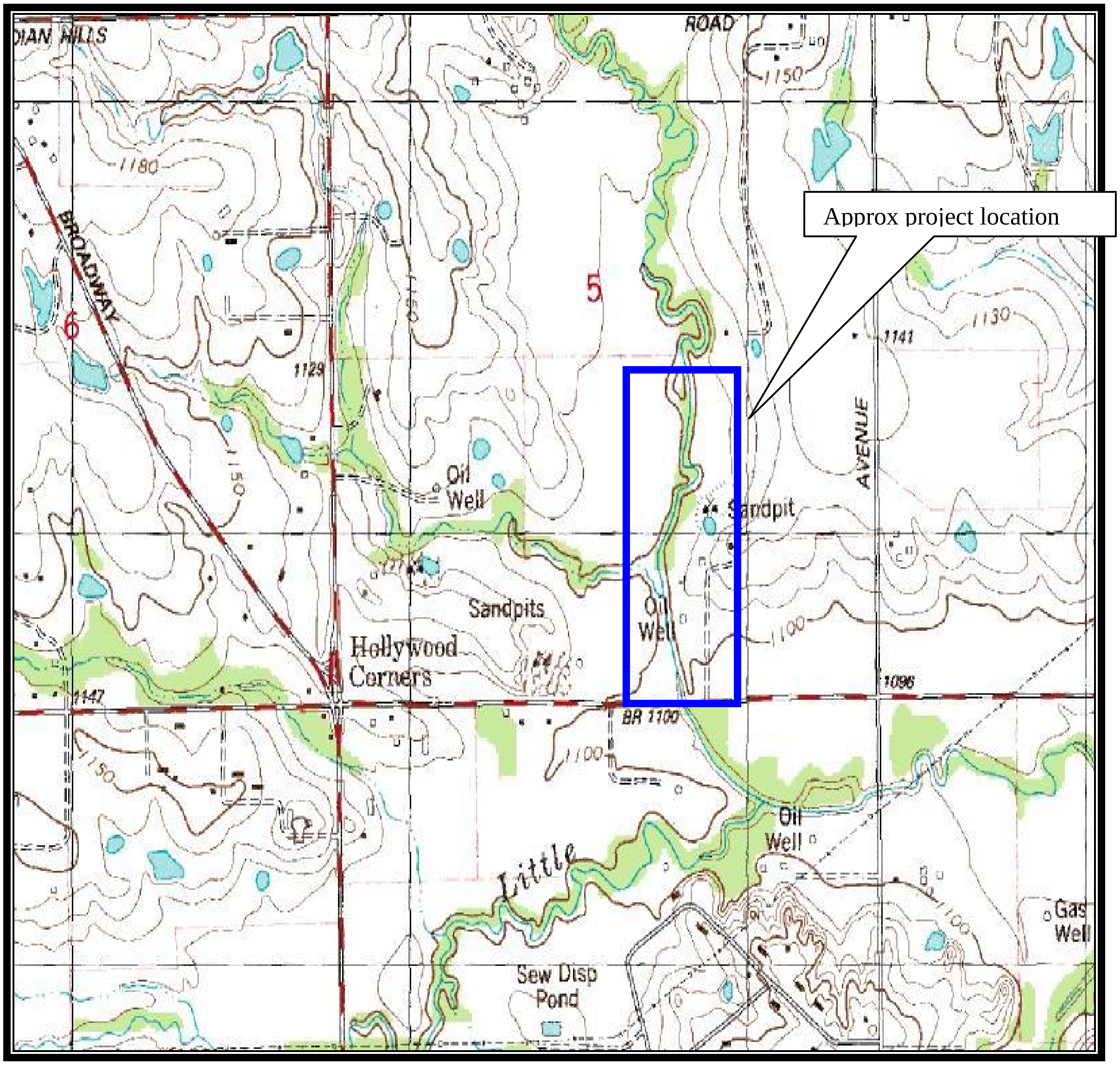
Personnel	*Years*	*Cost*
Wetland Educator	0.05	$3,000
Wetlands Program Coordinator	0.3	$10,333
Total		*$13,333*

Supplies:

Supplies	*Cost*
Office Supplies (paper, pens, staples, etc.)	$750
Computer Supplies (program updates, etc.)	$800
Documentation Material (camera, film, etc.)	$900
Waders, boots, shovels, gloves, etc.	$1,200
Resource Materials	$850
Planting materials	$833
Total	*$5,333*

Contracting:

Type	*Cost*
Restoration Design	$10,000
Minor Earthwork	$10,000
Larger Vegetative Plantings	$3,000
Educational Outreach	$3,000
Total	*$26,000*



A map showing the approximate location of the proposed project boundary. The City owns roughly SE ¼ of Section 5 T9N, R2

APPENDIX B
(Restoration Plan)

Stream Corridor Riparian Area Restoration

FY 2003 104(b)(3) Wetlands Grant, Project 2
EPA #CD-976400-01
OCC #568

Restoration Plan Development

Task 2

Oklahoma Conservation Commission
City of Norman

April 2008

Introduction

Past and current land use activities in both urban and rural watersheds have resulted in the loss of critical riparian wetland acreage. Often, riparian corridors are nonexistent due to urban encroachment, livestock mismanagement, and/or tillage practices. This results in streams that are isolated from the myriad of economic and environmental benefits associated with functioning forested riparian wetland areas. These flood prone areas are an integral component for improving water quality, maintaining and protecting the streamside environment and providing wildlife habitat.

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Benefits and Functions of Riparian Areas

Riparian areas are the areas adjacent to water bodies such as creeks, rivers, lakes, ponds and wetlands. They provide a unique land-water interface, different from surrounding lands (Riparian Area Management Handbook, 1998).

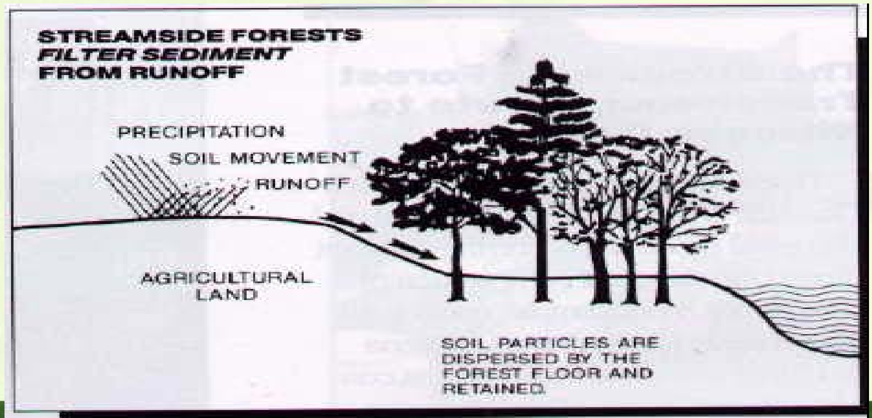
Healthy riparian areas provide a host of on-site and off-site benefits to humans and environment. Riparian areas play an important role in improving water quality, protecting the streamside environment, and preserving biodiversity. The landowner profits by preventing erosion from streambanks, increasing forage and timber products, improving fishing and hunting opportunities, and preserving the quality of the land and water for future generations. Society benefits from improved water quality and environmental values, such as biodiversity and aesthetics. Often, there are additional off-site benefits, such as reduced flood damage.

Erosion Control:

Vegetation growing along the banks of a stream holds the soil in place and reduces stream bank erosion. Removing this vegetation causes excessive erosion. Riparian areas are crucial to streambank stability.

Water Quality Enhancement:

Sediment and nutrients as nonpoint source run-off are significant pollutants in reducing water quality. Vegetated riparian areas counter these threats by retaining and/or transforming these concentrations of nitrogen, phosphorus and potassium ions through oxidation, reduction, assimilation or other biochemical processes before they enter waterbodies.



Reference: Maryland Department of Natural Resources

Biological Productivity:

Riparian areas provide habitat, including food, water, cover, and reproductive features, that support a diverse array of wetland-dependent or indicative species and population. Quality of the water is determined in part by its biological inhabitants.

Aquatic Species - Vertebrate and invertebrate species that complete their life cycle in water

Resident – Species that typically spend all life stage in an area or habitat of analogous physical conditions.

Transient – Species that typically move in response to changing habitat conditions and/ or with specific life stage requirements.

Semi-aquatic species – Vertebrate and invertebrate species that spend certain life stages in water.

Wetland Wildlife Species – Vertebrate species, typically mammals, birds, amphibians, and reptiles, that spend most or all of their life stages above the water's surface, but are heavily dependant on aquatic or wetland condition to fulfill basic needs.

Vegetation - Species of plants typically adapted to periodically anaerobic soil conditions.

Food Chain support - Providing primary and secondary productive that support faunal communities within the riparian area and in adjacent and downstream waterbodies.

Reduction of Flood Impact:

Peak flood Reduction – Riparian areas influence regional water flow regimes by intercepting storm runoff and temporarily storing excess surface waters, thereby reducing storm runoff peak discharges by storing and slowly releasing runoff over a longer period of time.

Erosion Potential Reduction – Riparian areas in the natural state are usually vegetated. This vegetation reduces the velocity of flood waters and wave action, there by lessening the potential for erosion of shorelines and flood plain areas. The root system of wetlands vegetation bind the flood plain and shoreline soils to further resist erosive forces.

Direct Human Benefits:

In addition to the societal benefit provided by normal riparian area function, several direct human benefits can be derived from riparian areas and their functions through managed use. Opportunities for human uses compatible with sustained wetlands conditions include:

Recreation - Riparian areas provide scenic shaded areas for play, amusement, relaxation, physical and mental refreshment, and observing wildlife. Fishing is prime in these areas.

Education – Riparian areas are ideal for monitoring aquatic life and for teaching the importance of water quality.

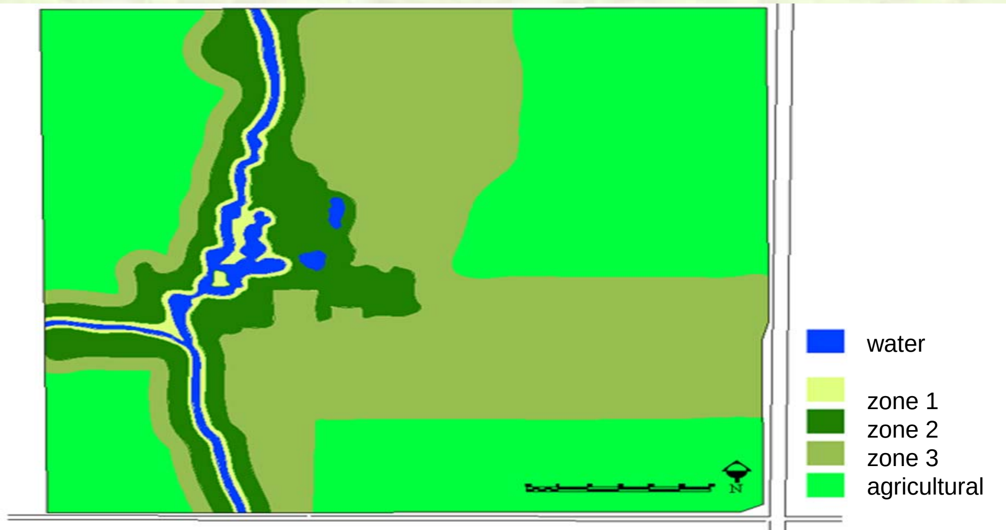
Project Goals

Riparian Wetland Area Restoration:

Develop a workplan to restore and enhance over one-half mile of forest riparian wetlands (both banks) on the North Fork Creek tributary to Norman's Little River.

Reestablish a native and locally indigenous bottomland hardwood forest and other associated attributes of a forested riparian wetland area.

Install best management practices in the forested riparian wetland area by reestablishing between 6 to 15 acres of hardwood forest in the riparian area. This equates to 50 to 100 feet of riparian "buffer" on either side of the tributary.



RIPARIAN AREA ZONING

Educational Opportunities:

Provide educational opportunities for the City in terms of planning and development as well as focusing attention on the importance of these areas for environmental and economical benefits.

Provide students experiential opportunities in the creation, maintenance and function of riparian wetland areas. This area would be made available to universities, public and private schools, the agricultural community, and other groups for research, education, and hands on learning opportunities.

Riparian Buffer Workplan

Riparian buffer design is developed based on Riparian Buffer Specification. The purpose of the RBS is to protect and enhance surface water and ground water quality and aquatic ecosystem health. Riparian buffers accomplish this by removing nutrients, sediments, organic matter, certain pesticides, and other pollutants from surface water and ground water recharge areas by deposition, absorption, adsorption, plant uptake, and denitrification.

Riparian buffers also reduce flood heights and flood velocities, contributing to the stability of streambanks and lake shores, and provide important wildlife habitat. Forested riparian buffers shade streams, thus improving aquatic habitat, and support productive forests which can be harvested periodically.

Riparian areas are divided into 3 zones according to Riparian Buffer Specifications.

Riparian Zone 1

Riparian zone 1 is developed along a one-half mile length on both the banks of north fork creek. Width of this ranges from 15' to 30' measured perpendicular to the stream bank. Total area of this zone is approximately 5 acres including existing area featuring zone 1.

Zone 1 is the region directly adjacent to the water body. The purpose of zone1 is to create a stable ecosystem along the water's edge and provide soil/water contact to facilitate nutrient buffering process. This area also provides shade to lower water temperature and improve aquatic life.

The predominant vegetation in zone 1 consists of species selected for their ability to stabilize the riparian system. Native tree species such as those suggested in the Riparian Buffer Plant Materials table are preferred. In the areas where the banks are too steep to support trees, a mixture of native grasses, forbs and shrubs will be chosen.

Riparian Zone 2

Zone 2 is an intermediate zone where active management may take place. Its purpose is to provide the necessary contact time and carbon energy resource for buffering to occur, as well as long term storage of nutrients in the forested areas.

Width of this zone ranges from 60' to 110'. Total area is approximately 18 acres including existing hardwood forest. Since the riparian zone 2 is dominated by tree species historically, hard core tree species are chosen for zone 2.

Riparian Zone 3

Zone 3 is designed for runoff control and provides sediment filtering, nutrient uptake, and the space necessary to convert concentrated flow to uniform, shallow sheet flow.

This zone covers a total area of approximately 60 acres which includes present natural grassland prairie. Dense, perennial grasses and forbs are used for this zone.

Site Introduction

The project site is situated northwest of the intersection of 12th Ave. NE and Franklin Road. Total site area is approximately 160 acres. The site is bordered by Franklin Road on the south, 12th Ave NE. on the east and agricultural farm lands on the west and north. The property can be described as:

Southeast Quarter of Section 5, Township 9N, Range 2W of the Indian Meridian, Cleveland County, Oklahoma.

Approximately one half of the site is located within the 100-year floodplain. These areas compose approximately 80 acres located in the southern one third and western one third of the property. The floodplain designation is zone A or areas of flooding during the 100-year event with an undetermined flood hazard factor.

Based on the aerial photography review, the property appears to have been used for agricultural/cattle purposes in addition to mineral exploration and extraction.

The properties located immediately adjacent to the north, south, east and west of the subject parcel are also described as agricultural/cattle production. One occupied residence is located along the north property boundary.

Three oil wells were known to have been drilled, only one of which is currently operating.

This property was originally purchased by the City in 2003 for a new 2.5- 4.5 MGD Wastewater Treatment Plan (WWTP). Those plans have since been shelved.

Some of the opportunities the property provides are:

- North Fork Creek
- Existing buildings (barns)
- Existing hardwood forest
- Native Prairie

Norman's Ecoregion

Ecoregions are defined as relatively homogeneous areas that can be mapped using factors such as land surface form, soils, landuse, and potential natural vegetation. Norman belongs to Central Great Plains – 27.

Central Great Plains – 27:

Species diversity

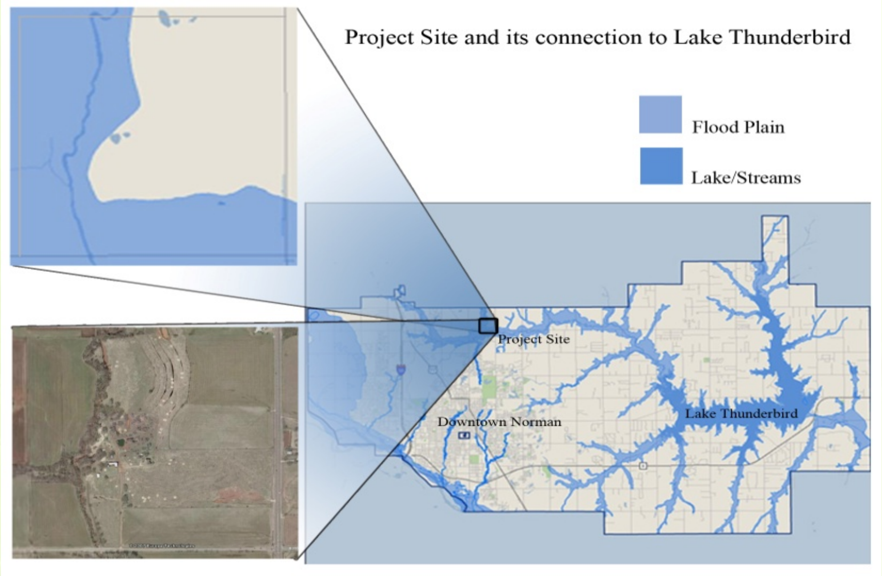
Three hundred twenty-eight vertebrate species are native to this ecoregion. Five species have been extirpated and13 have been introduced. One species is state-listed as threatened (but has been proposed for federal listing) and 21 are candidates of specific concern.

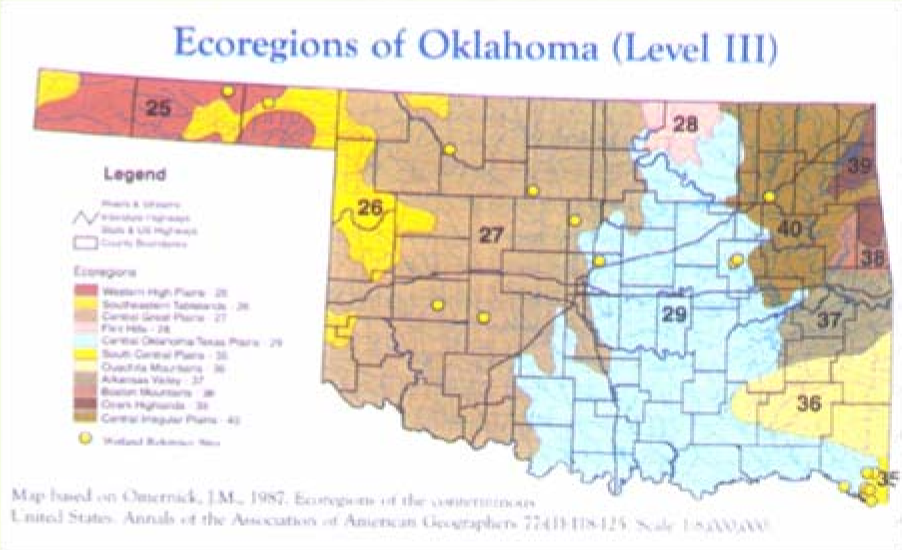
Natural communities

Grassland covers most of this ecoregion, with woodlands scattered in ravines and along the streams. Narrow bands of cross-timbers vegetation extend into the prairie from the east. Mesquite and shinnery oak woodlands extend into the eco-region from the west.

The grasslands in this ecoregion represent a transition zone between tall grass and short grass prairie communities. These grasslands consist of a mixture of species from both communities and are called the mixed grassland prairie. Little bluestem, side oats grama, and dropseeds are the dominating grass species. These grasses average about 20 inches (50 cm) in height. In the eastern region of the eco-region, little bluestem forms a dense sod similar to that found in tall grass communities. In more arid western parts of the ecoregion, little bluestem and other grasses occur in isolated bunches, with wildflowers in the spaces between. Tall grass prairie communities can be found in deep, moist soil, and short grasses are prevalent on these soils.

Herbaceous plants occur in areas where grasses do not use all the available moisture. Many plants bloom early in the year before they are shaded by grasses. Other species depend on a deep root system to provide sufficient water for summer and fall growth.





Woody plants are not abundant in many parts of the ecoregion due to insufficient water. Exceptions are the forested areas found along rivers and streams. Cottonwoods and willow are the most important trees of these forests, but hackberry and elms may be abundant.

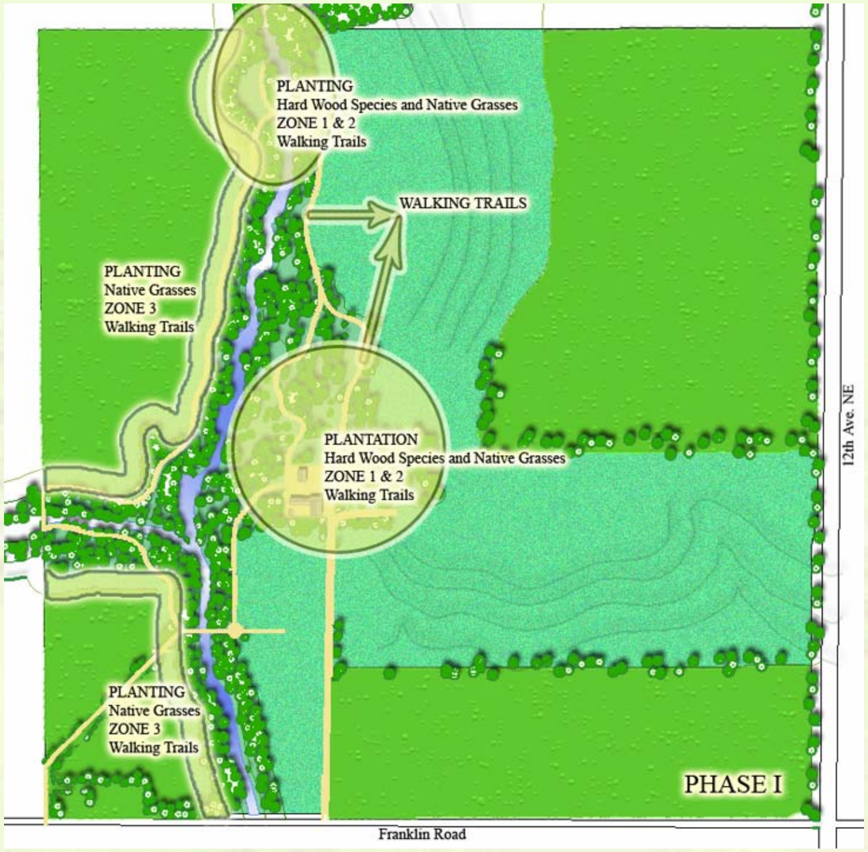
Riparian Buffer Plant Materials	
Hardwood Species	**Herbaceous Species**
Hackberry	Sea Oats
Soapberry	Indian Grass
Pecan	Big Bluestem
Bur Oak	Little Bluestem
Redbud	Switchgrass
Black Walnut	
Kentucky Coffee Tree	
Persimmon	
Chinkapin Oak	
Sugarberry	
American Elm	
Cedar Elm	
Eastern Cottonwood	
Red Mulberry	
Sycamore	
Mexican Plum	
Bitternut Hickory	
Possumhaw	

The selected species are chosen to restore the native habitat of the riparian buffer. Species include large hardwoods, under-story trees and shrub-like trees. These stream side dwelling species provide shelter and food sources for a variety of fauna, as well as sediment stabilization.

Herbaceous species will maintain a buffer between the hardwoods and native prairie. Grasses also act as a filter and are vital to a balanced buffer. The grassland habitat also provides a food source and shelter for smaller ground dwelling species.

Implementation

The City of Norman has three phases planned for this property. Via EPA 104(b)(3) Wetland Development Grant, the Conservation Commission at this time is only funding Phase I.



Phase I

Work description:

1. Planting along the channelized portion of the river on the north side of the property. Plants will mainly include native hardwood species and grasses.

2. Construction of walking trails as a loop from the barn to northern boundary of the property and back to the barn.

3. Planting of native grass species on both sides of the confluence.

The layout to the right demonstrates what is planned to be in place by the end of the grant period for this project. Below are a "before" and a desired photo-shopped "after" picture of one aspect for this phase of the project.

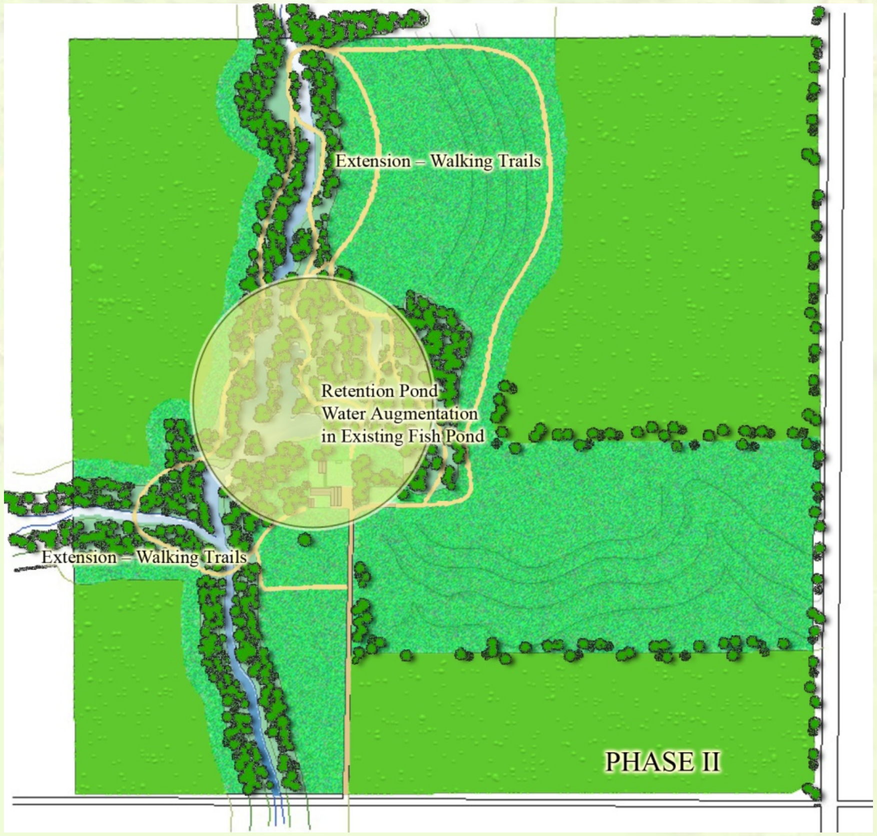
Phase II

Proposed

Work description:

The City plans to construct a wetland/retention pond on the northeast side of confluence and south side of the barn. Its approximate size would be 1.96 acres.

Additionally, an augmentation to the existing pond on the northeast side of the barn is planned.



Phase III

Proposed

Work description:

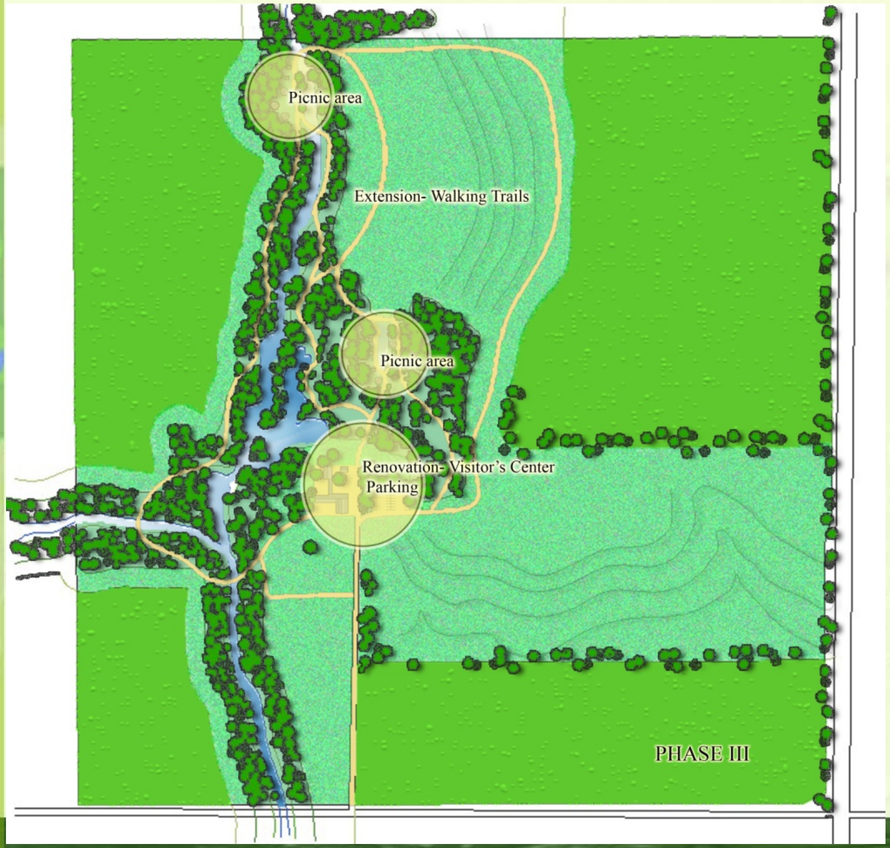
The City plans to renovate and adapt the existing barn as a visitor's center. They will also manipulate shaded areas for picnic venues.

Conclusion

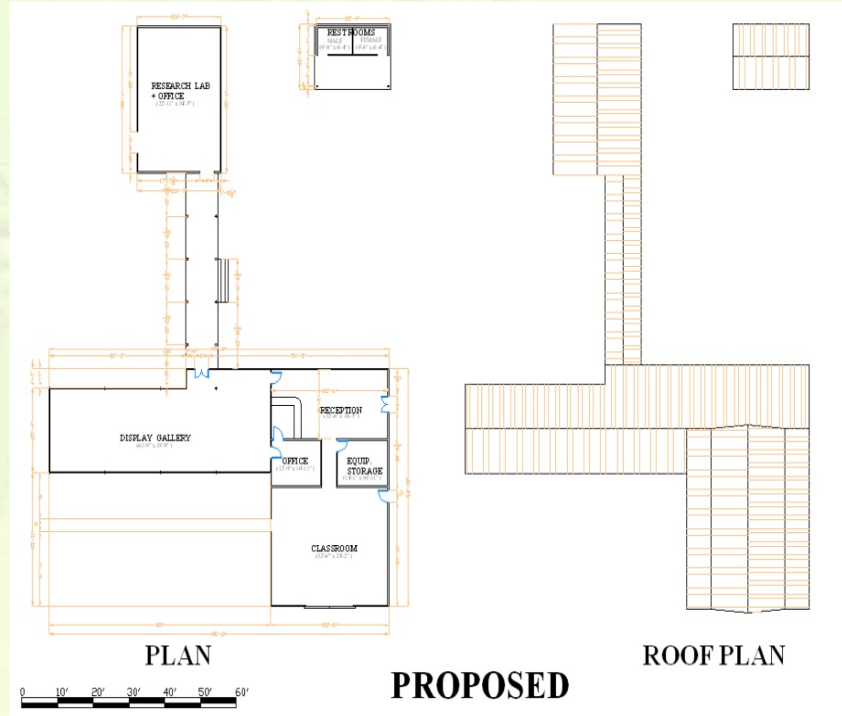
In addition to the environmental benefits of this project, the City of Norman as depicted on the previous and following pages, plans to use this property as an educational and recreational site. It will also exist as part of Norman's greenbelt network.

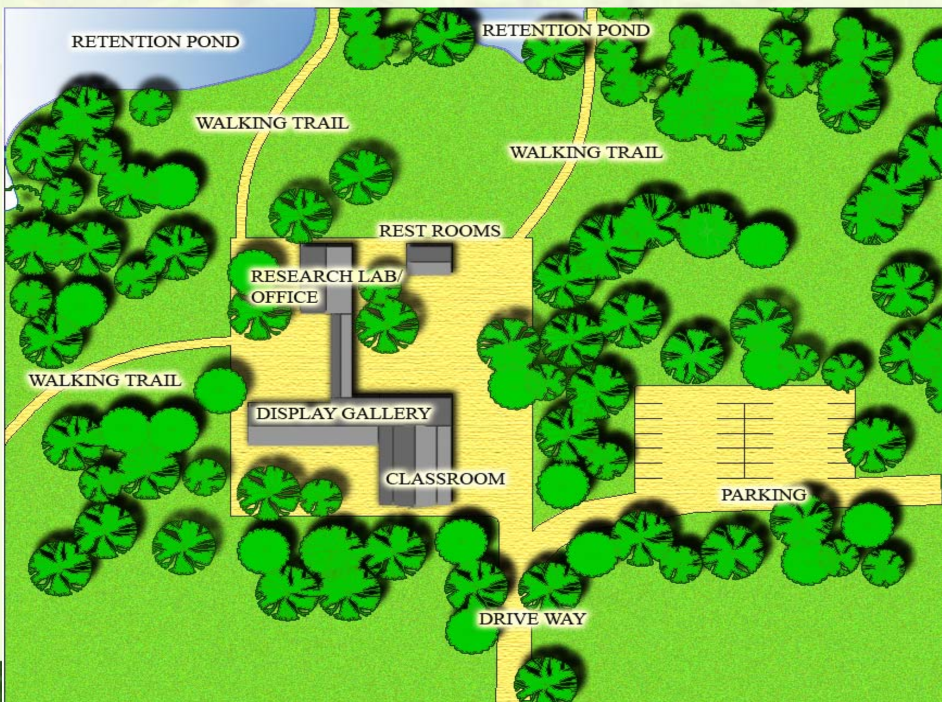
References

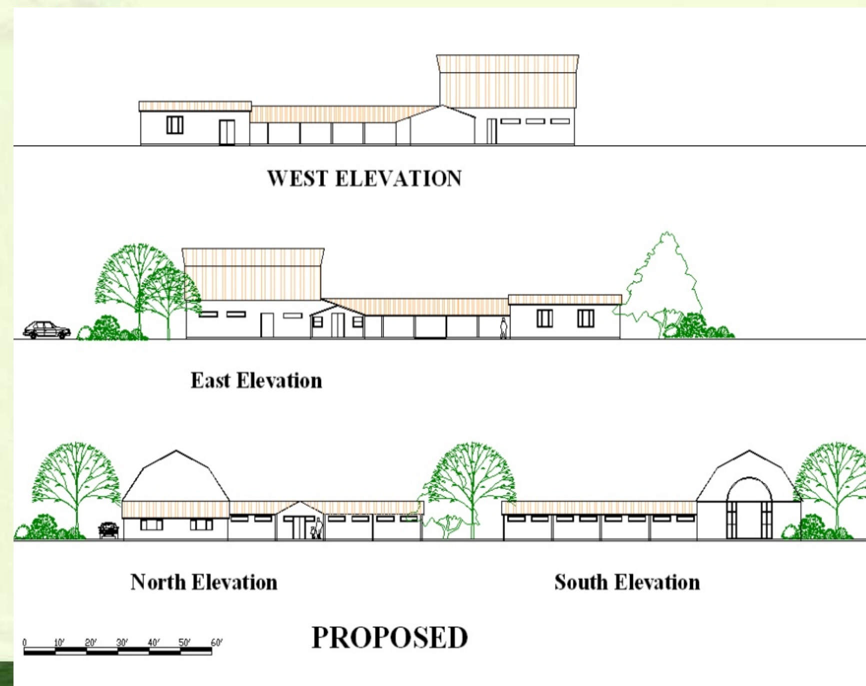
Oklahoma Cooperative Extension Service. 1998. Riparian Area Management Handbook. Oklahoma Conservation Commission and Oklahoma State University publication.




PICNIC AREA
NATURAL PRAIRIE
AGRICULTURAL LAND
AGRICULTURAL LAND
AREA FOR WASTE WATER TREATMENT PLANT
HARDWOOD FOREST
PICNIC AREA
WALKING TRAILS
RETENTION POND
VISITOR CENTRE
PARKING
EQUALIZATION BASIN1
EQUALIZATION BASIN 2
NATURAL PRAIRIE
LIFT STATION
OIL WELL
EQUALIZATION BASIN3
WALKING TRAIL TO LEGACY TRAIL
AGRICULTURAL LAND
PARKING


RESEARCH LAB + OFFICE
REST ROOMS
DISPLAY GALLERY
RECEPTION
OFFICE
EQUIP. STORAGE
CLASSROOM
PLAN
ROOF PLAN
PROPOSED
0 10' 20' 30' 40' 50' 60'


RETENTION POND
RETENTION POND
WALKING TRAIL
WALKING TRAIL
REST ROOMS
RESEARCH LAB/ OFFICE
WALKING TRAIL
DISPLAY GALLERY
CLASSROOM
PARKING
DRIVE WAY


WEST ELEVATION
East Elevation
North Elevation
South Elevation
PROPOSED
0 10' 20' 30' 40' 50' 60'

APPENDIX C
(Educational Opportunities)

PROJECT WET®
Water Education for Teachers

Basic Workshop @ OU, Norman

Saturday - October 4, 2008
9:00 am to 4:00 pm

Agenda

- Welcome & Introductions
- Icebreaker
- Goals & Objectives
- Activity - The Incredible Journey
- What is WET?
- Break
- Activity - Sum of the Parts
- Splash thru the Guide
- Assignments & Working Lunch
- Participant Led Activities
  - H_2Olympics
  - AGM
  - Is there Water on Zork?
- Wrap-up Activities & Evaluation

Project WET Workshop on October 20, 2007

FIRST NAME	LAST NAME	ADDRESS	CITY	STATE	ZIP CODE
MARY	HENDRICK	10408 NW 42ND ST	YUKON	OK	73099
WHITNEY	HOLCOMB	241 CIRCLEVIEW DR S	HURST	TX	76054
UYEN	VU	2320 SW 90TH ST	OKLAHOMA CITY	OK	73159
PAMELA SUE	BALLARD	7028 e 99TH ST S	TULSA	OK	74133
ALYSIA	MILLWEE	809 SE 9TH	MOORE	OK	73160
JENNIFER	PIKE	409 W LEEPER	BROKEN BOW	OK	74728
JOHN	BRALY	2804 DEWEY AVE APT 1	NORMAN	OK	73071
VICKY	HERNANDEZ	710 ELMWOOD DR	NORMAN	OK	73072
MATTHEW	MUSCANELL	6409 S DREXEL PL	OKLAHOMA CITY	OK	73159
ASHLEY	WEISZ	2221 NATCHEZ DR	NORMAN	OK	73071
CHALIDA C.	WORKMAN	207 B WADSCAK DR	NORMAN	OK	73072
CARMEN	MATTINGLY	1009 ELMWOOD ST	NORMAN	OK	73072
CHAD	STANSBERRY	307 POTOMAC DR	NORMAN	OK	73702
KRISTINE E.	TEIXEIRA	3419 FLICKERING CANDL	SPRING	TX	77388
LEE ANN	SCOTT	1700 OVERLAND TRAILS	CHOCTAW	OK	73020

PROJECT WET

Water Education for Teachers

Basic Workshop @ OU, Norman

Saturday - March 8, 2008

9:00 am to 4:00 pm

Agenda

- Welcome & Introductions
- Icebreaker
- Goals & Objectives
- Activity - The Incredible Journey
- What is WET?
- Break
- Activity - Sum of the Parts
- Splash thru the Guide
- Assignments & Working Lunch
- Participant Led Activities
    - H_2Olympics
    - AGM
    - Water Crossings
    - Reaching Your Limits
    - Water Messages in Stone
- Wrap-up & Evaluation

Project WET Workshop on March 8, 2008

FIRST NAME	LAST NAME	ADDRESS	CITY	STATE	ZIP CODE
MEGAN	MASTERSON	2920 CHAUTAUQUA AVE	NORMAN	OK	73072
SHELBY	FUHRIG	2508 BROADWELL OAKS	NORMAN	OK	73071
ELAINE	WISEMAN	728 JONA DAV TER	NORMAN	OK	73069
TIMBER	OAKS	406 NW 6TH ST	MINCO	OK	73059
MELISSA	CORBETT	2371 ALAMEDA PLAZA	NORMAN	OK	73071
ADAM	FORESTER	10648 NW 33RD ST	YUKON	OK	73099
LINDSAY	GARDERE	916 PINEBROOKE CT	NORMAN	OK	73072
MELISSA	SPURLOCK	1013 SWEETGUM	MOORE	OK	73160
ELLA	BURKHALTER	4704 TANGLEWOOD CO	NORMAN	OK	73072
MALLORY	CONDREN	2621 LANCASSTER LANE	OKLAHOMA CITY	OK	73116
ANDREW	WAGNON	817 BEAUMONT SQ	NORMAN	OK	73071
CARLINE	NWANKWOALA	1717 NE 50TH	OKLAHOMA CITY	OK	73111
JOSHUA	TRAIL	213 LINDSAY ST	NOBLE	OK	73068
JUSTIN	AYRES	1316 HOLLOW TREE TER	NORMAN	OK	73071
SHARITY	CARROLL	5030 N AIRPORT RD	HEALDTON	OK	73438

RIPARIAN BUFFER RESTORATION PROJECT

NORTH FORK CREEK

Tributary to Little River

A Grant Funded Through

OKLAHOMA CONSERVATION COMMISSION

U.S. Environmental Protection Agency Region 6

THE CITY OF NORMAN
UTILITIES DEPARTMENT
AND
PARKS AND RECREATION

Prepared By:
Janay Jeanis
City of Norman Forester
Shubha Adhikari
OU Planning Intern

Goals

- Riparian Buffer Restoration
  - Develop a work-plan Restore and enhance over one-half mile of forest riparian wetlands (both banks) on North Fork Creek, Tributary to Little River.
  - Reestablish a native and locally indigenous bottomland hardwood forest and other associated attributes of a forested riparian wetland area.
- Integrated planning

  - Integrate riparian area restoration with waste water treatment plant

  - Legacy trail system

  - City of Norman Greenbelt/ Greenway systems
- Educational Opportunities
  - Provide educational opportunities for the City in terms of planning and development as well as focusing attention on the importance of these areas for environmental and economical benefits.
  - Provide students experiential opportunities in the creation, maintenance and function of riparian

Site Introduction

- The project site is situated north west of the intersection of 12th Ave. NE and Franklin Road
- Total site area is 160 acres.
- The site is bordered by Franklin Road on south, 12th Ave. NE on east and agricultural farm lands on west and north.

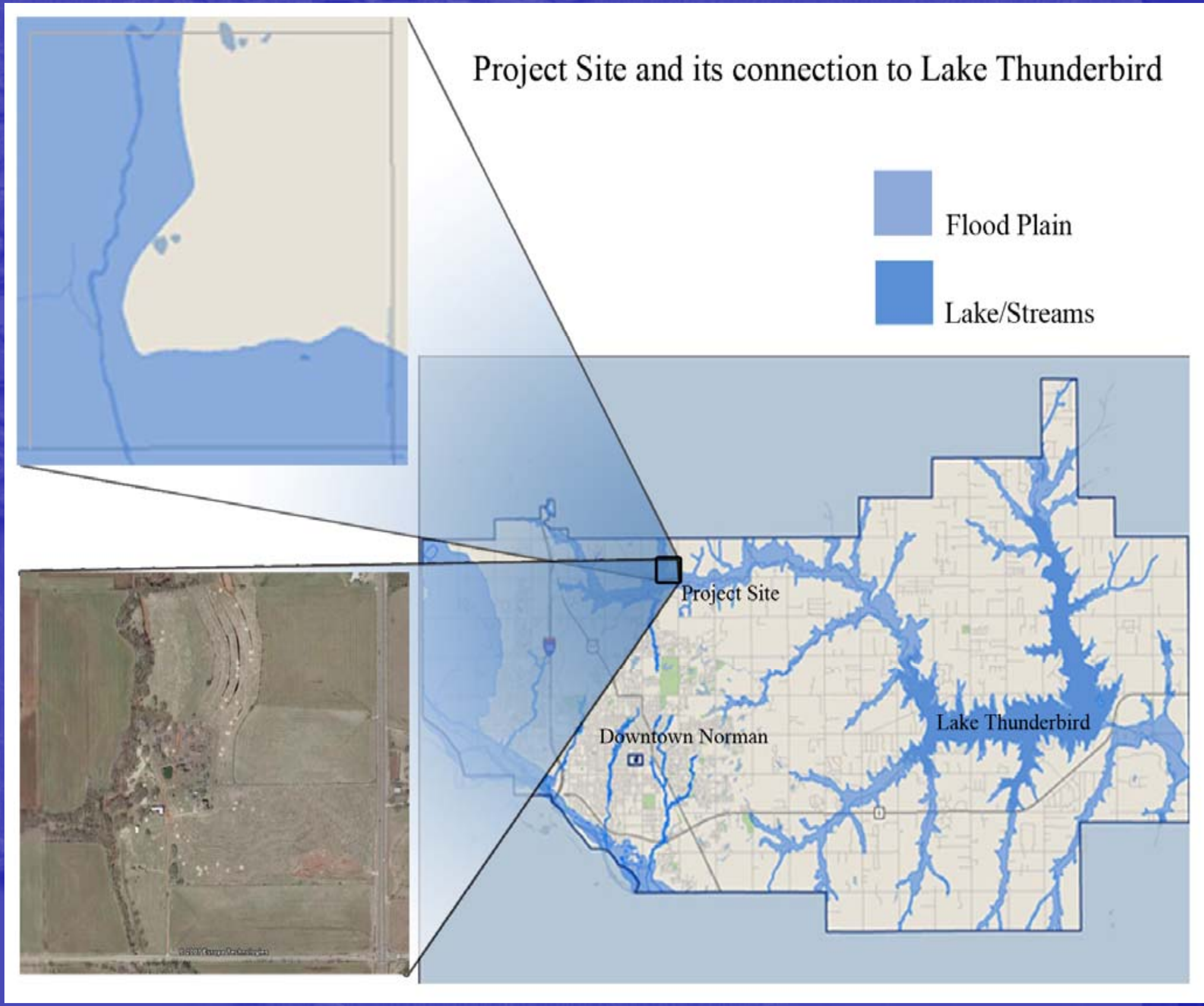
Opportunities

North Fork Creek

- North Fork Creek, a tributary Little River, which runs at a distance of 1/3rd the total length of the site from the west boundary, divides the site into two parts.
- Riparian strip along the creek can be restored and enhanced for the multi benefit.
- Water quality of the creek is crucial as it pours into Lake thunderbird which is the major source of water for the City of Norman

Connection to Lake Thunderbird

- Approximately one half of the site is located within the 100-year flood plain. These areas compose approximately 80 acres located in the southern one third and western one third of the property. The flood plain designation is zone A or areas of flooding during the 100-year event.



Opportunities

Hardwood Forest

- Moderately Well developed riparian corridor is present along the creek.
- Native mature tress along with well-established shrub and herbaceous species dominate the riparian zone.
- Cottonwoods and willow are the most prevalent trees of these forests, but hackberry, elms are also abundant.

Opportunities

Barn

- The property contains three barns, two of which have the potential to be renovated and developed as a Visitor's center.
- The Visitor's Center will provide general information related to riparian area, site specific information, bio-diversity.
- Might provide learning opportunities to general public and students conducting seminars and outdoor classes or just providing a place to have such seminars and classes.

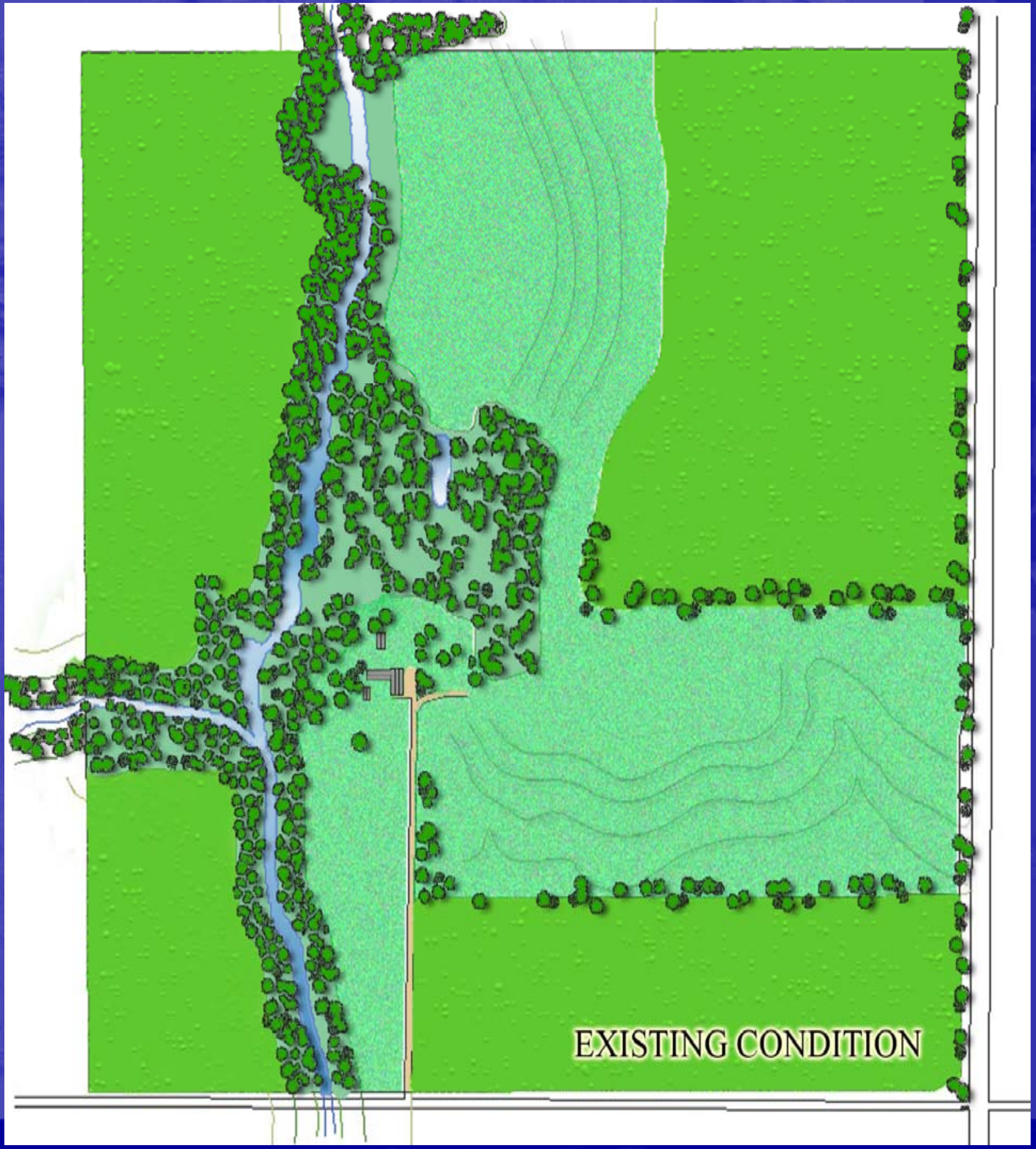
Opportunities

Flora & Fauna

- Several species of mammals, birds, reptiles and game fish already present in the area.
- Bio-diversity can be improved with proper restoration and management.

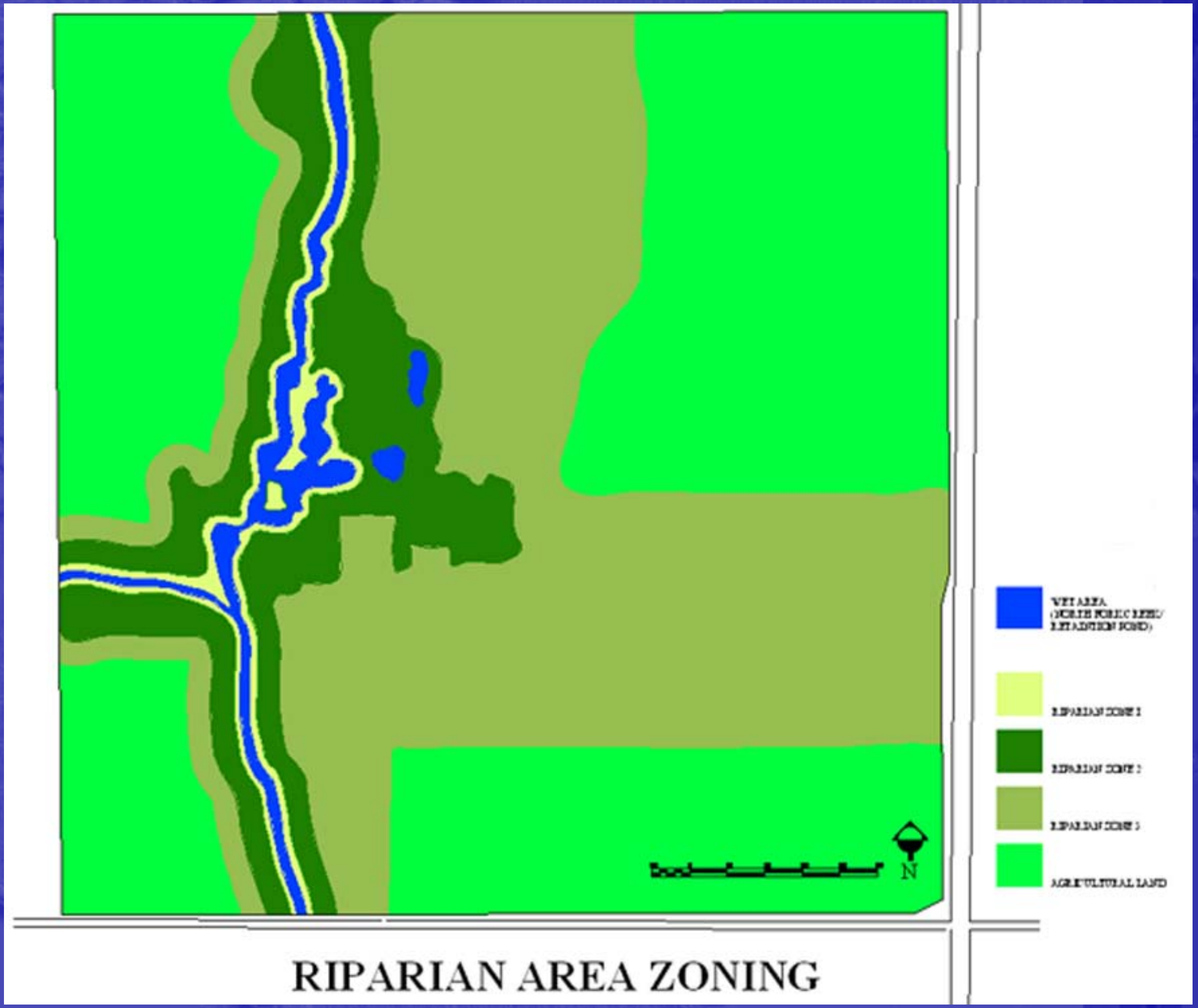
Existing Condition

- Bank erosion due to high velocity run off, inadequate riparian buffer and cattle activity.



Riparian Area Zoning Map

- Riparian Zone 1: 4.73 acres
- Riparian Zone 2: 17.59 acres
- Riparian Zone 3: 60.16 acres



Riparian Zone 1

Zone 1 is the region directly adjacent to the water body. The purpose of zone1 is to create a stable ecosystem along the water's edge and provide soil/water contact to facilitate nutrient buffering process. This area also provides shade to lower water temperature and improve aquatic life.

The predominant vegetation in zone 1 consists of species selected for their ability to stabilize the riparian system. Native tree species and in the areas where the banks are too steep to support trees, mixture of native grass forbs and shrubs will be chosen.

Total area: approximately 5 acres.

Average width 15' to 30' measured perpendicular from the stream bank.

Riparian Zone 2

- Zone 2 is intermediate zone hard core forest may establish.
- Its purposes is to provide the necessary contact time and carbon energy resource for buffering to occur, as well as long term storage of nutrients in the forest tress.
- Total area is approximately 18 acres
- Average width is 60’ to 110’

Riparian Zone 3

- Zone 3 is designed for runoff control and provides sediment filtering, nutrient uptake, and the space necessary to convert concentrated flow to uniform, shallow sheet flow.
- Dense, perennial grasses and forbs are used for this zone.
- Total area is approximately 60 acres which includes existing grass land prairie.

PHASE I

- Duration: 3 months – Sept., 2007 to Nov., 2007

Work description

- Plantation along the channelized portion of the river on the north side of the property. Plants will mainly include native hard wood species and grasses.
- Construction of approximately 2.5 miles of walking trails
- Plantation of native grass species on north –east side of the confluence, and west of the barn to mitigate scour.
- Planting native grass in the riparian zone 3 on the west side of the river

PHASE II

- Duration: 3 months- Dec., 2007 to Feb., 2008

Work description

- Wetland Construction: Construction of a retention pond on north-east side of confluence and south side of the barn.
- Approximate area: 1.96 acres
- Water Augmentation in the existing pond on north-east of the barn.

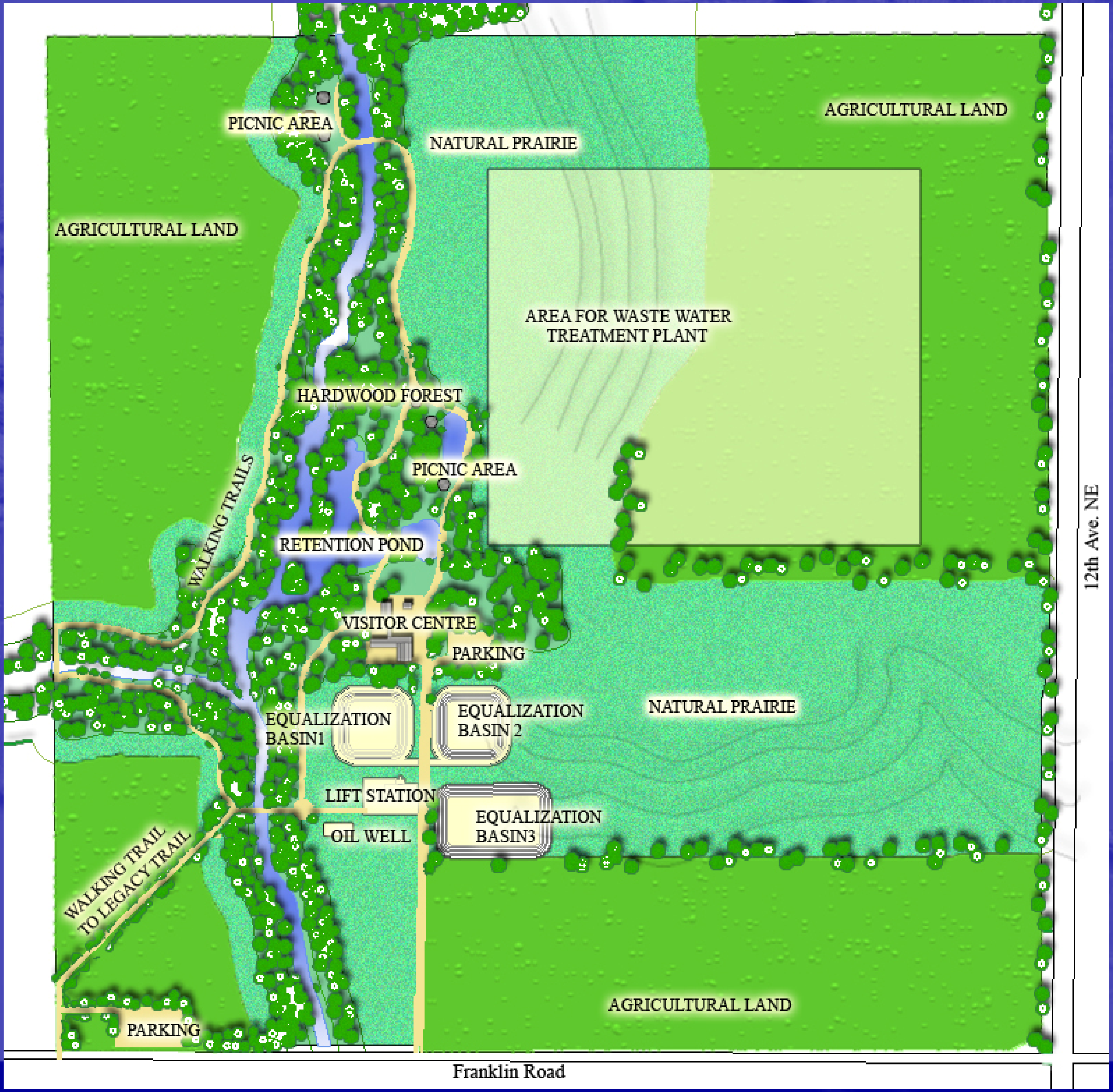
PHASE III

- Duration: 3 months- Feb., 2008 to May, 2008

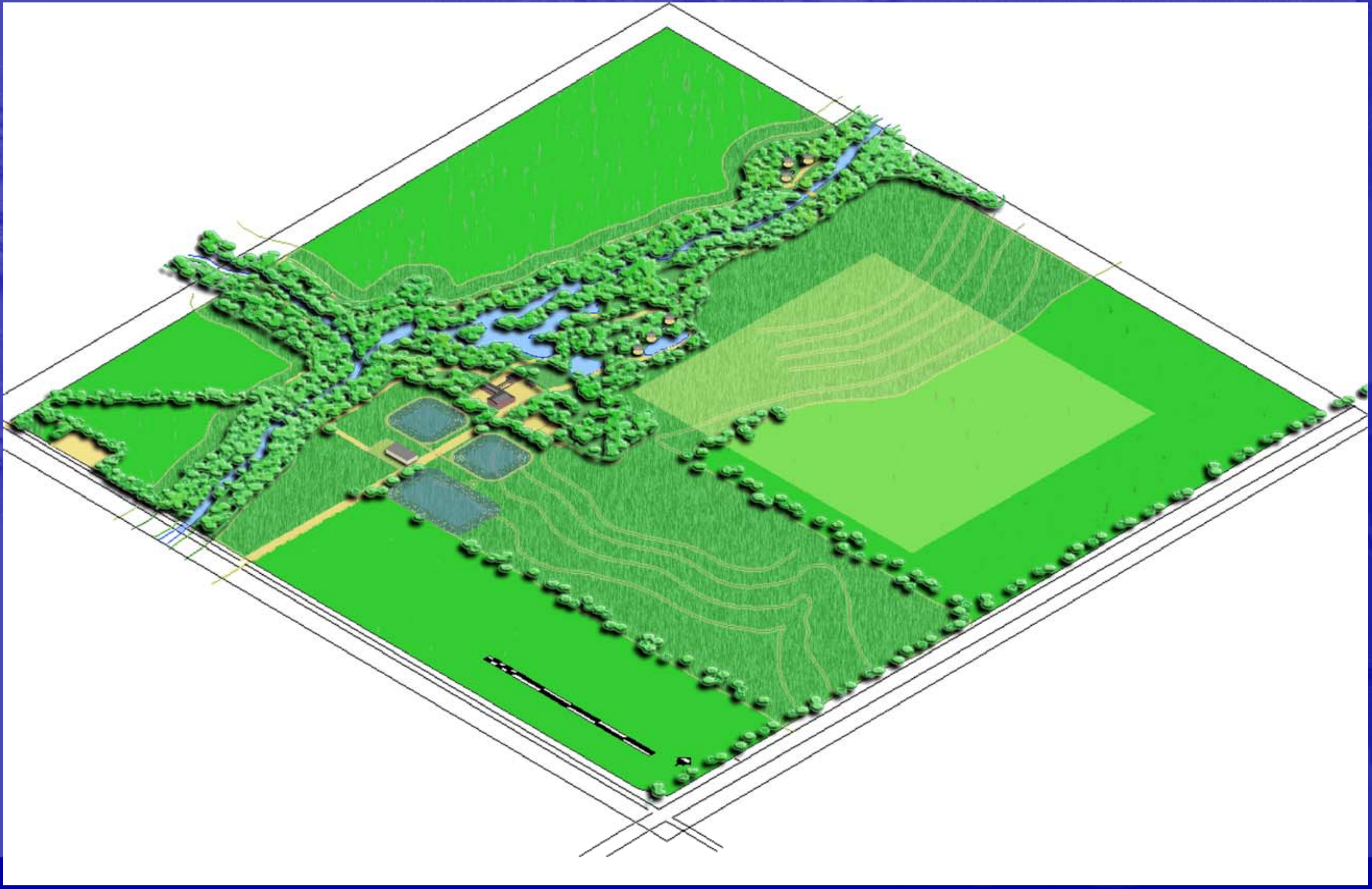
Work description:

- Renovation and adaptation of existing barn as visitor's center
- Construction of Gazebo in picnic areas.

Master Plan


PICNIC AREA
NATURAL PRAIRIE
AGRICULTURAL LAND
AGRICULTURAL LAND
AREA FOR WASTE WATER TREATMENT PLANT
HARDWOOD FOREST
PICNIC AREA
WALKING TRAILS
RETENTION POND
VISITOR CENTRE
PARKING
EQUALIZATION BASIN1
EQUALIZATION BASIN 2
NATURAL PRAIRIE
LIFT STATION
EQUALIZATION BASIN3
OIL WELL
WALKING TRAIL TO LEGACY TRAIL
PARKING
AGRICULTURAL LAND
12th Ave. NE
Franklin Road

Isometric view

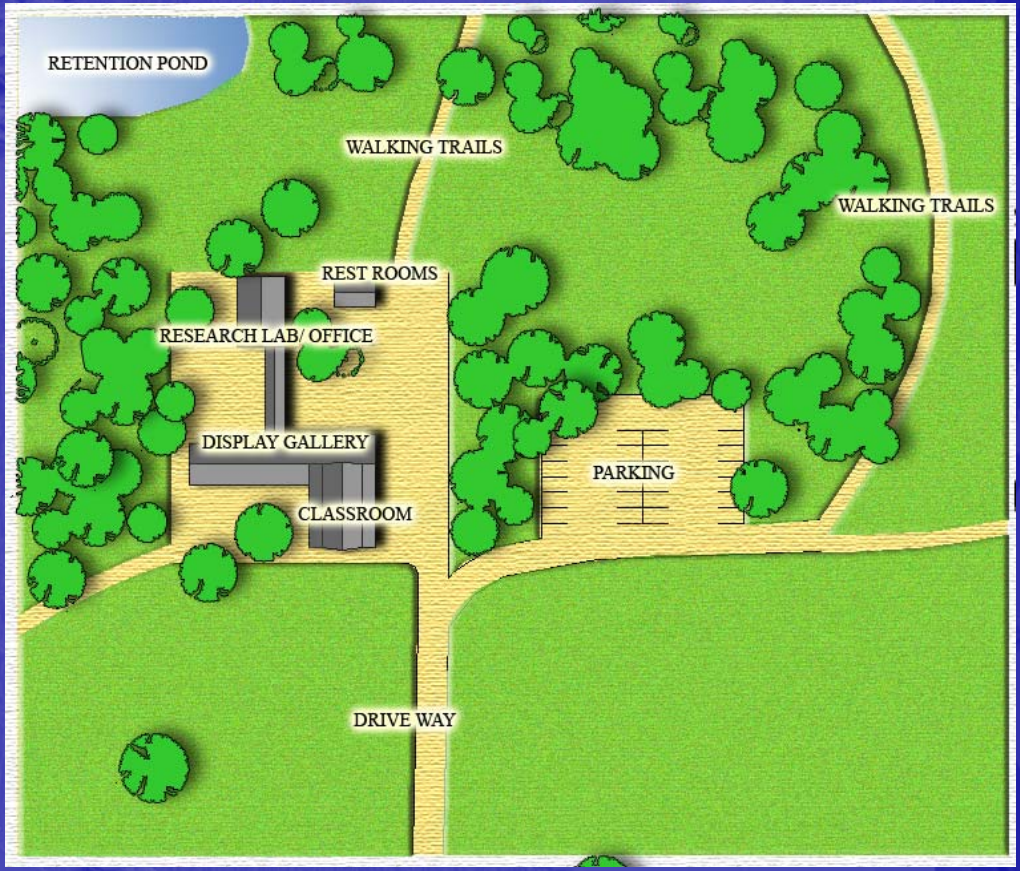


Visitor's Center Detail

Larger of the two barns is converted into a visitor's center and smaller one on the north is converted into an office cum research lab. Two barns are connected with a covered walk way.

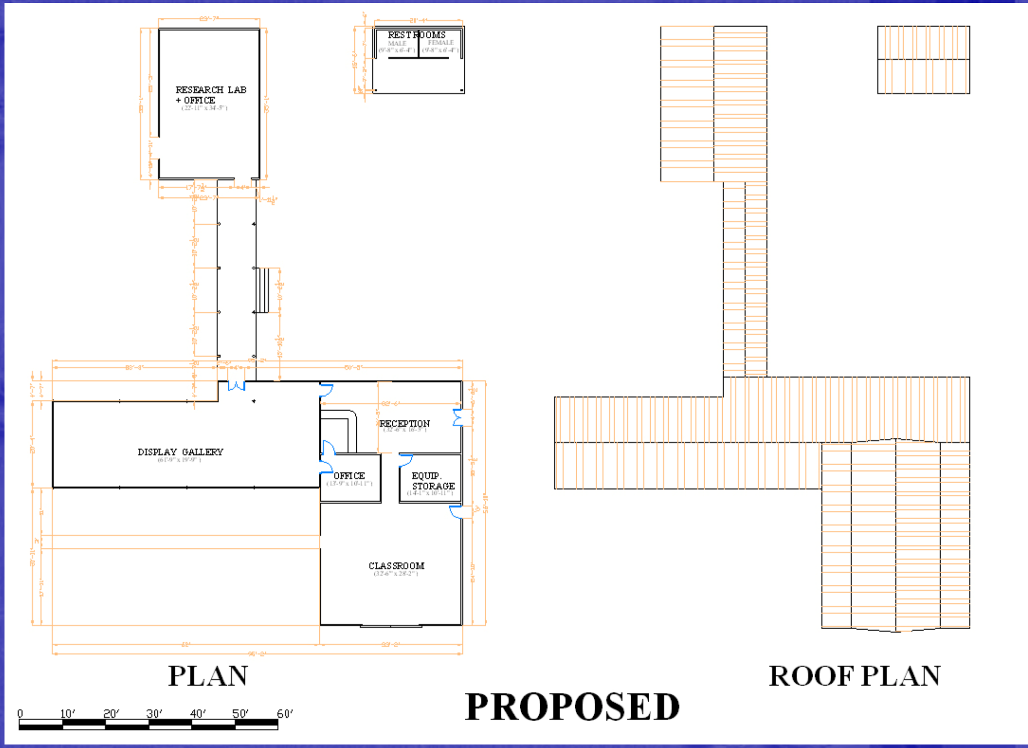
An additional structure separate from the two barns is constructed for the restrooms.

Parking is provided for visitors on the east side of the barn.

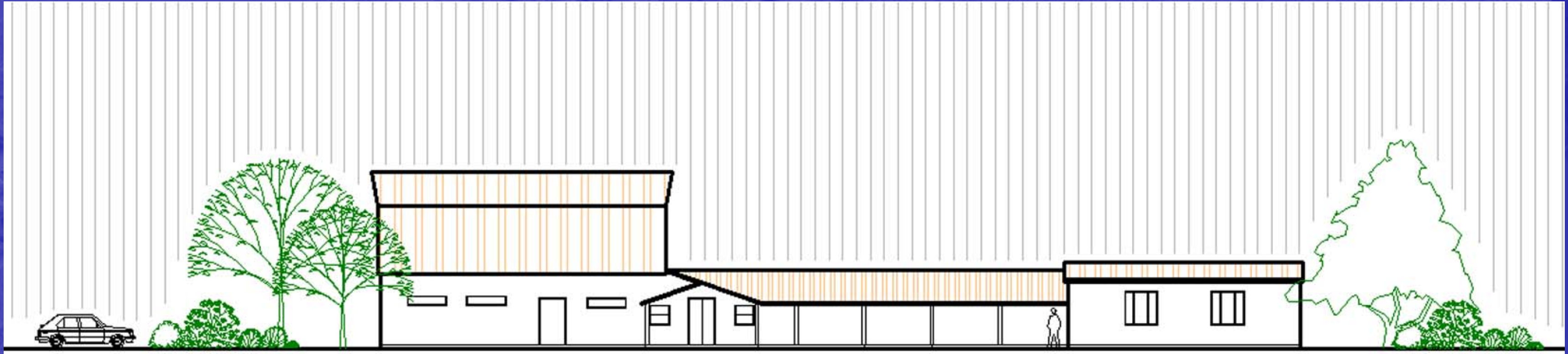


Visitor’s Center Detail Plan

- The larger barn will be renovated to accommodate a reception, an office, an equipment storage room and a classroom. Western wing of the barn is developed into a display gallery for educational purpose.
- Smaller barn will be renovated to accommodate an office cum research lab.
- Some windows have been added for better natural lighting and ventilation.
- Basic design has not been altered.



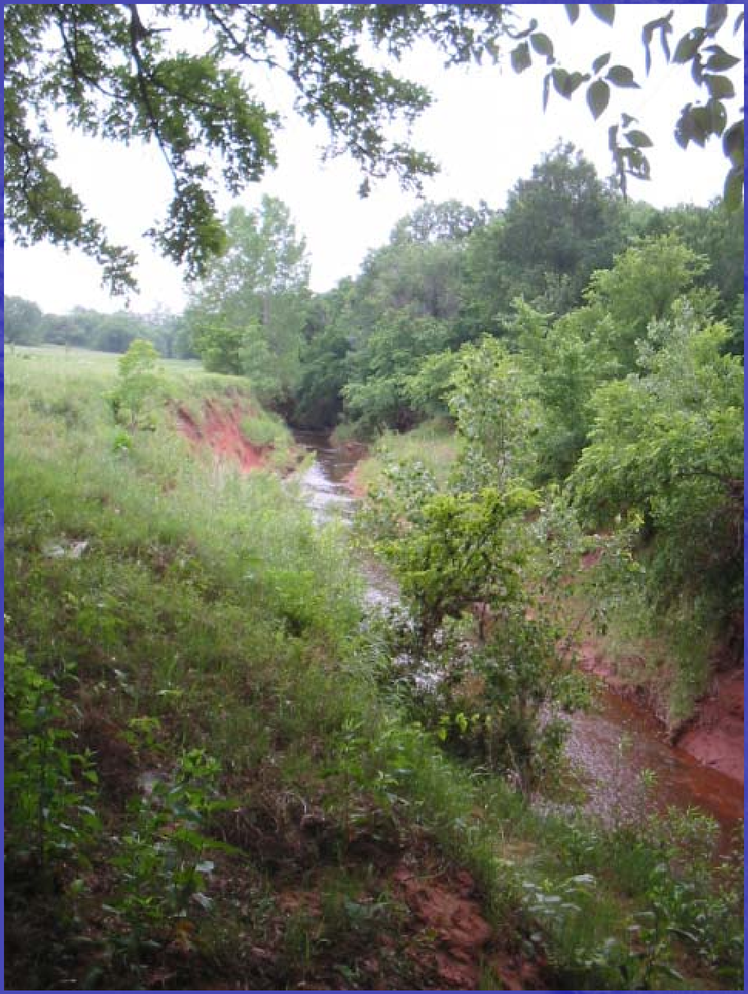
Visitor’s Center Elevations

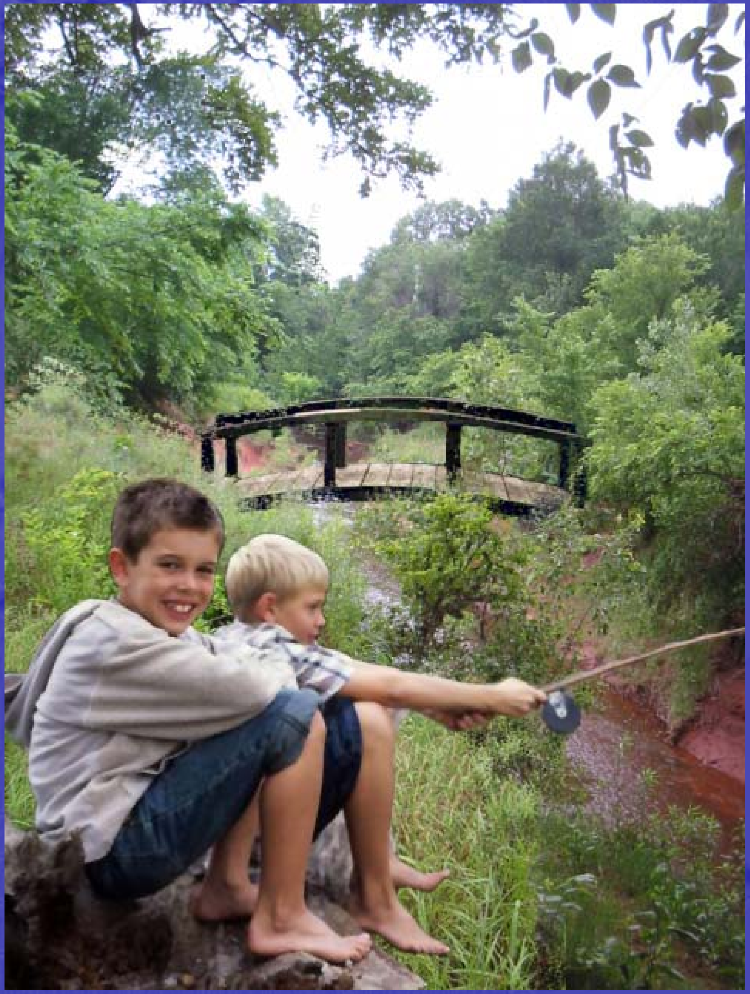


East Elevation

North Elevation

“Before” and “After” Picture of the creek from north looking south at the channelized area





Left hand side picture shows the existing condition and right hand picture show condition after plantation and installation of bridge.

“Before” and “After” Picture of the low laying area north east of the barn.

Left hand side picture shows the existing condition and right hand picture show condition after construction of retention pond .

“Before” and “After” Picture of the area near the channelized portion of the creek.

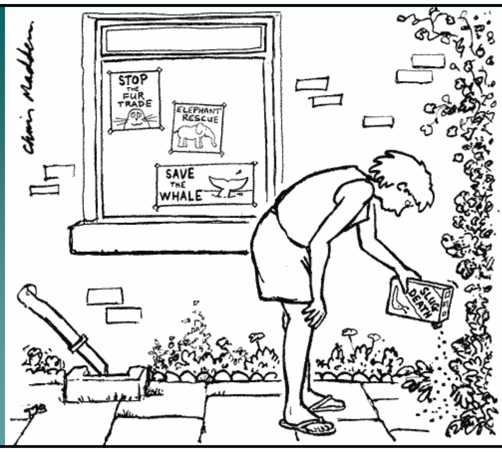
Left hand side picture shows the existing condition and right hand picture show condition after additional planting, construction of picnic area and gazebo.

Deliverables

- Booklet summarizing the project
- Work plan with time line and phasing details
- Booklet will also include general information regarding Riparian area its importance and management ad site specific details.
- Maps: Master plan, maps showing the phases, preliminary architectural drawing of renovation of the barn.

Thank You

- Questions and Concerns



Stream and Riparian Ecosystem Rehabilitation

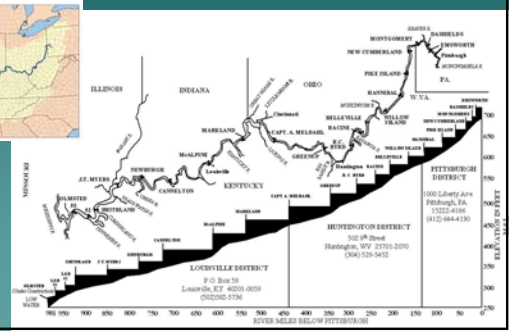
River Nairn near Inverness, Scotland

"Taming" Rivers

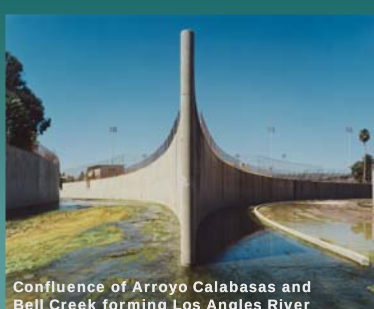
- Human kind has attempted to control rivers
  - Transportation
  - Drainage
  - Water supply
  - Wastewater conveyance

"Taming" The Ohio River

Ohio River Watershed

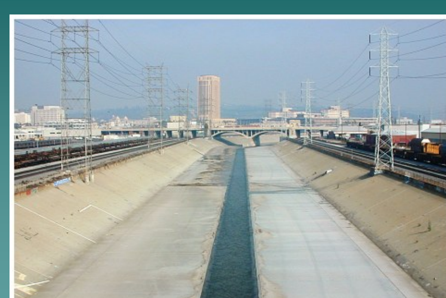


"Taming" of the Los Angeles River

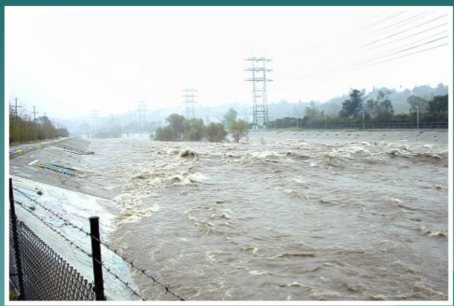


Confluence of Arroyo Calabasas and Bell Creek forming Los Angles River

"Taming" of the Los Angeles River

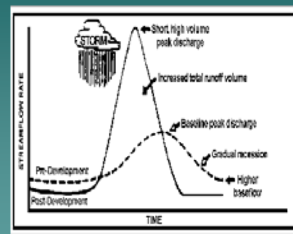


"Taming" of the Los Angeles River

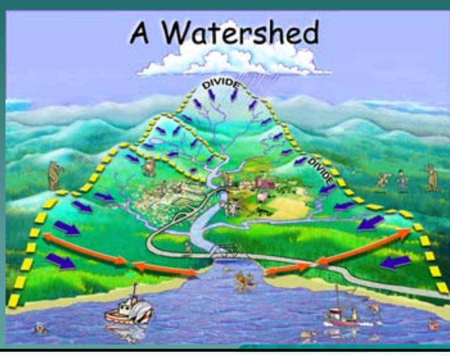


"Taming" Rivers is Stressful!

- Landscape changes
  - Hydrograph modifications
- Pollution
  - Point sources
  - Non-point sources
- Hydromodification
  - Dams
  - Landscape drainage
  - Channelization
  - Flow pattern alteration
- Many others!



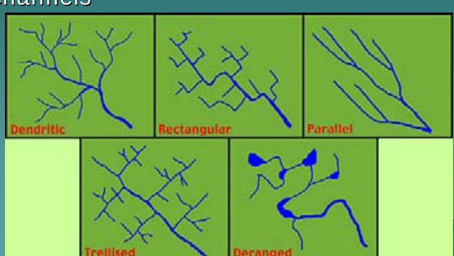
Watershed, Drainage Basin, Catchment



Watershed Geomorphology

Drainage Patterns

- Configuration of natural or artificial stream channels

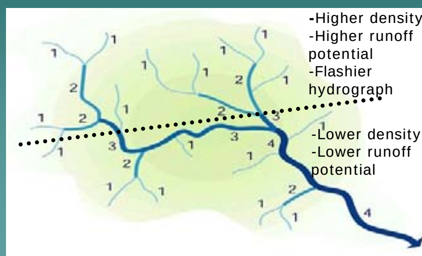


Stream Order

- Measure of position of stream in hierarchy of tributaries

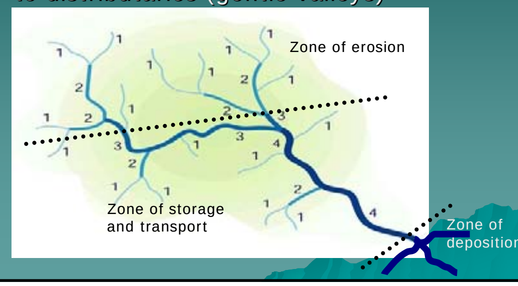
Drainage Density

- Relative density of natural channels in given area (often expressed as total length/watershed area (mi/mi^2))



Geomorphic Zonation

- Varies from headwaters (high gradient) through mid-reaches (material conduits) to distributaries (gentle valleys)

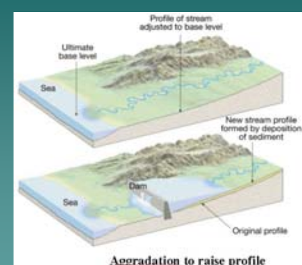


River Geomorphology

- Rivers as transporting mechanisms
  - Upstream potential energy changed to kinetic form along channels and kinetic energy transformed to heat, doing work
  - ***Rivers move sediments***
  - Potential energy of elevation is fed by solar-based energy of precipitation and evapotranspiration

Aggradation

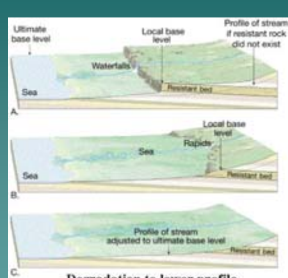
- Deposition of alluvial materials
  - Formation of point bars on inside curves
  - Deposition from overbank flooding
- Dramatic alterations by humans



Aggradation to raise profile

Degradation

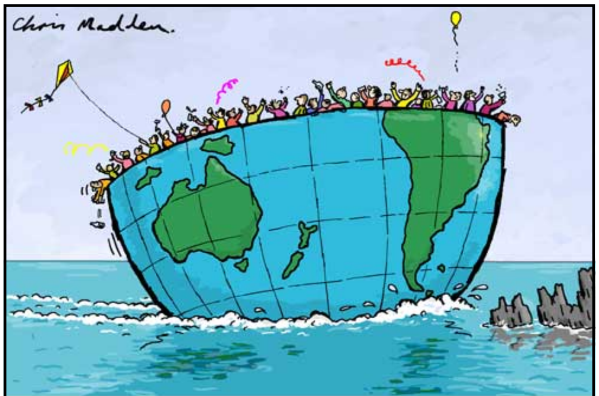
- Downcutting of surface geology
  - Sediment supply < sediment outflow
  - Climate shifts
  - Dam construction
- Dramatic alterations by humans



Degradation to lower profile

Riparian Ecosystems

- Land adjacent to body of water
  - Linear form along river or stream
  - Open to passage of energy and material from landscape
  - Functionally connected longitudinally (upstream/ downstream) and laterally (upland/aquatic)



THE SHIP OF FOOLS AND THE ROCKS OF SHORT-TERM ECONOMIC PLANNING

Riparian Ecosystems

- Important buffers
  - Sediment retention
  - Nutrient transformation
  - Temperature regulation
  - Hydrograph dampening
  - Habitat provision
  - Wildlife corridors

Models of Riverine Ecosystem Ecology

- River Continuum Concept (RCC)
  - Describes longitudinal ecological patterns along river
- Flood Pulse Concept (FPC)
  - Describes importance of lateral pulses of energy and matter to floodplain and associated oxbows, backswamps, etc.

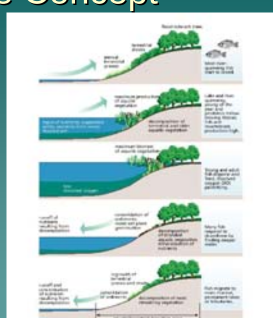
River Continuum Concept

	OM	Inv	P/R	Biodiv
Up	Large, allochth-onhous	Shred. Collect.	<1	Limited
Mid	Smaller, Mix	Graz. Collect,	>1	Inc.
Down	Mix, Autoch-thonous	Filter. Collect.	<1	Plank.

The River Continuum Concept
(Source: Vannote et al. 1980. Used with permission of NRC Research Press)

Flood Pulse Concept

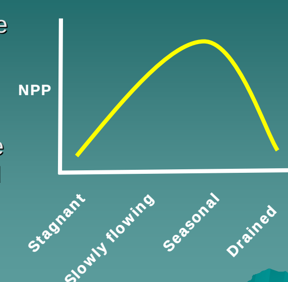
- Periodic pulses are major forcing function
- Nutrient exchange between river and floodplain impact biota



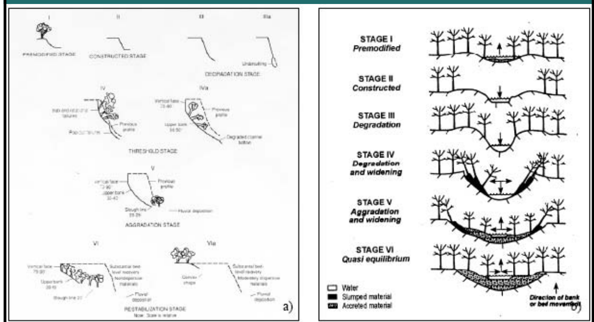
The flood-pulse concept diagrammed in five stages of an annual hydrologic cycle. The left column describes nutrient movement, the right describes typical life history traits of fish.

Flood Pulse Concept

- Periodic pulses are major forcing function
- Nutrient exchange between river and floodplain impact biota



Stream Channel Evolution



Stream and Riparian Restoration

- Bernhardt et al. (2005)
  - Estimate ~ $15 billion spent over 15 years in the continental United States on river and stream restoration projects
- To be successful, must understand hydrology, ecology and geomorphology of streams and related floodplain ecosystems

Lots of info…

- EPA Online Training in Watershed Management (http://www.epa.gov/watertrain/)
  - Stream Corridor Structure
    - http://www.epa.gov/watertrain/stream/
  - River Stability & Sediment Assessment
    - http://www.epa.gov/watertrain/warsss/
  - Fundamentals of the Rosgen Stream Classification System
    - http://www.epa.gov/watertrain/stream_class/
- SUNY ESF Fluvial Geomorphology Module
  - http://www.fgmorph.com/

Applied Fluvial Geomorphology

- *Fluvial*:
  - Of, relating to, or inhabiting a river or stream
  - Produced by the action of a river or stream
- *Geomorphology*:
  - Study of the evolution and configuration of landforms

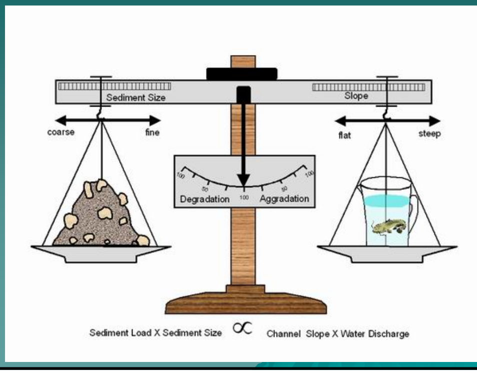
Applied Fluvial Geomorphology

- What to read?
  - Leopold, LB, MG Wolman, and JE Miller. 1964. *Fluvial Processes in Geomorphology*, WH Freeman, 522 pp.
  - Leopold, LB. 1994. *A View of the River*. Harvard Press, 312 pp.
  - Rosgen, D. 1996. *Applied River Morphology*. Wildland Hydrology, 390 pp.

Fundamental Concepts

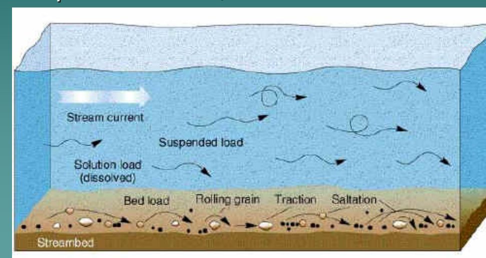
- Sediment "balance" (Lane 1955)
- Bankfull stage and discharge
- Stream channel dimension
- Stream channel pattern
- Stream channel profile

Lane’s Stable Channel Balance



Lane’s Stable Channel Balance

- Sediment transport: solution load, suspended load, bed load

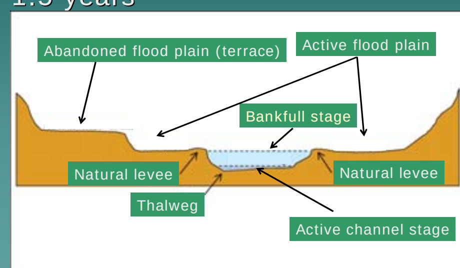


Bankfull Stage and Discharge

- Bankfull stage corresponds to discharge at which channel maintenance is most effective
  - e.g., moving sediment, forming and removing bars, forming and changing meanders and bends, generally doing work that results in mean morphologic characteristics of channels

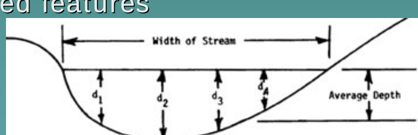
Bankfull Discharge is ***key***

- On average, recurrence interval of 1.5 years



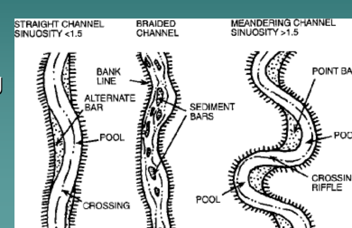
Stream Channel Dimension

- Width is a function of flow occurrence & magnitude, size & type sediment, bed & bank materials
- Mean depth varies with stream reach based on sequence of riffle & pool bed features

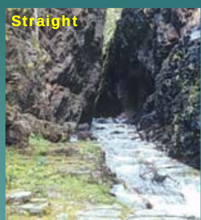


Stream Channel Pattern

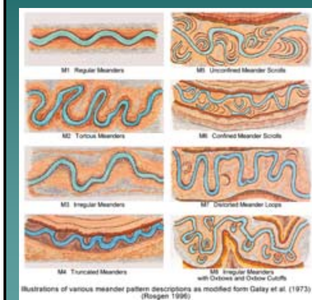
- Streams are rarely straight but rather follow a sinuous course
  - Straight
  - Braided
  - Meandering

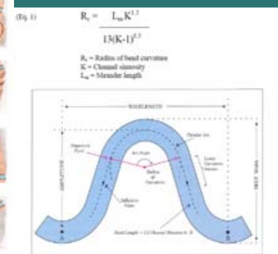


Stream Channel Pattern



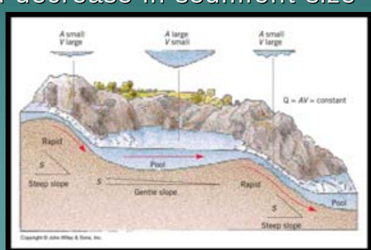
Stream Channel Pattern





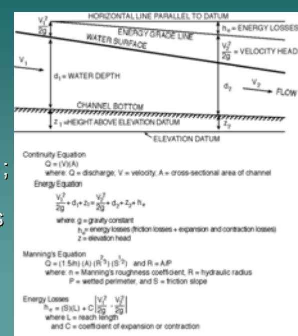
Stream Channel Profile

- Channel gradient decreases downstream with increase in flow and decrease in sediment size



Stream Profile

- Refer to Lane's balance
- Steep gradient streams dissipate energy along longitudinal profile; as gradient decreases changes in profile, dimension and pattern occur



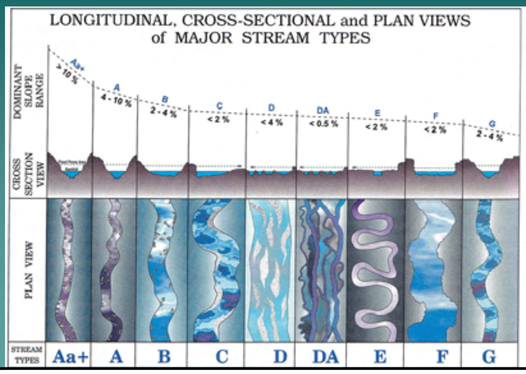
Stream Classification

- Classification based on channel morphology:
  - Predict river behavior from appearance
  - Develop specific hydraulic and sediment relationships for given stream type and its state
  - Provide mechanism to extrapolate site-specific data to stream reaches having similar characteristics
  - Provide consistent frame of reference for communicating stream morphology and condition among a variety of disciplines

Level I Classification

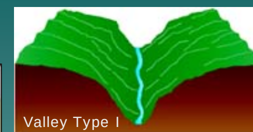
- Provide for initial integration of basin characteristics, valley types, and landforms with stream system morphology
- Provide consistent initial framework for organizing river information and communicating aspects of river morphology
- Assist in setting priorities for conducting more detailed assessments and/or companion inventories
- Correlate similar general level inventories such as fisheries habitat, and riparian habitat with companion river inventories

Level I Classification

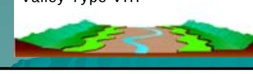


Level I Classification

Level I stream types occur in different landscapes – with training, classification can be determined from topographic maps and aerial photographs



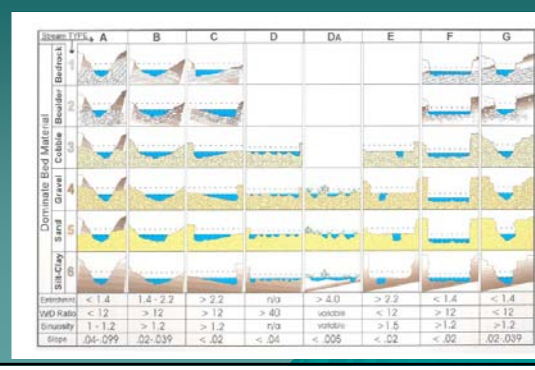
Valley Type VIII



Level II Classification

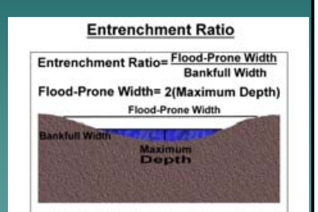
- Requires field measurements from specific channel reaches and fluvial features
- Employs finely resolved criteria to address
  - sediment supply
  - stream sensitivity to disturbance
  - potential for natural recovery
  - channel response to changes in flow regime
  - fish habitat potential
  - Etc.

Level II Classification



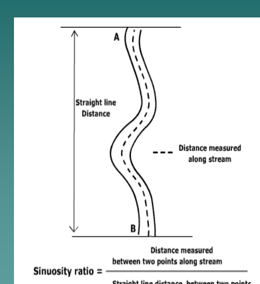
Entrenchment Ratio

- Vertical containment
- Degree of incision in valley floor
- Ratio of flood-prone area width to surface width of bankfull channel



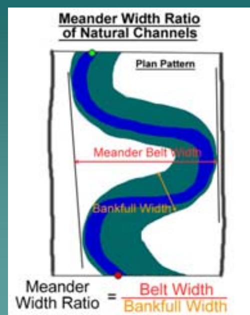
Sinuosity

- Ratio of stream channel length to valley length
- Meander geometry directly related to sinuosity (consistent with principle of minimum energy expenditure)

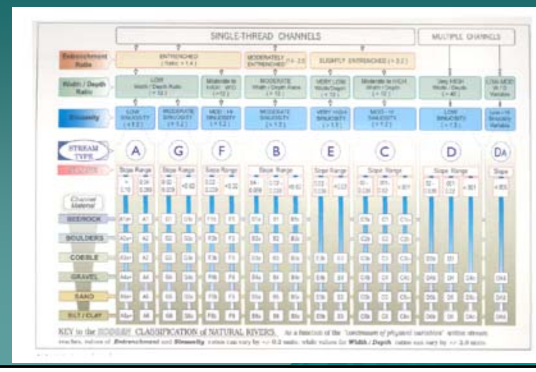


Meander Width Ratio

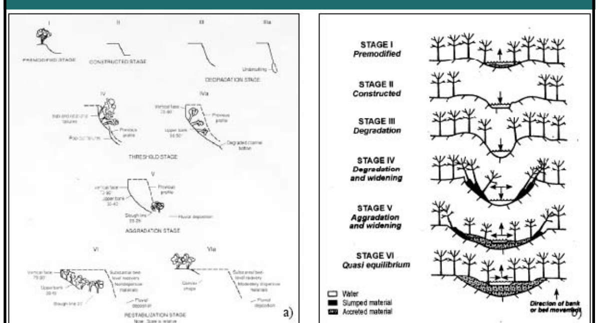
- Belt width/bankfull channel width
- Important link between meander width ratio and stream type



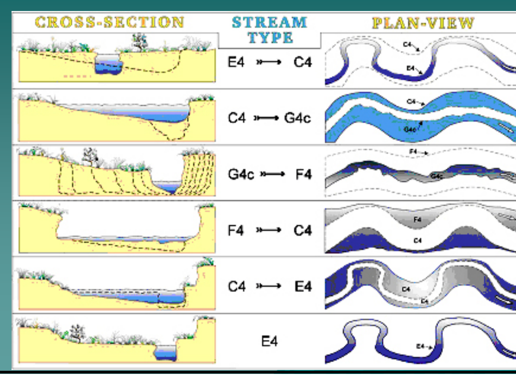
Stream Classification



Stream Channel Evolution



Stream Channel Evolution



Restoration Techniques

- Rehabilitation of watercourse reaches
  - Relatively short reaches
- Restoration of continuity between watercourse reaches
  - Passage of water along stream course
- Rehabilitation of river valleys
  - Long reaches and associated valley as one hydrologic entity

Restoration Techniques

- Dam removal
- Channel restoration
- Restoring and creating floodplain ecosystems

Dam Removal Example

- Manatawny Creek, PA
- 238 km^2 watershed
- 2.5-m low-head dam (1850)
- Removed fall 2000
- One of best studied dam removal projects

Channel Restoration Example

- Kissimmee River, FL
- Ecologically significant Kissimmee-Okeechobee-Everglades System

Channel Restoration Example

- C38 canal construction
  - 1961-1971
  - 166-km river channeled to 90-km long 9-m deep, 100-m wide canal

Wetland	% Δ
Marsh	-86
Wet Prairie	-48
Shrub-scrub	-51
Forest	+62
Other	+72

Channel Restoration Example

- Flooding frequency ~ 25% historic frequency
- Ecological recovery followed hydrologic reconnection of river to floodplain
- (It's the hydrology, stupid)

Restoration of Floodplain Ecosystems

- Floodplain *__just__* *__as important__* as channel itself
  - Channel
  - Levees
  - Point bars
  - Meander scrolls
  - Oxbows
  - Sloughs
  - Back swamps
  - Terraces


Porcupine River, AK

Restoration of Floodplain Ecosystems Example

- Olentangy River Wetlands Research Park, OH
- Notches in artificial levee based on river stage data
- Substantially increase flooding frequency

Measuring Success

- Before-after studies
  - Difficult to “prove” success
- Measurement of indices
  - Comparison to “standards”, e.g., water quality of biological metrics
- Comparison to unrestored reference
  - Eventual divergence in structure and function, with restored system having better biological, chemical and physical indicators than disturbed system
  - Most accepted method

Measuring Success

- **Remember bankfull**

Assessing the relationship between riparian vegetation, stream morphology and stability

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OU NSF REU Summer 2007
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July 27, 2007

Abstract

Streams and their associated ecosystems have great ecological and societal importance, yet they are increasingly altered and destroyed by anthropogenic disturbances. Riparian vegetation is known to interact with the stream by stabilizing banks against erosion, collecting sediment in flood waters, moderating light and temperature of waters, and providing nutrients and habitat that support diverse ecosystems. This work analyzes plant life-forms and density in an entire riparian region and relates this to stream morphology and stability. A new vegetation assessment is developed to quantify structural (or spatial) density of these life forms. Only two streams were studied, so there are not sufficient data for conclusive results. Stream morphology did not differ between the streams. An estimate of stream stability, or predicted erosion, was found to relate with both stream density and structural life-form diversity. This result is consistent with previous findings and provides some validation for the new vegetation assessment.

This material is based upon work supported by the National Science Foundation under Grant No. EEC-0552716.

Introduction

Streams

Streams are complex ecosystems that provide many functions important to nature and society. Because streams carry runoff water into larger bodies of water, they are indicative of watershed condition, affected by catchment land cover and land use (Allan, 2004), and their health is necessary to preserve and improve water quality. They are considered to be important transition regions between terrestrial and aquatic ecosystems, and also play a role in connecting ground water to surface water (Lamontagne et al., 2001). A stream's variable flooding, geomorphology, and change in altitude provide a heterogeneous habitat conducive to great biodiversity (Naiman et al., 1993). Stream integrity is degraded by many common anthropogenic disturbances, often resulting in large-scale consequences for ecosystems and, eventually, humans.

Riparia

Many vital stream functions are inseparable from the surrounding ecosystem, or the riparian zone. Riparia are known to play a critical role in stream health and stability. Well-vegetated riparia affect water quantity and perform water quality transformations. Vegetation slows and decreases the amount of runoff entering the stream, and also slows the flow of flooding streams, which moderates large flooding events. Riparian regions are buffers that improve the quality of water by purifying runoff. As the terrestrial element of the important transition ecosystem of streams, the riparian zone is also known to affect stream ecosystems through biological, chemical, and physical processes. (Allan, 2004)

Some critical biological processes performed by the riparian area include microbial activity and providing ecological structure and function. Because riparia are a buffer region between the terrestrial and aquatic systems, riparian zones control the flow of nutrients into fresh water (Gregory, 1991). Under the right conditions, both microorganisms and plants remove pollutants and excess nutrients from ground water in different biogeochemical cycles, as in the important case of nitrogen attenuation (Lamontagne, 2001). Tall riparian vegetation offers ecological structure by providing a canopy over the stream, which moderates the water temperature and solar input (Gregory et al, 1991). This improves the ecosystem because cooler temperatures are more habitable for fish, and shade prevents algae and invasive plants from dominating. Allochthonous organic matter provision from branches and leaves provides nutrients to the stream and riparia, increasing microbial activity (Gregory et al, 1991). Finally, riparia are very diverse regions because they are subject spatial heterogeneity caused by localized flooding, geomorphology, and change in altitude (Naiman et al., 1993; Beechie et al., 2006).

The primary chemical processes provided by riparia involve biogeochemical cycling of nutrients. An important example of the consequences of altering these cycles is the hypoxia problem in the northern Gulf of Mexico (Rabalais et al., 2001). In the latter part of the twentieth century farmers increasingly over fertilized crops with nitrogen. In several states, nitrogen-rich runoff passes through depleted riparian barriers, which can not effectively remove the excess nutrients. Nutrient-rich streams run into the Mississippi River and empty in the northern Gulf of Mexico, all the while causing eutrophication that depletes oxygen concentration in the waters (Alexander, 2000). Since 1993 the resulting mid-summer hypoxia has covered an average of 16,000 square kilometers, approximately twice the area covered in 1985, when first measured (U.S. Geological Survey, 2004). While this problem is primarily caused by excess fertilizing, the depletion of riparian zones does not allow for the natural cleaning processes they might otherwise provide.

The physical structure of riparian vegetation aids stream structure and function as well. The network of roots stabilizes sediment in stream banks, preventing erosion (Mamo and Bubenzer, 2001) and encouraging a stable stream form (Rowntree and Dollar, 1999). Riparian vegetation near the stream and in the floodplain can slow the rate of flow and trap sediments, especially at meanders and point bars, impacting water quantity and sedimentation. Reducing water quantity can help prevent excessive flooding, while sedimentation can counteract erosion in an unstable stream. Many aspects of land use can alter riparia and negatively affect streams. Riparian vegetation is commonly cleared for agricultural purposes, yet grazing in and around streams causes erosion and introduces excess nutrients into the stream (Belsky et al. 1999). There are many other anthropogenic disturbances, such as irrigation and damming of streams and rivers, which harm stream ecosystems. Removing riparian vegetation takes away protection in all of these areas, leaving a stream more vulnerable to degradation and greater disturbance.

Stream morphology and riparia

Streams can take many different forms, or morphologies. These morphologies depend on many factors, including the geologic foundation, soil type, climate, and ecological character of a stream. Different morphologies vary in sinuosity, cross section, and lateral stability (Beechie et al., 2006). Stream form can change over time as erosion and sedimentation patterns fluctuate (Brooks and Brierley, 2002). Some changes are natural, such as lateral change and changes in meandering behavior (Schumm, 1985). Other changes can occur as a result of land use and land cover changes. Anthropogenic disturbances often cause true stream form instability, which is marked by vertical change or alteration in channel size (Schumm, 1985).

Types of riparian vegetation have been shown to affect stream morphologies (Gurnell, 2007), largely because plants differ in their ability to stabilize the bank against erosion, slow the stream flow, and retain water and sediment. There has been debate about whether forested or grassed riparian regions are more effective at stabilizing banks. In the Appalachian Mountains, forested riparia were found to have longer, finer foots, and better resist erosion (Wynn et al., 2004). However other studies found that forested banks destabilized channels when compared with grassed banks, and suggest that grassy banks can retain more sediment to counteract erosion (Allmendinger et al., 2005; Trimble, 1997). Yet most studies support that all types of vegetation increases bank stability (Rowntree and Dollar, 1998). When a near-pristine river was studied in Australia, it was found to have unusually resilient equilibrium and constant stream form, suggesting that un-harmed riparia provide strong stream stability controls (Brooks and Brierley, 2002). Because vegetation constrains and stabilizes a channel, it has been shown to decrease the amount of braiding and lateral mobility in stream form (Gran and Paola, 2001; Murray and Paola, 2003) and increase meandering (Miller et al., 2000).

Much of the research in this area has focused on the in-stream affects of vegetation, such as woody debris (Brooks and Brierley, 2002). Others have looked into the affect only of a thin strip of vegetation adjacent to the stream, focusing on root depth and the flow resistance of low vegetation (Wynn et al., 2004; Allmendinger et al., 2005; Rowntree and Dollar, 1998; Simon and Collison, 2002). Yet the entire riparian area is known to play important functional roles in stream ecosystem by removing pollutants and slowing flow from runoff entering the stream, purifying ground water, and providing a diverse habitat (Gregory et al., 1991). Finally, research comparing different kinds of vegetation has often involved isolation of certain types, such as grass and trees, without looking at the cumulative affect of many vegetation types (Gregory and Gurnell, 1988). It seems there is a need, then, to look further into the role of the entire riparian region, and to probe more deeply into the effects of different plant life forms. Therefore, the goal of this study is to analyze the relationship of stream form and bank stability to density and diversity of many basic vegetation life forms in the entire riparian zone, grouped by structural attributes for rapid identification.

The need for riparian assessment methods

Considering the importance of the riparia to stream structure and function, riparian assessment tools are necessary for study and categorization. Many riparian assessment methods exist, but they are used for a variety of purposes and few are widely satisfactory or commonly used (Innis et al., 2000). Many methods are qualitative and relatively simple, such as the EPA Rapid Bioassessment and USDA Riparian Management Handbook. Most other methods may be found on the other extreme: complex, labor-intensive, and often species-specific (Dallmeier, 1992; Stohlgren, 1995; Releve method found in Mueller-Dombois and Ellenberg, 1974). Both of these levels of specification have useful applications, although there is criticism about the whether current riparian assessments are ecologically relevant (Gregory et al, 1991). The complexity of ecosystems is difficult to capture in rapid surveys, but there is a need for simpler quantitative methods that describe important riparian characteristics. Methods of assessing plant communities and life strategies would be useful for many purposes, but both require knowledge of species and groupings by factors that are not easily evident.

This study introduces a new method in its first stages for assessing riparian diversity and density. The method is appropriate for planning level assessments, can be conducted fairly rapidly, and does not require training or knowledge of taxonomy. It is a structural assessment, using easily distinguishable plant types, and examines the top-view spatial area occupied by each life form.

Materials and Methods

General

In this study, two streams were analyzed for stream morphology and riparian vegetation characteristics. Little Elm Creek is a second order stream in Ottawa County, OK. The reach studied is 923 feet long, begins downstream from a small road, ends just before a small forested region, and passes through a grazing-impacted pasture. Near the start of the reach is a drainage inlet from a nearby agricultural field. The second stream studied is North Fork in Cleveland County, OK, which is fourth order. The reach studied is 1366 feet long, begins downstream from a road and golf course, and has a thick, diversely vegetated riparian buffer between the stream and surrounding fields. Photos of each stream can be found in Appendix A.

To select areas for riparian observation, six six-foot wide transects were extended from edge of water to the outer edge of riparian vegetation (or 60 ft in the case of Little Elm, where there was no noticeable vegetation change). These transects were paired on each side of the stream and located upstream, downstream, and in the middle of the reach. The survey can be found in Appendix C.

Riparian diversity determination

To classify riparian vegetation, plants were split into the following groupings (or life forms) for ease of identification: mosses, grasses, herbs, ferns, shrubs, and trees. Trees and shrubs were further split: trees by diameter at breast height, and shrubs by height. The number of groups represented in the six transects was considered an estimate of the structural diversity of vegetation along the reach.

Riparian density estimation

A structural density was estimated by percent cover in the under-story and canopy of the riparian area. Percent cover of each type in the under-story for each transect was estimated by eye in short, homogeneous regions. If only a few plants of one type were found, this estimate was achieved by counting and weighing with an average coverage of many plants of that type found within that region. While this estimate is analogous to percent bare-ground, breaking the cover into various life forms allows for richer analysis. Percent cover in the canopy was determined by eye at several points along a transect. Total percent cover for all types in the under-story and canopy were considered an estimate of structural density.

Soil measurements

Soil texture, color, and O-horizon (litter thickness) were determined at the start and end of a transect, and at either side of notable terrace changes. Soil was gathered with a stainless steel soil probe. Textures, such as clayey, loamy clay, clayey loam, loam, and gravel were determined by feeling the soil by hand. Soil texture was later quantified for further analysis such that clay = 4, loamy clay = 3, clayey loam = 2, and loam = 1. Soil color was estimated by eye with Munsell charts. Water was not added to soil unless it felt dry, so the soil varied in wetness, which may have affected color identification. The O-horizon was estimated as the apparent thickness of un-degraded organic matter at the top of the soil.

Dominant species determined

Dominant species found in transects at Little Elm were pressed and later keyed to the lowest taxonomic level possible for the researchers.

Stream morphology

Stream morphology characterization was conducted by collaborators (see Medford, 2007). The entire reach of each stream was surveyed for the elevation of bank full indicators, flood prone area, thalwag, right and left edge of water, and bank terraces.

Pebble count

A pebble count was conducted by collaborators at ten cross sections along each stream (see Medford, 2007).

Bank Erosion Hazard Indexing (BEHI)

The bank erosion hazard was determined for each stream by collaborators (see Medford, 2007). This included measurements of bank height, bank angle, root depth, root density, and percent of surface protection. Measurements were taken on each stream at the three cross sections where transects were performed.

Results

Riparian Density

The total percent cover for all life forms in the under-story and canopy were considered an estimate of structural density (Figure 1).

In Little Elm the understory was estimated to have 95 percent cover, ranging from 83 to 100 percent, mostly in the form of native and non-native grasses (Bermuda grass and tall fescue). The bare ground was primarily caused by bank erosion and cattle paths, both located near the streambed. There was 0 percent canopy cover in the transects performed at Little Elm, and only two trees (green ash) fell within the studied reach.

North Fork was estimated to have only 45 percent cover in the understory, ranging from 31 to 66 percent in the six transects. This estimate may be unusually low because of recent flooding that spread a thick cover of sediment over the beginning of many of the transects, possibly covering moss, grass, herbs and low-growing vines. The canopy was estimated at 74 percent cover for the stream, ranging from 63 to 84 percent in the six transects.

Canopy cover and percent bare ground differ significantly between the streams, with $p < 0.001$. These data clearly show that Little Elm has a denser understory and North Fork has a denser canopy. If overall density is considered to be an average of understory and canopy, North Fork has overall denser vegetation at 60 percent cover and Little Elm at 48 percent cover.

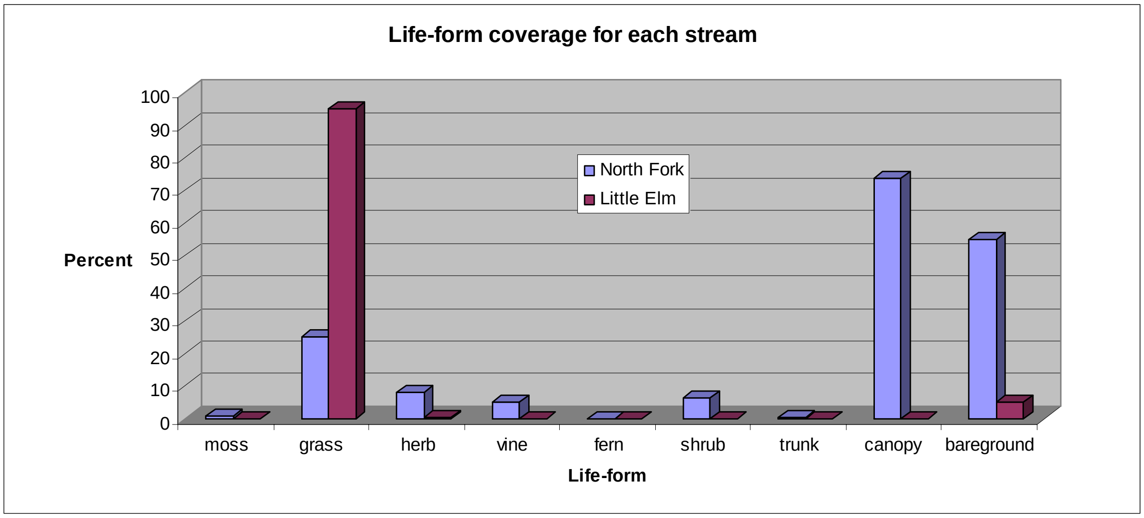

Figure 1: The density of each life form for each stream. Trunk refers to the tree coverage in the understory. North Fork has more life forms represented and a much greater canopy density, but has less overall vegetative density in the understory.

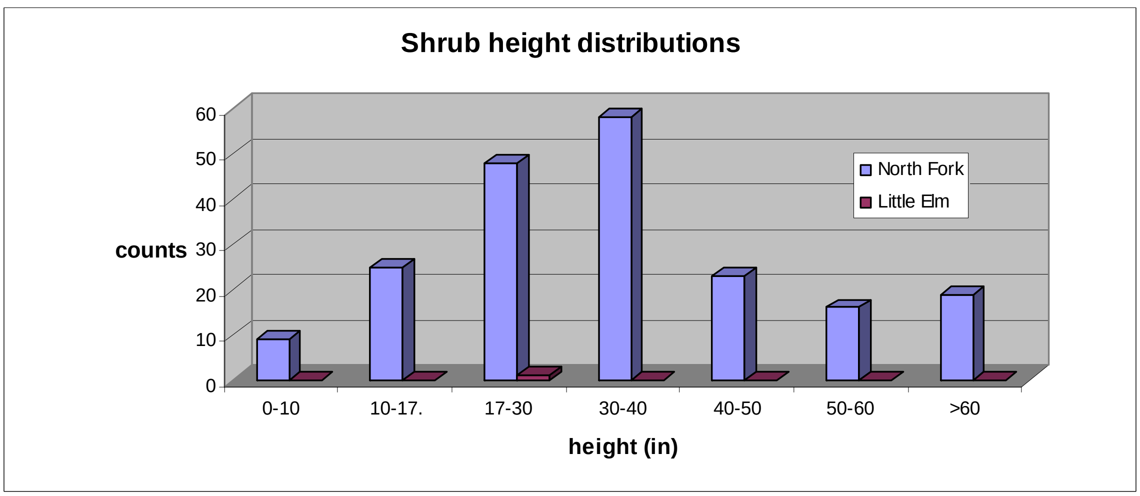

Figure 2: The diversity of shrub heights found in each stream. Little Elm transects had virtually no shrubs, while North Fork had shrubs in every structural grouping.

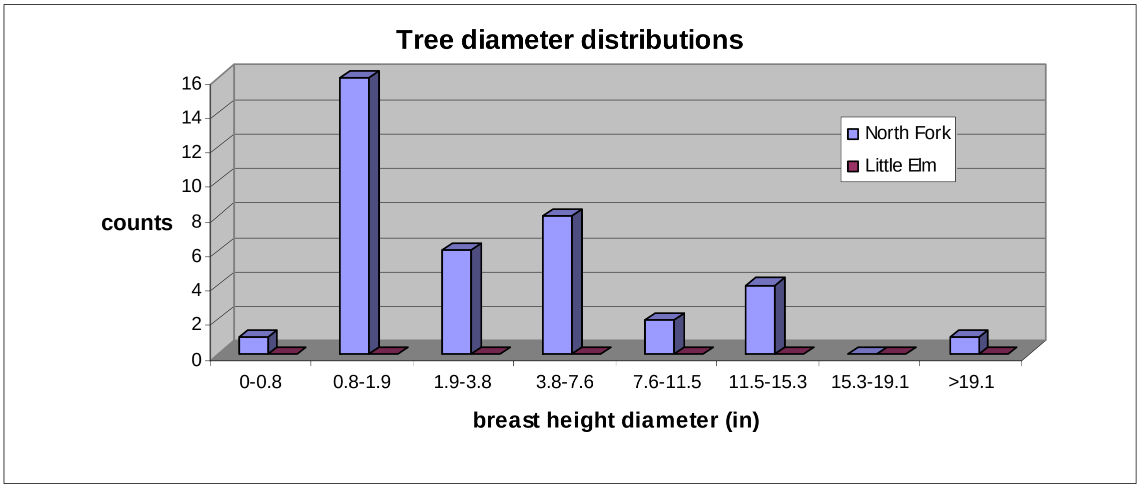

Figure 3: The diversity of tree widths found in each stream. Little Elm transects had no trees, while North Fork had trees in almost every structural grouping. The smallest grouping could have included many more small trees, but the line drawn between small trees and large shrubs occurred within this grouping.

Riparian diversity

The number of life form groups represented in the six transects was considered an estimate of the structural diversity of vegetation along each reach (Figures 1, 2, and 3).

Little Elm transects included grass, a few herbs, and one shrub (17-30 inches tall), a total of three life form groups represented. North Fork transects found moss, grass, herbs, vines, shrubs of all heights, and all tree groups except one; a total of seventeen out of nineteen life form groups represented. As expected, grass cover, herb cover, shrub cover, and canopy cover all differed significantly between the two streams, with $p < 0.05$. North Fork had little moss, and neither stream had ferns. The number of life form groups found in each stream was significantly different ($p < 0.001$). These data clearly show that North Fork has more diverse vegetation than Little Elm.

Soil characteristics

Soil texture, color (broken into hue, value and chroma), and organic litter layer are all significantly different between the two streams (Table 1). Little Elm has more clayey soil, a greater hue, smaller value, smaller chroma, and larger litter layer than North Fork.

As may be expected, some properties of the soil changed with distance from the stream. Regression analysis shows that soil texture is predicted by distance from stream with $p=0.006$ such that texture = 3.09 - 0.0133*distance. In other words, the texture of the soil becomes loamier (less clayey) farther away from the stream. Of soil color, only value was nearly significantly predicted by distance from stream ($p=0.111$), such that value = 3.19 - 0.00354*distance. This means the soil becomes darker with distance from the stream. Lastly, litter layer was significantly predicted by distance from stream ($p=0.039$), with litter = 0.106 + 0.00299*distance. In other words, the organic litter layer on top of the soil is thicker farther from the stream. One reason for this may be that flood waters erode the organic layer more often near the stream, reducing build-up.

Soils		
	Little Elm	**North Fork**
N	27	20
Texture**	3.23 +/- 0.86 (loamy clay)	1.95 +/- .71 (loam/clayey loam)
Hue**	10YR	5YR
Value*	2.92 +/- 0.39	3.30 +/- 0.47
Chroma**	2.15 +/- 0.37	3.30 +/- 0.87
Litter (in)*	0.28 +/- 0.38	0.08 +/- 0.10

Table 1: Descriptive statistics for soil characteristics of each stream taking each measurement into account. 1-way ANOVAs determined p-values, which indicate significant differences between streams: * $0.01 < p < 0.05$, ** $p < 0.01$

Stream morphology

The survey found both streams to be of the same classification, F4. Exceptions included on cross section at each stream, which both had the classification B4c, but were not considered representative of the entire reach. The two other stream form characteristics calculated from the survey, width/depth and entrenchment ratios, are not significantly different between the two streams. It appears from these results that the two streams are of the same form.

Morphology		
	Little Elm	**North Fork**
N	5	6
Characterization	F4	F4
Width/depth ratio	21.73 +/- 14.79	21.31 +/-3.97
Entrenchment ratio	1.49 +/- 0.40	1.27 +/- 0.08

Table 2: Descriptive statistics for stream morphology of each stream from cross sections. 1-way ANOVAs show none of these to differ significantly between the streams ($p < 0.20$)

BEHI		
	Little Elm	**North Fork**
N	6	6
BEHI (%)	34.70 +/- 7.11	29.38 +/- 1.663
PE (yd^3/yd)	0.045 +/- 0.033	0.077 +/- 0.041
Basin (mi^2)	2.49	15.36
nPE (yd^3/(yd* $mi^{2)}$)*	0.019 +/- 0.013	0.0050 +/- 0.0027

Table 3: Descriptive statistics for BEHI of each stream from right and left bank of three cross sections. 1-way ANOVAs determined p-values, which indicate significant differences between streams: * $0.01 < p < 0.05$, ** $p < 0.01$

Bank Erosion Hazard Indexing (BEHI)

The BEHI for the two streams is not significantly different, suggesting that their banks are similarly susceptible to erosion. Predicted erosion (PE) volume (yd^3/yd**)** calculated from the BEHI provides an estimate of the amount of sediment that will erode from a bank, and was not significant either. However, as North Fork is a larger stream than Little Elm, its greater flow can be expected to erode more sediment. So we normalized PE volumes (nPE) for the size of their watersheds (see Appendix C). This estimate assumes that the two streams are in similar climates, receiving similar rainfall patterns, and also that the land in the drainage basin is similarly developed. The estimate may meet these assumptions well enough, as it provides significant differences between the streams and also correlates well with the other data (Table 4).

Vegetation and stream form

Finally, stream form and stability can be related to these estimates of riparian density and diversity along the reaches. Table 4 shows the resulting correlations. Normalized predicted erosion (nPE) correlates much more strongly with the three vegetative estimates than the original value (PE), which indicates that the drainage basin transformation may have been appropriate. Width/depth ratio and entrenchment, the two aspects of stream form, do not correlate with any of the riparian characteristics. However, neither aspect is significantly different between the two streams, so significant correlations could not be expected. At least these results do not exclude the possibility of finding such a relationship in a larger sample. Stream stability, or erosion hazard, relates much more strongly to vegetative characteristics. Normalized predicted erosion (nPE) is negatively related to number of life form groups represented along the reach, meaning greater diversity in a transect relates to a decrease in predicted erosion of that bank. Greater density in canopy cover is also negatively related to normalized predicted erosion. When these correlations are run separately on the two streams there are no significant relationships ($p > 0.3$), suggesting that perhaps stream stability is not particularly sensitive to changes in local density or diversity.

Hypotheses		diversity	density	
		no. life form groups	% bare ground	% canopy
Stream morphology	Width/depth	-0.364	-0.437	-0.328
	Entrenchment	-0.392	-0.252	-0.338
Erosion / stability	BEHI	-0.35	-0.39	-0.49*
	PE	0.28	0.32	0.43*
	nPE	-0.52**	-.64***	-.61***

Table 4: Pearson correlations between density, diversity, stream morphology and stability. P-values indicate the significance of correlations:
*$0.1 < p < 0.2$, ** $0.05 < p < 0.1$, *** $p < 0.05$

These results indicate that density and diversity may relate to more stable banks. However more bare ground, or less dense vegetation in the understory, relates to more stable banks, suggesting the opposite. These results are impacted both by the small sample size of studying only two streams, and also by the fact that greater canopy density does not allow as dense growth in the understory, confounding density results. A third, important factor in the bare ground estimate for North Fork was recent massive flooding, which left a thick layer of sediment in the flood plain. This sediment may have covered mosses, grasses, herbs and even vines, lowering the overall percent cover in many of the North Fork transects.

Discussion and Conclusion

The goal of this research was to detect a relationship between stream morphology and the vegetation density and diversity in the entire riparian area. Due to unusual weather patterns that caused excessive flooding, only two streams could be studied for comparison. With such a small sample, results are difficult to analyze, as it impossible to know the reason for the correlations found. While this greatly limits the generalizability of results, possible meanings are discussed.

Results for stream morphology show no difference between these two streams, so no relationship can be determined from this study. This may not be surprising, however, as both stream reaches studied have been notably disturbed. North Fork Creek, despite its heavy vegetation and expected stability, has steep banks with considerable erosion. Channel incision is known to destabilize banks by increasing bank height, which reveals more bare ground and also dries out the soil and affects wetland plant communities (Micheli and Kirchner, 2002). Therefore the vegetation at North Fork, while dense and diverse, may not affect the stream form as strongly as it would were the banks more shallow. The reach studied is also downstream of a road, so the stream is impacted by vehicle parts and garbage. North Fork's drainage basin includes a golf course and heavily developed land, which may have contributed to heavy flooding and erosion seen this season (Appendix B). Little Elm is just downstream of a road as well, receives drainage from a nearby agricultural field, and is frequently forded by cattle. These disturbances can be expected to destabilize the streams and cause changes in morphology. Therefore, their identical stream morphology does not necessarily negate the possibility that riparian vegetation relates to morphology.

While these results do not support the initial hypothesis, the bank erosion hazard index (BEHI) provides a measure of bank stability that shows more interesting relationships. From the bank erosion hazard index, relationships between vegetation characteristics and stream stability can be determined. Results for the predicted erosion (PE) volume generally revealed that greater vegetation density and diversity relate to more stable stream banks. This finding is reasonable considering current knowledge of stream and riparia. Density of vegetation has previously been shown to stabilize banks (Trimble, 1997; Rowntree and Dollar, 1998; Brooks and Brierley, 2002; Wynn et al., 2004; Allmendinger et al., 2005), and in confirming this finding the methods of this study are supported. The relationship between stability and vegetation diversity does not appear to be well known. Biological diversity is important for the function of stream ecosystems, so it is not unexpected that biological diversity would relate to stream structure as well. Structural diversity was hypothesized to relate to stable banks because the various root lengths, thickness, and ability of vegetation to retain sediment should increase the performance of stream banks overall. This hypothesis is supported, however the generalizability of results may be in question.

Unfortunately, there are many limitations to the generalization of conclusions drawn from this study. These limitations arise primarily from the small sample size, as well as the riparian assessment tool. Because only two streams were sampled, it was impossible to control for many variables that impact stream form and stability. These variables may include the geological foundation, soil types and climate factors affecting a stream. While the streams studied are located within two-hundred miles of each other, we cannot assume they are similar in these ways. Next, in applying simple statistical correlations, the assumption of independence in the data was not met because many data points came from the same stream. A much larger number of streams would allow for this independence, increase statistical power, and wash out the affect of uncontrolled variables on correlations. Also, the riparian assessment tool is based on structural life forms, which are easy to identify, but may not be of great ecological importance to the stream. Grouping plants according to other physical or biogeochemical factors could prove more useful for assessing ecological integrity, which may be more important for the structure and function of the stream (Innis et al., 2000; Gurnell, 2007). Despite the simplicity of structural life forms, implementing the method was not as rapid as hoped. Any further use of the method should follow significant revision.

Discovering the role of riparia in stream structure and function has wide-scale importance, and is particularly necessary to inform stream restoration and maintenance (Gregory and Gurnell, 1988). Many streams and riparian zones are heavily impacted by anthropogenic disturbances. There is debate about which types of vegetation are most conducive to stream health and restoration. Research into the affects of certain vegetative characteristics on the stream could lead to more specific and relevant vegetating techniques. Greater knowledge of the riparia can also inform stream maintenance, so that future problems are avoided. Protecting the appropriate kinds of riparian vegetation may also help ensure stream form stability.

Future work in this area could involve the study of vegetative affects in a more controlled environment, comparison of reference streams to impacted streams, revision of the riparian assessment, or simply testing more streams to further this study. While correlations can be determined easily enough in the field, finding causal relationships requires significant control and may be more effectively achieved in a laboratory setting. One such experiment involved growing alfalfa in varying degrees in a sandy flume before releasing water into the system, and then analyzing the resulting channel morphologies (Gran et al., 2001). Controlled experiments may be difficult to implement, requiring a longer time to watch the stream change form. Results, while more powerful, may also be less ecologically relevant and generalizable. Comparing stream form and vegetation of healthy reference streams to impacted streams may provide insights into what kinds of vegetation are important for healthy stream structure and function. The riparian assessment could also be revised to be more rapid and more ecologically relevant. Its current function may not be much greater than simpler, more qualitative methods, or analysis of aerial photographs. Finally, this study could still find meaningful results if only more streams were studied, and this would be an obvious next step in the research process.

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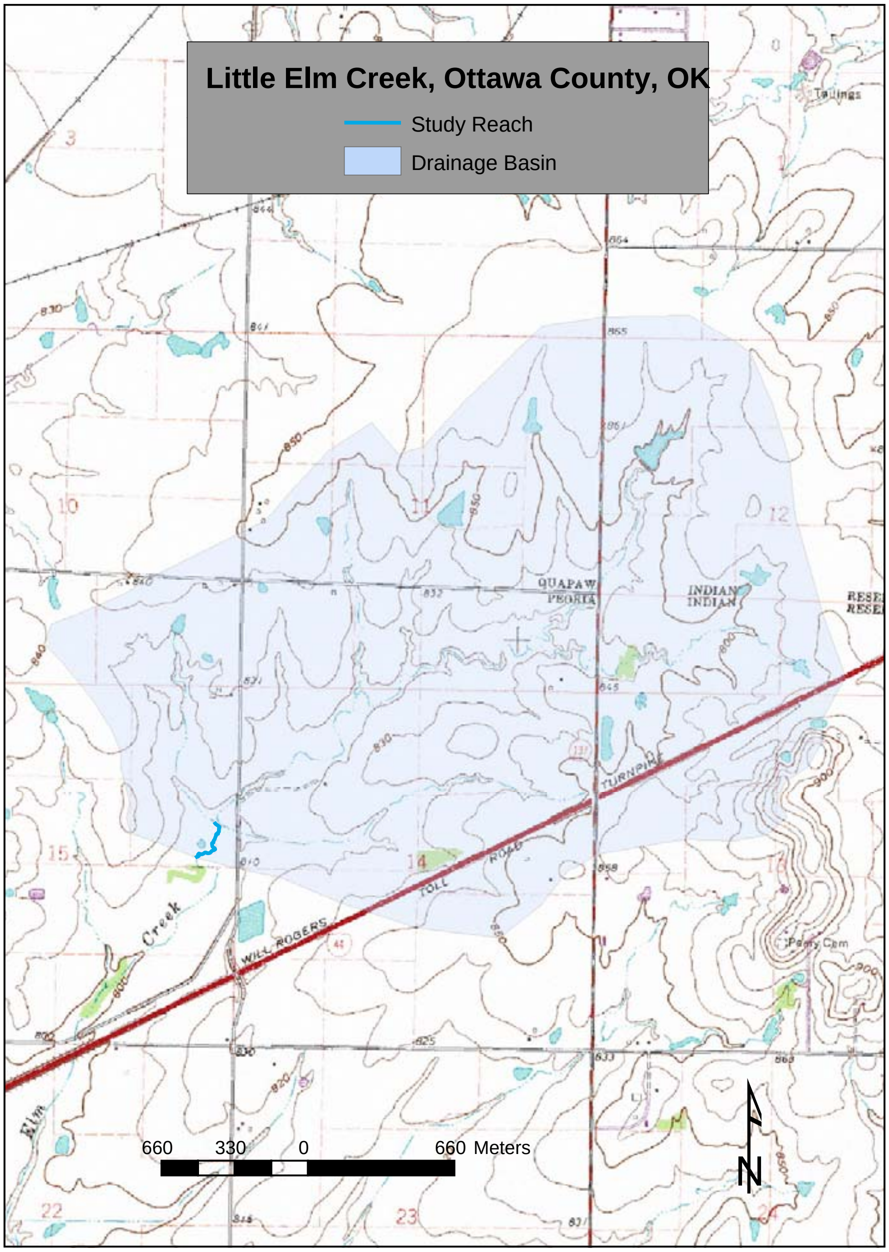
Appendix

A. Reaches

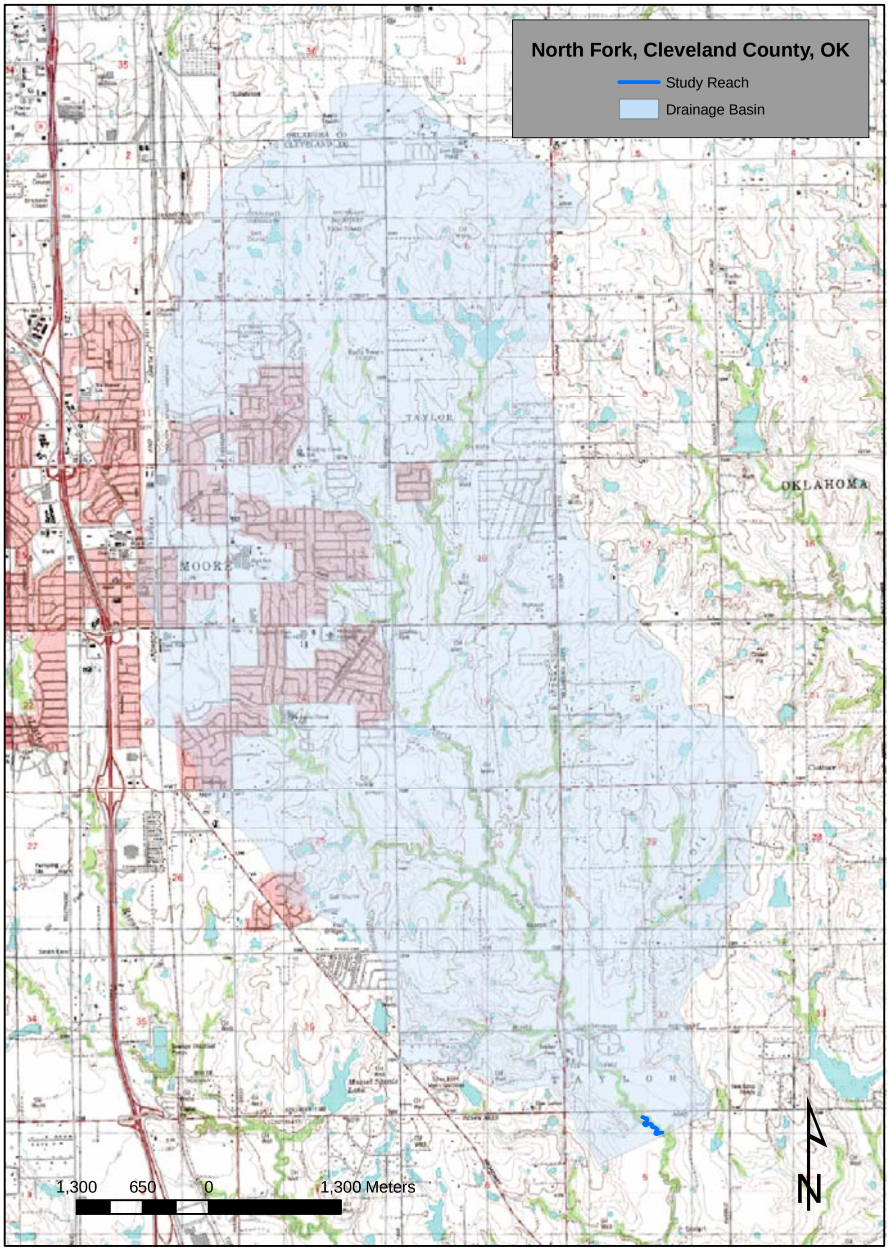
Above: Little Elm Creek reach. Left: The reach studied (blue) begins near a drainage stream from the field above, and passes through a pasture. Right: View of the stream and pasture.

Above: North Fork Creek reach studied. Left; The reach (blue) and riparian area (green) is downstream of a road and surrounded by fields. Right: Dense riparian vegetation characterizes the reach. Also note that North Fork is much wider than Little Elm.

B. Drainage Basins



Above: Watershed for Little Elm Creek. Total area: 2.5 miles squared.



Above: Watershed for North Fork. Total area: 15.4 miles squared.

C.

Riparian Assessment Survey	Margaret McCahon OU CEES REU 2007
Stream: Date: Transect # : Survey point: Side of stream: Inspector:	Dominant species: Co-dominants:

Sample	Distance (ft)	Litter thickness (in)	Soil textures	Soil color	Particle-size anal.	Notes
1						
2						
3						
4						
5						
6						

Transcect: ___________ Location range: ______ - ______

structure	moss-like	grass-like	herb-like	fern-like	shrub-like	tree-like / canopy
counts						
S.A. / % cover						
details						
dominant species						

shrub ht. (in):	0-10 in	10-17 in	17-30 in	30-40 in	40-50 in	50-60 in	> 60 in
counts							
S.A. / % cover							

tree circum. BHD (in):	0-2.5 in	2.5-6 in	6-12 in	12-24 in	24-36 in	36-48 in	46-60 in	> 60 in
counts								
S.A. / % cover								

Transect: ___________ Location range: _____ - _____

structure	moss-like	grass-like	herb-like	fern-like	shrub-like	tree-like / canopy
counts						
S.A. / % cover						
details						
dominant species						

shrub ht. (in):	0-10 in	10-17 in	17-30 in	30-40 in	40-50 in	50-60 in	> 60 in
counts							
S.A. / % cover							

tree circum. BHD (in):	0-2.5 in	2.5-6 in	6-12 in	12-24 in	24-36 in	36-48 in	46-60 in	> 60 in
counts								
S.A. / % cover								

Influence of spatial distribution of riparian zones on low-order streams

By Nathan Medford

Lehigh University, Class of 2009

OU REU 2007

Table of Contents

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Abstract

Although many physical characteristics of an ecosystem define a stream's form; one that has received little attention in the current literature is the distribution and form of a riparian zone. The question explored in this project is whether the spatial distribution patterns of riparian vegetation affect the geomorphologic structure of a stream. Many may observe that the riparian zone certainly does have an impact upon the stream, in particular the effects of the riparian zone's ability to filter non-point source water pollutants. However, the question that is being asked is whether the vegetation of this zone is enough to affect the state of the stream and possibly even its form. The root systems of the vegetation of these zones has an ability to absorb the energy from shear stresses acting upon the stream banks caused by flowing water. It is therefore hypothesized that increased distribution of forested riparian zones results in a more constant stream form for low order streams.

This hypothesis was tested in the following manner. First reaches along two streams were selected for the study by determining where the spatial distribution of the riparian zone is similar on each bank, but different among the stream reaches. Longitudinal and cross-sectional profiles were then surveyed at the upstream end of the designated reach of stream, in the middle of the reach, and then at the downstream end of the reach. This survey data was then used to determine stream form and the Rosgen classification (Rosgen, 1994, 1996). This data combined with a Bank Erodibility Hazard Index (BEHI) is a partial indicator of stream channel stability. Autocorrelations were then be used to determine the influences of the distribution of forested riparian zones on stream form and state. It was determined that forested, riparian vegetation distribution has a greater effect on the stream state, especially of the stream banks, than specific, quantifiable effects on stream form.

Introduction

Fluvial geomorphology is a vast field that encompasses many areas of study at many different scales. However, in any study it is important to remember the overriding controls that exist for every fluvial system. These include the geology, climate and topography of a fluvial system or drainage network. These more general variables determine the supply of flow and sediment which enter a system and control the processes which shape it. It can be helpful to think of the flow regime and sediment supply as independent variables which are fixed by the catchment's overall characteristics (Piégay and Schumm, 2003), which in turn are what determine the form and function of the stream.

The scale upon which one compares these variables is also important. In conducting a study of fluvial geomorphology, one must determine the spatial and temporal scale upon which it will be based. Spatial scales can be as large as drainage systems for entire continents, or as small as the habitats created in point bars along meanders in a first-order stream. Temporal scales are also very important for the study of fluvial systems. It is often necessary to assume a timescale upon which certain characteristics can be assumed constant. If a scale is picked that is relatively short, the important underlying characteristics of the larger catchment may oftentimes be considered constant (Knighton, 1998), and the reactions of a system to changes in other variables may be noted. This is the case in this study.

The form of the stream is the result of the fluvial processes controlled by the underlying characteristics of the drainage basin, by variable sediment loads, and by variable discharge stages. The form of the stream is very important, as it leads to the function of the stream. Form is highly variable over time and the purpose of this study is to better understand how the form of the stream at any given moment is affected by riparian vegetation. This will be done by comparing the morphology and the stream state of two streams with differing distributions of forested riparian zones.

There are three important dimensions of stream form that will be discussed. First, is the planometrics of the stream. This is the overall shape and pattern of the system as it goes from its headwaters to its base level. It is determined by two different elements of form, the cross-sectional profile and the longitudinal profile. The cross-sectional profile is the shape of the channel perpendicular to flow, and it is largely determined by local fluvial processes. It is also the most easily disturbed of the morphologic elements, and therefore must be studied at the relatively stable parts of the stream, the riffles. The longitudinal profile of the system in contrast can be thought of as being constant over moderately short-term time scales (Knighton, 1998). The longitudinal profile is often dependent upon the location of a stream reach in regards to the catchment, with greater slopes occurring farther upstream in the system, and more gentle slopes occurring farther downstream. The combination of these different dimensions of stream form that give the system its overall morphology, and all must be studied concurrently.

In this study, great emphasis is placed upon the bankfull discharge, and using this as a marker for the many different aspects of stream morphology. Bankfull dishcharge can be considered the stage at which the active channel is filled and corresponds with a peak flow interval of about one and a half years. It is the flow that is the most effective at distributing sediment and significantly accounts for stream form in most fluvial systems (Dunne and Leopold, 1978). Wolman (1955) discusses the importance of quantification of the results of a stream study, which has led to the plethora of findings which take a look at form from a numerical standpoint doing away with the more qualitative system of the past. These specific measures are often combined in a series of ratios, which are used in many classification schemes.

In order to understand and compare the morphologies of stream reaches that are distant from one another, many classification systems have developed. An important system was recently developed by David Rosgen (1994, 1996). This system was applied, in this case, as it is very comprehensive and takes many different factors into account. There are four main levels in the "Rosgen system," and this study is mainly concerned with the first three. The first level is of the "geomorphic character" of a system and deals with the catchment and the stream's place in it on a broad level. The next level is a "morphological description" of the stream form and requires field determination. The third level is one of "stream state" and ties the stream form in with the function of the stream, leading to the possibility of companion studies (McCahon, 2007). The final level concerns validation of the results of classification, however this will not be touched upon in this study. The purpose of using this classification in this study is to get a sense of the how the stream's form is changing along an area of nearly constant riparian zone vegetation distribution. While the classification system will not be able to pick up subtle changes along the study reach, it will be able to give a general sense of the stream's form along the reach.

This study, as mentioned previously is not just concerned with stream form, but its connection with the function of the system. A characteristic of this stream function, or stream state, is often the riparian vegetation that it supports (Rosgen 1996). At the greater landscape level, riparian vegetation can be thought of as a corridor which allows for the transport of species, sediment, and nutrients between common ecosystems (FISRWG, 1998). Therefore riparian vegetation is very important for the health of the environment and proper functioning of the stream, while the relationship to stream form is not completely understood. However, there are certain connections which are generally well known between riparian vegetation and streams. First, riparian vegetation protects the banks of a stream. It is able to add cohesion to the bank (Jacobson and Pugh, 1997). It also provides surface protection for the bank from the sediment load in the flowing water, the scouring caused by stream flow, and the other detritus flowing into and destroying stream banks (Rosgen, 1996). Finally the root systems from riparian vegetation are able to take shear stresses from the adjacent flowing water instead of having them impact the materials in the bank (Ikeda and Izumi, 1990). The riparian vegetation also plays an important role as the habitat for many of the creatures which live in this ecosystem as well as improving the quality of the ecosystem within the stream itself (Naiman et al., 2005).

The following definition of riparian vegetation will be applied in this study. Riparian vegetation is the vegetation that is relatively close to the stream, oftentimes being contained within a greater, inactive floodplain. The distribution of wooded, riparian vegetation will solely be considered, as it has a denser and has a deeper root system which increases its affect upon the stream form and state. This is not uncommon and has been adopted in many studies, including those of Hession and others (2003). In the study, I will be only looking at the general spatial distribution of the vegetation which can be delineated by the use of recent aerial photographs.

In deciding how the study was to be designed, there was a need to address the concern of scale mentioned previously. Montgomery (1999) provides a framework for the delineation of the study of fluvial form through a framework which he developed; termed the "process domain." He compares this scale to that of the river continuum. The current study comes closer to looking at the streams in the sense of the process domain. This is the idea that there are areas where a particular geomorphic process governs the habitat characteristics. It serves as a link between the fluvial processes and the domain which they form for the accompanying ecosystem. Montgomery also mentions the larger scale of the "river continuum," which is a better framework for looking at the flow of water, sediments, and species through the catchment system as a whole. My study will focus on smaller process domains, by attempting to isolate a reach of the stream with similar riparian vegetation distribution and attempting to determine the relationship which is inherent between the form of this reach and the surrounding vegetation.

The links advocated in the process domain concept are not completely understood for all areas. It is this link which can be used to relate stream form to stream state. These two aspects of the fluvial system are two different levels of the Rosgen classification system (Rosgen, 1994), and their synthesis is the object of this study. Form of the stream, which includes the planform and geomorphic dimensions, determines the function and state of the stream, which includes its stability, its ability to transport sediment, its creation of habitat, its support of vegetation, or its ability to adjust after disequilibriums. Stream form and stream state are not the same thing however. There are many other factors that contribute to fluvial processes, which include the underlying geology or the current climate.

These variables must also be taken into account when deciding upon the relationship between form and function (Jacobson and Pugh, 1997). These complications are a reason that this relationship must be further studied.

The idea of stream stability is one that is closely tied to that of the relationship between stream form and stream state. Stability is very much dependent on the time scale upon which one studies the system. Rivers are constantly evolving in the long term, but they are generally considered stable when they maintain equilibrium on an intermediate level, between short-term fluctuations and long term evolution. Rosgen (1996) states that a stream is stable when it is neither aggrading or degrading and can transport the detritus of its catchment.

The purpose of this study is to better understand the interaction between fluvial form and state, by relating the distribution of riparian vegetation to the specific fluvial form of stream systems. The question explored in this project is whether the spatial distribution patterns of riparian vegetation can actually affect the geomorphologic structure of a stream. The answer is very important for many reasons, the greatest of which may be stream management. Streams and the flow of water through fluvial systems are the ultimate source of freshwater for man. Also, riparian zones are beginning to be overused, having too many functions which they are required to support (Beever and Pyke, 2004). Therefore the connection that they have with the stream must be better understood. The stream's ability to support vegetation makes the distribution of riparian vegetation a function of stream form, oftentimes termed a stream function. However, it is also widely accepted that the presence of vegetation in the riparian zone does have some affect upon stream state. This study attempts to determine the details of the interrelationship between form and state. The question that is asked by this study is whether a stream function can have an effect upon the form that it is in turn ultimately reliant upon. It is a question of positive feedback. Does the stream form affect stream function which in turn pushes that form further away from an initial equilibrium point (Hupp and Osterkamp, 1996), or is the vegetation merely indicative of certain landforms in these fluvial systems (Beever and Pyke, 2004)?

Many studies have looked at how streams and their flow affect vegetation, proving that there is certainly a link between these two subjects. Flow and the underlying hydrology has a great effect upon the species of vegetation and their abundance in a riparian zone. The distinction between a losing a gaining stream and the determination of whether flow of the stream is recharging the water table are also important. The amount of water available to the root systems of the vegetation will dictate what can grow there (Kondolf et al., 1987). There are also studies that contend that specific geomorphic forms, affect the plants that grow alongside it. Hupp (1982) describes that the specific slope of a reach, and not the position of the reach in relation to the catchment, determines the species distribution of vegetation. Yet, Beever and Pyke (2004) explain that these changes in slope, or a broader form, are often caused by the constraining factors of local geology, therefore further study of these variables is often needed. The fluvial processes of the stream also affect the plant distribution in the riparian zone. The processes of sedimentation and the stratification of soil are important in determining the plants that will grow there (Hupp and Osterkamp, 1996). When these varied effects are combined, indicator species have been found that correspond with certain landforms along a fluvial system (Beever and Pyke, 2004). Therefore, it is plain that there is a connection between the form of the river and its function. Form determines the types and distribution of vegetation in the riparian area as it is ultimately responsible the riparian habitat.

However, the idea of the positive feedback system must still be considered. When the form of the stream pushes vegetation in a certain direction, does the vegetation continue that drive towards a state of disequilibrium and in turn affect the form? Gregory and Gurnell (1998) consider the entire catchment when contemplating this question and detail three important effects that vegetation has upon the fluvial system and its form and function. Vegetation controls the supply of water and sediment into the system, it affects the morphology of the channel itself, and it changes the routing of water and sediment through the entire system. The current study in turn concentrates on the second effect, the effect on the morphology of the channel itself. However this study also explores channel state as well.

Channel morphology may be affected by riparian vegetation through the transfer of energy and shear stress, from the bank materials, to the root systems of the vegetation and bed materials. Bank vegetation dissipates energy, resists flow, and reduces shear stress (Jacobson and Pugh, 1997). By affecting the stream's power to move sediment, the fluvial processes, processes which create stream form, are in turn affected. In fact, forested catchments, and forested riparian zones have been shown to have an even greater effect upon form than the presence of urbanization. Kang and Marston (2006) describe how the streams in urbanized catchments did increase in width moving downstream, but not more than would be expected by the increase in drainage area size. The presence of a high density of trees in their study basin negated the increases in runoff from the urbanization of the surrounding land due to the subsequent increase in impermeable areas. Trees in the riparian zone were affecting form.

The transfer of shear stresses has been suggested as a means by which riparian vegetation can affect stream morphology, a function of stream form. This could in turn make a stream more stable, which is a matter of stream state. Ikeda and Izumi (1990) consider the implications of the transfer of shear stresses theoretically, and develop a set of equations for streams that have heavy riparian vegetation and sparse riparian vegetation. The equations for the streams with more vegetation predict that the stream will be deeper and narrower than a stream with similar flow characteristics and sparse vegetation. They then test their equations using field data, and conclude that their equations do predict the actual effects of changing amounts of riparian vegetation. The greater stability to stream banks also causes less migration of the stream channel (Gregory and Gurnell, 1998, Hession et al., 2002). Jacobson and Pugh (1997) showed through a study of historical, aerial photographs that more vegetation in the riparian zone does make the stream slightly more stable. These stability concerns are also very important in the management of streams and are considered in this study.

Upon consideration of the current literature, there are disagreements concerning the effects of an increase in riparian vegetation. Ikeda and Izumi (1990) predict narrower streams and Hession and others (2002) find that streams become wider. This shows the caution that must be taken in these studies to always look at the underlying hydraulics and determine their effect upon the stream form and stream state as well (Gregory and Gurnell, 1998). It oftentimes may have a greater effect than that of the vegetation. There are a plethora of other factors which may influence stream conditions even more than vegetation in certain conditions (Jacobson and Pugh, 1997), which is why more studies are needed and studies are needed for specific areas with unique attributes. This current study fulfills these needs by looking at the connection between the distribution of riparian vegetation and stream form (reach morphology) and stream state (bank stability) in a unique area (Central and Northern Oklahoma).

There is an expectation of a correlation between the reach morphology and the distribution of vegetation due to the research background on this subject. With a greater distribution of vegetation one would expect to find less change of form along the study reach. With little riparian vegetation, it could be concluded that there should be greater changes in form. Prior evidence would also seem to support the idea that greater distribution of vegetation will stabilize the banks and this will ultimately improve the stream's state as well as affect its form. Banks are ultimately very important to form as they provide for much of the sediment supply in a system and they control the lateral migration of the channel (Beschta and Platts, 1986). Therefore in this study, stream reaches were classified at the two ends of the reach and in the middle of the reach in order to determine if form changed. A measurement of stream state (bank stability) was completed at each of these locations as well, in order to confirm the previous results of others and to confirm the regular functioning of the study reaches.

Methods and Materials

In this study the first step that was taken was to make an appropriate selection of field sites. This was accomplished through the use of the computer program *ArcGIS* to view recent aerial photographs of the suggested sites. The advantages of using the aerial photographs in this manner to determine the stream reaches for the study were numerous, but most importantly it ensured a general familiarity with the reach that was quite helpful when specific boundaries were decided upon for the survey. Reaches were also chosen on the basis of some additional characteristics. These included the presence of the requisite reach length containing two full meander wavelengths or a longitudinal profile distance of 20 -30 bankfull widths, reach access from the property owners, and most importantly a nearly constant distribution of similar riparian vegetation on either side of the stream. It is necessary that the general distribution be the same on both banks of the stream because by maintaining the consistency of the riparian vegetation, a control is established by which to compare the classification levels along the corresponding reach. Two locations were decided upon, due to constraints on time. They were chosen to represent the extremes of riparian vegetation distributions, one having thick and wide distribution (North Fork Creek, Cleveland County, Oklahoma), and the other having sparse and thin distribution (Little Elm Creek, Ottawa County, Oklahoma). In this way the efficacy of the riparian zone's control upon the stream's form and state can be judged.

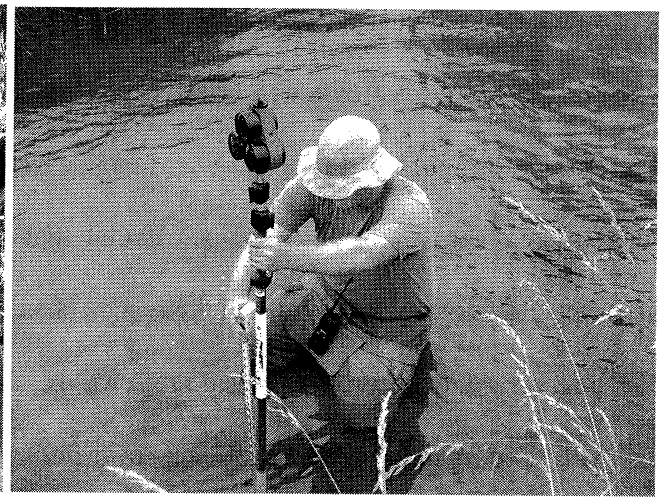
Surveying began on Little Elm Creek on June 21, 2007. It was completed in much the same manner as proposed by Harrelson and others (1994). However, the field technique was slightly modified for this study with additions from the suggested techniques of Powell and others (2004), and from other sources. The first task completed was to define the reach. For the purposes of this study, a reach needed to contain at least three riffles to be surveyed. An ultimate upstream and an ultimate downstream riffle are needed for classification purposes, as well as to provide stable endpoints for the longitudinal survey. Then roughly half way in between these riffles, another riffle must be identified in order to be surveyed and later classified.

Upon determining the extent of the study reach, the height from the current stage to the bankfull stage is then determined using a surveying line, and a tape measure. This was determined using visible bankfull indicators along the reach. These can include, changes in vegetation, scour lines, point bars, undercuts of the bank, changes in particle size, stain lines on rocks, or active flood plains (Harrelson, 1994). The survey line is stretched across a pool corresponding to where a bankfull indicator has been identified and the tape measure is then used to find the height from the line to the bankfull indicator and then from the line to the water surface. The difference of these two lengths is the desired height, of the current stage to the bankfull stage. This height is then used to mark the position of the bankfull stage at the riffles which are to be surveyed laterally. The maximum bankfull depth may then be determined at these riffles, and from this depth, the height of the flood prone area may be calculated. The height of the bankfull stage and flood prone stage should be marked on the bank using survey flags (see pictures 1 and 2). These important stage levels may then be survey later more accurately. By calculating and marking the flood prone stage's height, the extent needed for the survey is also determined. The flags will give the surveyors a sense of the extent of the survey they must complete for each cross-section.

Picture 1 (L): A cross-section from the Little Elm Reach and Picture 2 (R): of the North Fork Reach, showing placement of flags to indicate bankfull and floodprone elevations.

The reach must now be surveyed. In this study, "total station" surveying equipment (see picture 3) was used, and the data was transferred to a hand held computer, running the program, *Survey Pro* to record all of the data collected. The survey began at the downstream riffle, where a cross-sectional survey was completed. This entails going from the highest terrace on one side of the stream to the highest terrace on the other side, ensuring to record the elevation and position of every important feature in between. These features include all the terraces, the banks, the thalweg, the edges of water, the bankfull elevations, and the flood prone elevations. The person holding the rod then works their way up the stream, making sure to survey the thalweg and measure its depth every 10 feet (see picture 4). If the stream reaches a bend or meander, the left and right edge of water should also be surveyed for the longitudinal survey in order to later have a better map of the asymmetries of depth around the bends.

While working to from one end of the reach to the other, cross-sectional surveys should be completed of riffles. As many of these surveys should be completed as possible in order to determine how the morphologic measures of the stream change with longitudinal distance along the reach.



Picture 3 (L) The total station survey equipment. Picture 4 (R) Survey and measuring thalweg depth.

A survey of the bed material must now be completed. The general technique used to determine the median size of the bed materials is modified by a procedure proposed by Wolman (1955). This "pebble count" is completed by finding ten cross sections in the proportion of pools to riffles found along the reach. At each cross section ten samples will be taken. The surveyor works his way from one bankfull indicator on one side of the stream to the same elevation on the opposite side. This ensures a sampling of the material from the entire active channel. A tape should be stretched across the reach along the cross section in order that the surveyor may take his samples at even intervals, again ensuring a complete sampling of the active channel. When a sample is taken, it should be done blindly and by bending over and picking up the first material with which the hand makes contact. This material is then measured along its intermediate axis and its length recorded.

The final survey completed in this study is the Bank Erosion Hazard Index (BEHI). BEHI is an index created in order to rate and rank banks as to the extent of their possible erosion, using a common system (Rosgen, 1996). It involves measuring the root depth of the vegetation on the banks, measuring the bank angle, and qualitatively determining the percentage of "root density" and "surface protection." This data combined with the survey data will be used later to determine the various indexes for the BEHI rating system.

Now that they field work has been completed and all the data has been collected it must be analyzed. The goal of this study is to classify the stream reach at the beginning, in the middle, and at the end in order to see if form changed significantly with a constant riparian area. Then different measures of the reach morphology can be calculated at cross-sections to have a more specific knowledge of how form changed along the reach. The bank stability will be calculated by completing the BEHI analysis and a projected erosion rate will be estimated. Ultimately the data of individual streams will be compared with other streams of differing vegetation distributions around the area. Also, the morphologic and stream state data will be combined and compared to riparian distribution calculations.

For classification purposes some additional information was needed concerning the stream reaches and their respective drainage basins. This information was found using the program *ArcGIS.* This program allows the user to use geo-referenced aerial photographs or topographic maps to calculate areas and other dimensions of geographic features. In this case, the drainage basin area was calculated using the topographic maps by following ridge lines between fluvial networks (see Appendix I, figure 1). Also, the sinuosity of the stream was found using this program and the aerial photographs previously obtained. This was done by using the program to find the length of the reach after it was delineated on the photographs, and then finding the length of the valley which contains this reach (see Appendix I, figure 2). The length of the valley was estimated as being straight length from the upstream riffle to the downstream riffle.

Much of the work of classification was completed using a computer program called *RIVERMorph*. It is a program designed to use survey data collected in the field to model a stream's form and processes. It gives the user summaries of stream form and stream state for management purposes. During the field work specific tags of the differing stream features were added to all of the survey data so it could be directly used with the program. This program was used in this study to find the classification of the reach at each of the riffle cross-sections that were completed at North Fork, and three of the riffle cross-sections at Little Elm Creek. It was then used to find the entrenchment ratio and the width to depth ratio of the riffles at the cross-sections, and the longitudinal distance of these riffles from the initial downstream cross-section (see Appendix I, figure 3).

For two of the five cross-sections completed at Little Elm Creek, the bankfull stage elevation, and the flood-prone area elevations were not surveyed. Therefore, they were not able to be classified using the Rosgen system. However, the probable height and position of the flood-prone elevation and the bankfull stage elevation were calculated and then used to calculate the entrenchment ratio and the width to depth ratio at these two locations. First, the bankfull elevation was calculated at these riffles and used to find the probable flood-prone stage elevation. This was done by using the average distance from the active discharge stage to the bankfull indicators (computed in the field) to determine the maximum bankfull depth for these cross-sections. Then the two points that these elevations would fall between were found among the survey data, and a linear regression was completed between them. A linear regression was chosen, as the survey procedures dictated that between survey points there are no significant changes in the bank geometry. Using these lines the horizontal position of the bankfull stage elevation and flood-prone stage elevation were found and used to find the bankfull stage width as well as the flood-prone area width. These dimensions were then used in the calculation of the width to depth ratio and the entrenchment ratio at the two riffles.

It is also important to note that for the data processing of the survey data from North Fork some special compensation had to be made. After the survey, it was determined that a mistake had been made in turning the total station and there was a sudden decrease in elevations that was not a natural phenomenon. Fortunately this jump came at a section of the reach were there was a pool. So, the water level elevation was assumed to be the same for both points along the reach, and then the requisite height was calculated that was needed to bring the thalweg and recorded water depth up to the elevation of the previous point. This correction height was then added to all the subsequent points upstream of this point in the survey.

I then completed the BEHI for the three defining cross-sections at each stream, on both banks. This assessment was also contained in the program *RIVERMorph*. There were some outside calculations needed, before the data was added to the program. First bank height was calculated using cross-section data from the survey, as the elevation change between the edge of water and the high terrace. Bankfull height was computed in the same way, using survey data, and the edge of water as the base level. Then all the field data for the BEHI was inputted and an index number for the BEHI was outputted to the user with an adjective to describe this number's general meaning. The program then allows the user to decide a means to calculate the amount of sediment being lost to fluvial processes along the bank and then makes this calculation. This amount is also noted by the user. The method used in this case was the "Near Bank Stress Method," (*RIVERMorph*), as it could be used with data we had already collected in the field.

Finally a spatial analysis of the riparian vegetation surrounding the reach was completed for both of the stream reaches. The reach was again delineated on the aerial photographs using *ArcGIS*, and the riparian zone area was found along the reach. This was done for North Fork by marking where the forested area with canopy cover ended and the agriculturally utilized land began. For Little Elm Creek, this was completed by measuring the canopy cover provided by the few trees along the reach. Once this zone was marked, the location of all the riffle cross-sections was marked for each stream and the width of the riparian corridor at each cross-section was calculated. This dimension was determined not as the width of the riparian zone perpendicular to flow, but as the width of the zone perpendicular to the corridor's general layout (see Appendix I, figure 4). This was completed at all of the cross-sections of North Fork Creek, and a single cross-section at Little Elm Creek that had a tree adjacent to it (XS5).

Results

The classifications for both streams were completed using the first three levels of the Rosgen method. They were very similar. At the first level of classification, the level of "geomorphic character," (Rosgen, 1996) the valley type for both North Fork and Little Elm Creek was of "type X" (Rosgen, 1996). This is a wide valley with gentle slopes. The soils are generally fine and originate from riverine and lacustrine processes. The relief for each basin adjacent to the reaches was 0.0039 ft/ft for Little Elm Creek, and was 0.0026 ft/ft for North Fork. Where the two streams differ is in their order and drainage basin area. The order of the reach on Little Elm Creek is second, and the order of the reach on North Fork is fourth. The drainage basin area for Little Elm Creek is 2.49 square miles, while the area of the drainage basin for North Fork is 15.36 square miles.

The "Level II" classification, or the "geomorphic character," of the study reach was also determined. The bankfull width, the floodprone width, the maximum depth, the width to depth ratio, and the entrenchment ratio were all determined for each cross-section of each stream (see table 1a and 1b). This data was sufficient to give a broad classification for the stream reaches under the Rosgen system (Rosgen, 1996). It was found that two of the three cross-sections on Little Elm Creek were generally classified as "F" type streams (XS1 and XS10), and the third was generally a "B" type stream (XS6). Five of the six cross-sections (XS1, XS2, XS3, XS4, XS6) were classified as "F" type streams on North Fork, including the beginning, final, and middle riffles of the reach. The sixth riffle (XS5) was generally classified as a "B" type riffle and was located between the middle riffle and the upstream riffle.

Cross Section	Bankfull width (ft)	Floodprone width (ft)	Maximum depth (ft)	Entrenchment ratio	W/D ratio
1	7.08	8.07	0.57	1.14	16.47
5	5.51	11.49	0.58	2.09	9.50
6	12.66	18.93	0.79	1.49	27.52
7	6.22	9.91	0.60	1.59	10.31
10	10.76	12.04	0.46	1.12	44.83

Table 1a: Morphologic description of Little Elm Creek Reach

Cross Section	Bankfull width (ft)	Floodprone width (ft)	Maximum depth (ft)	Entrenchment ratio	W/D ratio
1	25.50	30.22	1.57	1.18	28.33
2	21.00	25.61	1.72	1.22	20.59
3	18.85	23.57	1.62	1.25	16.12
4	25.88	28.78	1.84	1.11	21.05
5	22.03	36.78	1.72	1.67	21.84
6	22.53	26.93	1.58	1.20	19.94

Table 1b: Morphologic description of North Fork Reach

Then, the pebble counts provided the knowledge of the predominant channel materials for both reaches (see Appendix II, Figure 1a and 1b). The median particle size for Little Elm Creek was 5.96 mm and the median particle size for North Fork was 3.00 mm. Once the pebble counts for both study reaches were taken into account the classification of the streams could be continued to an even finer level (see Table 2a and 2b). Therefore, it was determined that the specific geomorphic classification for the upstream and downstream riffles (XS1 and XS 10) of Little Elm Creek was "F4" and that the middle riffle (XS6) was specifically a "B4c" stream type. The upstream, downstream, and middle riffles of North Fork (XS1, XS4, XS6) had the same classification, "F4." Two other riffles had this same classification (XS2 and XS3). The riffle, on North Fork, that was dissimilar from these in the general classification, was also dissimilar in this more specific classification, having a rating of "B4c." It should be noted that the classification for both streams remained nearly constant along the reach as well as being nearly constant between reaches.

Cross Section	Longitudinal Distance (ft)	Classification
1	0	F4
6	503.219	B4c
10	922.71	F4

Table 2a: Classification along Little Elm Creek

Cross Section	Longitudinal Distance (ft)	Classification
1	0	F4
2	42.815	F4
3	443.892	F4
4	569.737	F4
5	973.209	B4c
6	1365.532	F4

Table 2b: Classification along North Fork Creek

Because the study reaches had a constant distribution of riparian vegetation on either bank, it was also important to look at whether the form of the stream changed at a finer scale with longitudinal distance along the stream. A statistical analysis was completed of the correlation between the major measures of stream geomorphology with the longitudinal distance upstream from the downstream riffle. Neither of the streams showed significant correlations between their geomorphic measures and distance upstream from the downstream riffle (see Appendix II, Figure 2a and 2b).

The next level of the Rosgen stream classification system involves "stream state," or assessing the stream function. This was accomplished through the BEHI analysis (see Appendix II, Figure 3a and 3b). There were oftentimes significant differences between the rating for paired banks on the stream. However when the values were averaged at a particular cross-section, it was again shown that these values were relatively constant along the reach. Adjective erosion potentials ranged from "moderate" to "very high."Also, a predicted erosion rate calculation was carried out in this study. Again, this showed a fairly constant rate along the length of the stream, when the average rate between the left and right bank was considered (see Appendix II, Figure 4a and 4b). However, the differences between banks were oftentimes relatively large. A normalized predicted erosion rate was calculated in this study, so a direct comparison could be made between the two streams even though they have differing drainage basin areas. The normalized rate is defined as the predicted erosion rate divided by the area of the reach's drainage basin (see Appendix II, Figure 5a and 5b).

A spatial analysis of the riparian width was also carried out. This analysis showed extreme differences between the two study reaches. The land around the Little Elm Creek reach is used as a pasture for cattle, right to the edge of the water. Therefore there are few trees and mostly grasses. North Fork Reach had a well forested riparian zone on either side of its banks before giving way to the land use for agricultural purposes. The riparian zone of Little Elm Creek was much less wooded with many fewer trees than the riparian zone of North Fork (see Appendix I, Figure 2). Little Elm Creek had a small riparian vegetation area of 249 m^2 and the reach on North Fork had a larger calculated riparian vegetation area. It had an area of 14275 m^2. The next spatial analysis was to find the width of the riparian corridor at each cross-section surveyed on each study reach (see Appendix II, figure 6). Ultimately, the North Fork reach had a larger riparian vegetation area and greater riparian corridor widths at all of its cross-sections than the Little Elm Creek reach did.

It is not possible to directly compare the areas of the riparian vegetation from the two reaches in this study, as they come from two very different- sized drainage basins. However, a means of comparing these riparian areas was necessary. The "normalized area" of the riparian zone was used. This is defined as the ratio of riparian vegetation area to drainage basin area. Even with this correction, the North Fork still has a larger value for its "normalized area" than Little Elm Creek (see Appendix II, Figure 7). Because this is a measure of the riparian vegetation distribution across the entire study reach, corresponding values for measures of form and function must be found for the entire reach. Therefore, averages for each stream were taken of the entrenchment ratio across all the cross-sections, of the width to depth ratio across all the cross-sections, and of the BEHI rating from every bank and every cross-section surveyed on the reach (see Appendix II, Figure 7, and Tables 3 and 4). Thus, it is shown that the reach with a greater riparian area is less entrenched, has a smaller width to depth ratio, and a smaller BEHI rating. However, the differences in the averages between the two streams are rather small, and the averages are included in each other's range of standard deviation.

The next correlations were drawn between the width of the riparian corridor at individual cross-sections, and the value of individual measures of form and function at the cross-sections. This was first

	Entrenchment ratio	W/D ratio	BEHI Rating
Average	1.49	21.73	34.70
Standard Deviation	0.40	14.79	7.11

Table 3: Average Values (over each cross-section) with Standard Deviations for Little Elm Creek

	Entrenchment ratio	W/D ratio	BEHI Rating
Average	1.27	21.31	29.38
Standard Deviation	0.20	3.97	1.66

Table 4: Average Values (over each cross-section) with Standard Deviation for North Fork Creek

completed through a statistical analysis. Correlation tests were completed using the program *Mini-Tab* and are presented in Table 5. The measures of stream form (entrenchment ratio and width to depth ratio) show negative correlations, with high probabilities of error (see Table 5). The measures of stream state, through the BEHI analysis, tend to show better correlations with the width of riparian vegetation at the corresponding cross-section. This included a BEHI difference term, which is the absolute difference between the BEHI values for the left and right banks (see Table 5). Next, the predicted erosion rates were also correlated to the riparian vegetation width. These needed to be normalized between the streams, as they were not on an absolute scale. The average of the rate, at the two banks of a cross-section, was compared to the riparian width. The difference in the predicted rates between the two banks at a cross-section was also compared with riparian width (see Table 5).

Parameter	Pearson Correlation Constant	p
Entrenchment Ratio	-0.130	0.704
Width to Depth Ratio	-0.138	0.686
Average BEHI	-0.582	0.225
Difference BEHI	-0.547	0.261
Average Pred. Erosion (vol.)	-0.604	0.204
Average Pred. Erosion (mass)	-0.618	0.191
Difference Pred. Erosion (vol.)	-0.464	0.353
Difference Pred. Erosion (mass)	-0.694	0.126

Table 5: Combined data for all cross-sections between the two streams – Statistical analysis of the "Parameter" correlation with its corresponding "Riparian Corridor Width"

Discussion and Analysis

The first trends noticed in this study are those of the general averages between the two reaches. As noted previously, the reach on North Fork had a larger "normalized" riparian area than that of the reach on Little Elm Creek. By comparing these two reaches' average measures of form, it is determined that there may be a slight connection between the riparian vegetation area and the channel form. It should be noted that the specific channel features, such as bankfull width, maximum bankfull depth, and floodprone width, were not compared. This was due to the fact that the streams were different sizes, and therefore ratios of channel features were used to compare the two reaches. These ratios, entrenchment and width to depth, seemed to vary indirectly with the riparian zone area between the two streams. This result would seem to fit with the background work done on this subject (Beschta and Platts 1986, Jacobson and Pugh, 1997, and Knighton 1998). There also seemed to be an indirect variation between riparian zone area and the average BEHI rating of the stream reach. The effects of riparian zone area on stream form, may be due to this fact, that an increased area seems to increase bank stability.

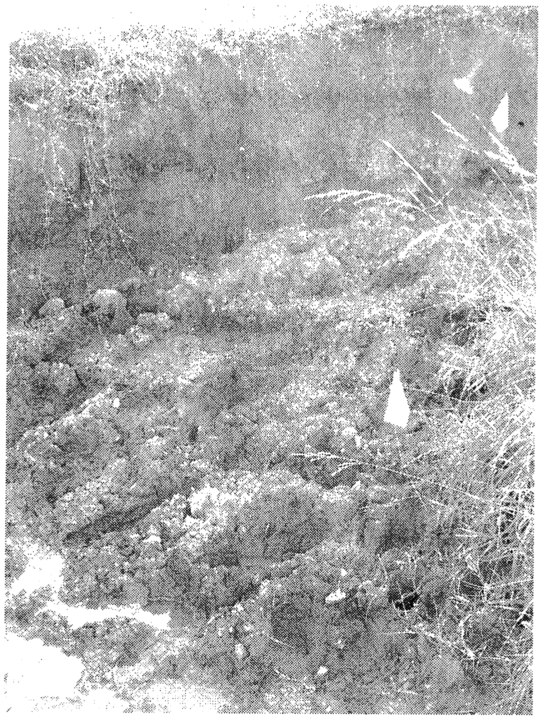
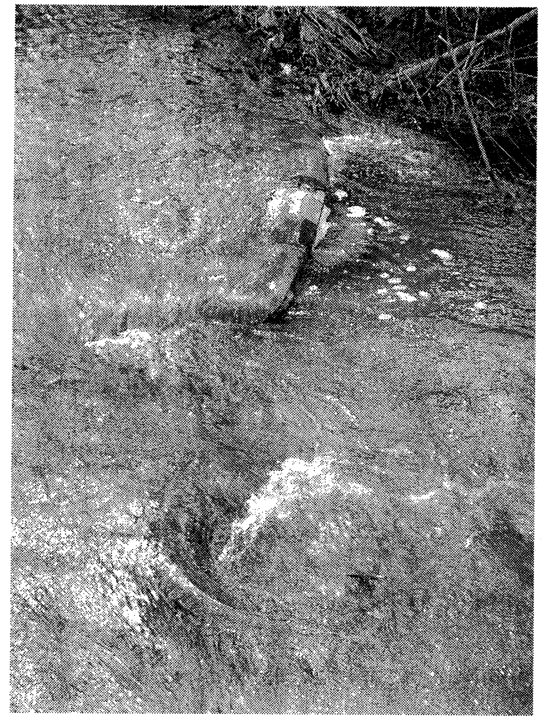
However these trends can hardly be termed as conclusive, as there was simply not a statistically significant different form between the two streams. Both the averages for the entrenchment ratio and the width to depth ratio fell within the range of each other's standard deviation. The same was true for the BEHI averages along the entire stream. The problem with this study ended up being that we were trying to compare too many variables that were kept constant. The riparian vegetation distribution was kept constant between the two reaches, as the stream form and its measures. Therefore, no real trends could be seen as to how riparian vegetation distribution may affect the stream form, as everything remained nearly constant. This technique of analysis would be more successful with more study reaches of differing forms and with differing riparian vegetation types. Then there could be more average values computed for each stream, and a trend might be found between the normalized riparian vegetation area and some measure of stream form, or in the BEHI. The other reason that these results may be brought into question is due to the fact that the method for measuring the riparian vegetation area was not ideal. Canopy cover may not be the best measure of the riparian vegetation area. Better measures of this area may be basal area, or some other function of vegetation density (McCahon, in print).

Another purpose of this study was to see if there would be longitudinal trends in the form or function of the stream along the reaches. This was thought to be important as reaches with constant riparian vegetation distribution on either bank were chosen in order to determine if form would change differently along a reach with a high distribution of forest vegetation versus a dearth of these plants. Form did not change significantly along either reach, and the ratios which measure stream form did not show any trend in variation along the reaches. This could suggest that vegetation has less of an impact on stream form than initially presented. The effect of vegetation may not be significant enough to change the reaches classification. The entrenchment ratio and the width to depth ratio do not change nearly enough to warrant any sort of visible trend in the data. Also, it has also been reported that for reaches with drainage basins greater than 10-15 km^2 (Zimmerman, 1967), the effects of vegetation may be marginalized. The reach on North Fork has a drainage basin area greater than this, and this may be another reason that either the presence of woody vegetation does not seem to affect form. A final reason that the vegetation effects of the stream may be marginalized is because this type of stream, the "F4" type, is less likely to be affected by riparian vegetation (Rosgen, 1996). This is due to the fact that the channel is so highly entrenched. The root systems may not be deep enough to truly affect form in any substantial manner.

However, the lack of any sort of reasonable trend with longitudinal distance to stream form may be due to systematic errors in this study as well. The reach may just not be long enough to reach the needed thresholds for significant change in form. This relates back to the "process domain" idea (Montgomery, 1999). This study merely looked at one part of one process domain. It is possible that these stream and its reaches would be better represented using a river continuum model. Our results certainly exhibited a nearly identical continuance of stream form along the reach, and the absence of any trends may be due to the fact that these reaches of stream are part of a larger continuum that very gradually changes form from its headwaters to base-level. Further study may be interesting to see how form would change before and after a break in the general distribution of riparian vegetation. While this would increase the number of variables in the study, there may be more significant changes in the stream form to be examined at a location such as this. This study also in part refutes the idea of applying Montgomery's "process domain" concept to streams in low-relief basins. He does contend in his publication that the idea of the "process domain" fits better into mountain catchments.

The average BEHI rating was also plotted against longitudinal distance (see Appendix III, Figure 1). However, in this case, there was a strong correlation. On Little Elm Creek, the BEHI rating varied directly with longitudinal distance upstream from the downstream riffle; and on North Fork the BEHI rating varied indirectly with longitudinal distance upstream from the downstream riffle. These results seem counterintuitive. It may be that the area of forested catchment upstream from the cross-section has less of an effect than initially understood. However, there are other mitigating factors for this relationship. The banks of Little Elm Creek were substantially affected by their use by cattle as a means to reach the stream channel, which could skew the BEHI along this channel. Also, the banks of North Fork may be significantly affected by the large amounts of detritus that are found within the channel and along the banks, which could be increasing the affect of scouring on the banks (see Pictures 5 and 6).

The final correlations that were observed in this study concerned the measures of stream form and function with the riparian corridor width at each of the cross-sections where measurements were made. First, an attempt was made to correlate form with this riparian vegetation distribution data, and it did not fit very well with it. Upon statistical analysis, the confidence of a possible correlation was very low for the entrenchment ratio ($p=0.49$) and for the width to depth ratio ($p=0.42$). Also, the Pearson

Picture 5 (L): Picture of Right Bank (XS6) of Little Elm Creek showing the damage done by cattle trampling and Picture 6 (R): Picture of the detritus present in the stream banks and bed in North Fork Creek

correlation coefficients for both the entrenchment ratio and the width to depth ratio were very low (ρ=-0.138 and ρ =-0.130, respectively). Again, the evidence suggests that the woody riparian vegetation does not have a significant affect upon stream form. This could be due to the reasons given earlier in this section, yet there are other possible sources for this finding due to problems with the methods of the study. A width of zero meters was entered for most of the riparian corridor widths along the cross-sections of Little Elm Creek. This was due to the fact that there was little woody vegetation, but perhaps there are better means of demarcation for riparian vegetation than canopy cover.

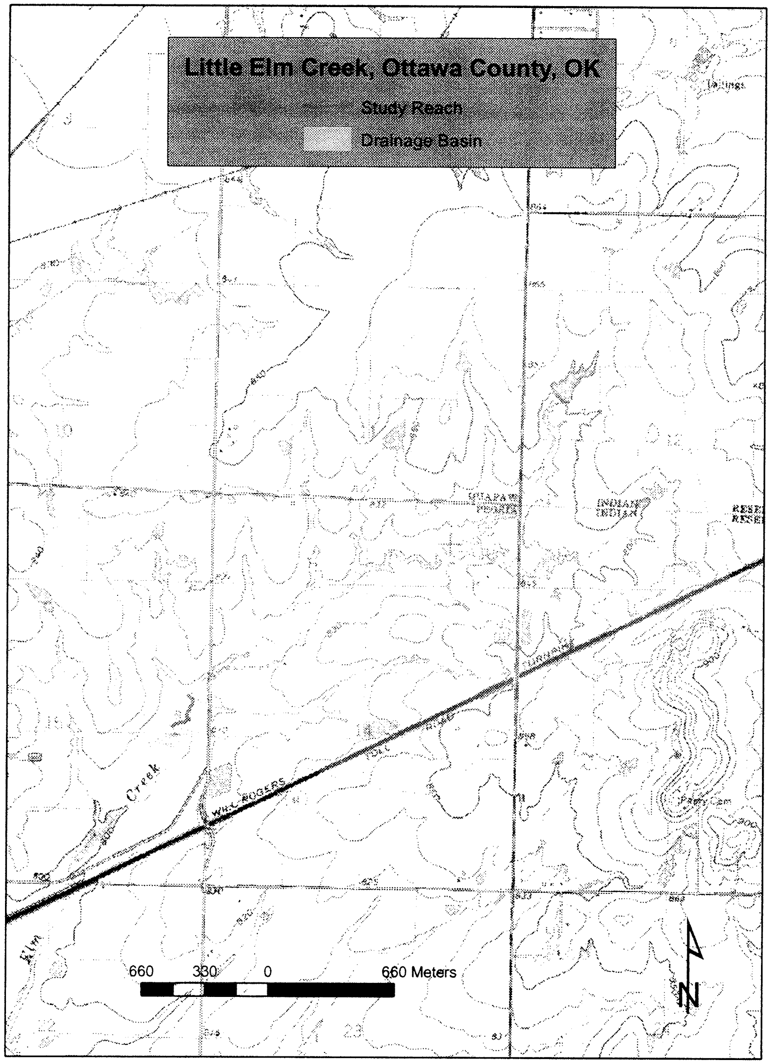
However, measures of stream state showed stronger correlations between their values and measured widths of vegetation. Upon the statistical analysis of the average BEHI rating at a cross-section with the riparian corridor width, a rather large confidence was found in a correlation (p=0.23). This data suggests that there is a stronger relationship between stream state and the distribution of riparian vegetation than between stream form and the distribution of riparian vegetation. The BEHI rating and the riparian width are also shown to vary indirectly, which agrees with prior data in this study. However, the confidence values are still not absolutely high. This could be due to many of the possible errors or mitigating factors listed above. The difference in the BEHI values was also analyzed in this study, as a possible measure of stream instability. If one bank is more stable than another, there might be more impetus for lateral migration of the stream channel. However, this value may not be a good measure of stream instability, and more study would ultimately be needed to determine if the BEHI difference between two banks could be used as a measure of stream instability.

The projected erosion rates were another measure of stream state related to bank stability that were calculated in this study. These rates provided the best correlations with the riparian corridor width, again showing that stream state relates better to spatial measures of vegetation than stream form. And again, this relationship is indirect, and this is again what would be expected from the previous data, and previous literature on the subject. With more woody vegetation present along a bank, there is more protection and stabilization afforded to that bank (Hession et al., 2002). Also, the differences in these values were considered across the banks as a possible measure of stream instability. If there was a net flux of sediment in or out of the cross-section than channel migration may occur. But as with the BEHI difference between banks, there is no real evidence to support this value as a measure of stream instability.

Finally, the practice in this study of only testing the correlations for linear relationships is due to the fact that first, there are simply not enough data points to prove any other sort of relation. However, there is also no reason to believe from the background reading that they relationships would be anything other than linear. Also, no specific, qualitative relationships were presented in this paper. This is due to the fact that only two streams tested. With only two data points, or two general groupings of data, there were no attempts made to determine the exact linear regression for the relationship.

Conclusion

Ultimately, this study was rather inconclusive. The data collected does not support a direct link between stream form and the spatial distribution of riparian vegetation. However, there are some weak connections that may prove important with further study. Yet this study ultimately states that for these streams, and this stream type, riparian vegetation simply does not greatly affect the form of the stream. As Jacobson and Pugh (1997) also state, there is not enough evidence, at this time, to support the idea that vegetation would act as a panacea for all stream management problems, concerning stream form. Measures of stream state did have stronger relationships with the distribution of the riparian vegetation, however it is important to remember that this study merely analyzes the effects of the vegetation on the stream banks, which are only one part of a stream's overall state. Also, there is already significant evidence which supports the theory that vegetation leads to greater bank stability (Hession et al., 2002, Ikeda and Izumi, 1990, and Jacobson and Pugh, 1997). For these two stream reaches, there was little evidence of a positive feedback mechanism between the stream state and stream form. This would have been the ultimate reason for a connection between the distribution of riparian vegetation and stream form, yet there was little supporting evidence to make this claim as we could not discover any discernible trend between the riparian vegetation and stream form. The importance of this study is to provide a framework for future studies which may build upon the work started here. More convincing relationships between stream state and riparian vegetation may have been found with more study reaches, and possibly some sort of relationship could have been discerned for stream form as well.



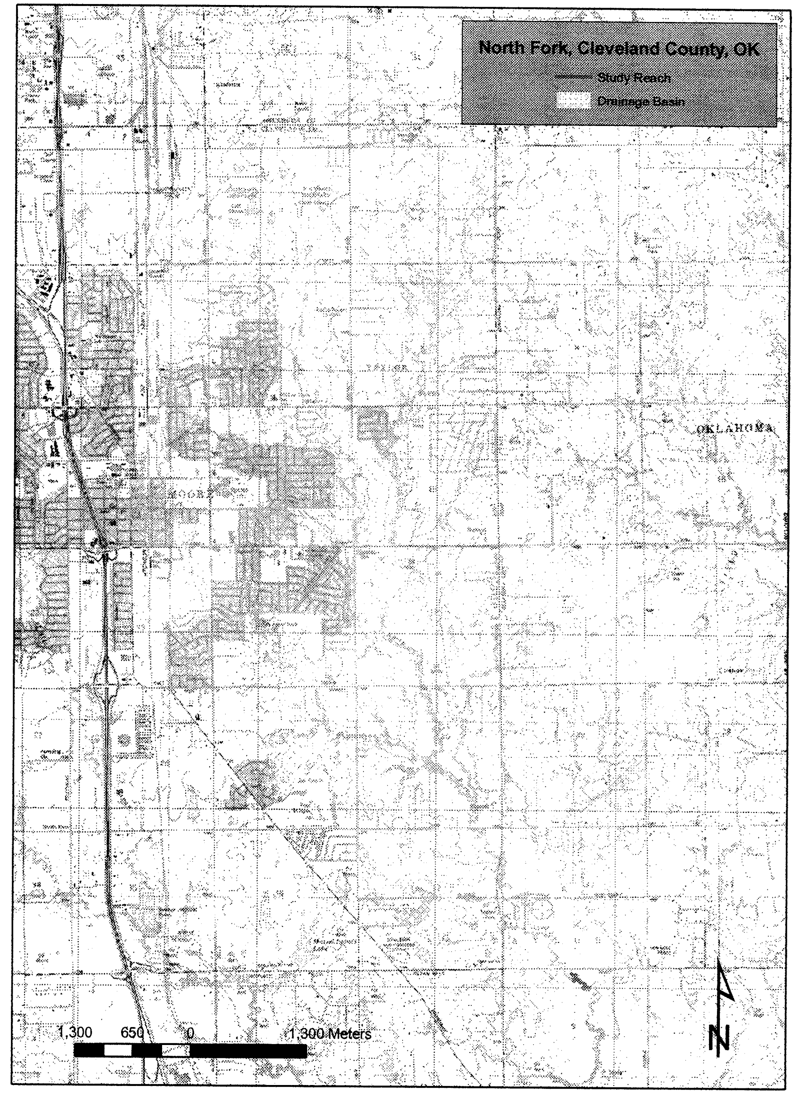


Figure 1: Drainage Basin for Little Elm Creek (L) and North Fork (R)

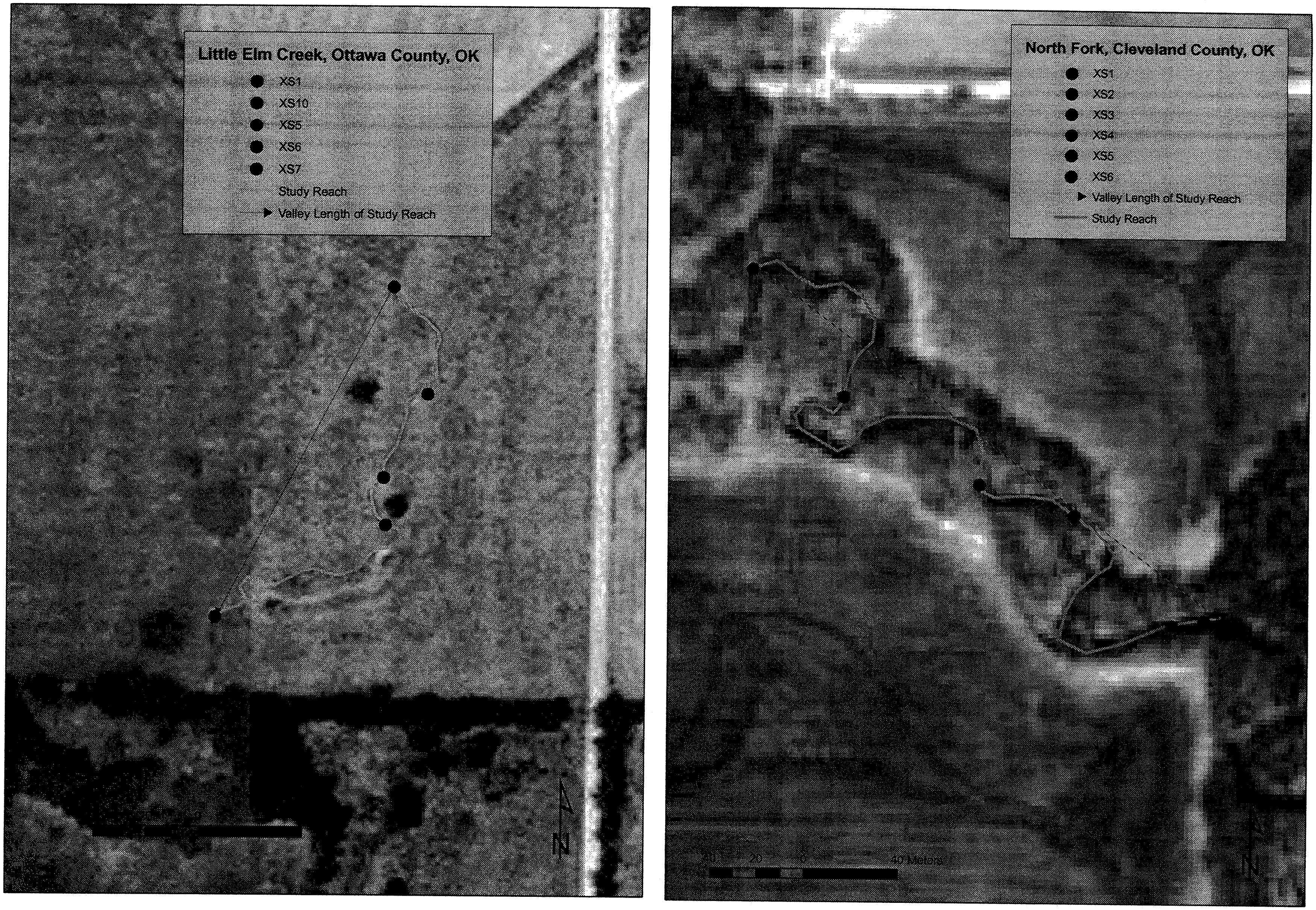


Figure 2: Little Elm Creek Reach (L) and North Fork Reach (R) showing study reach length, valley length, and the location of the riffle cross-sections

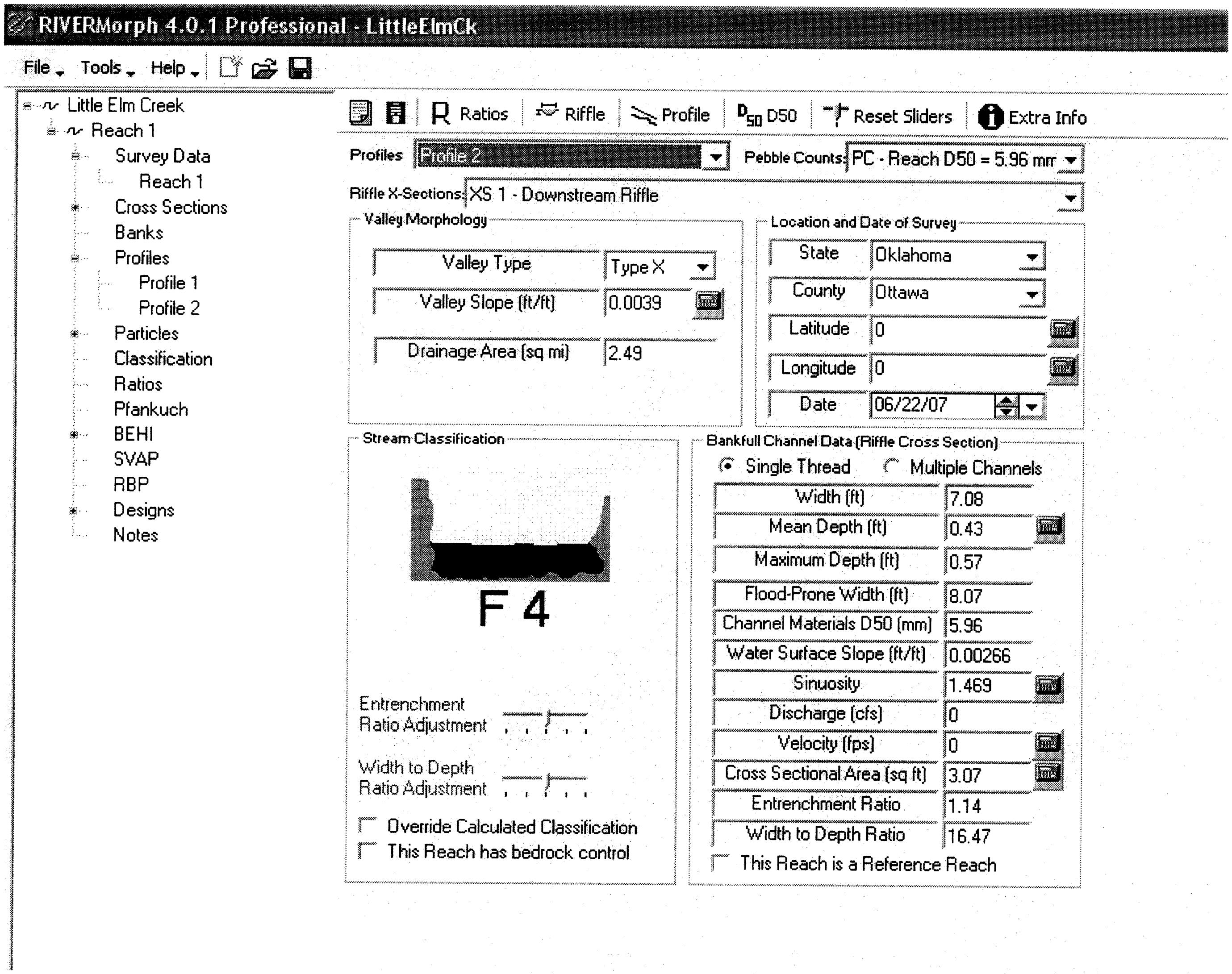


Figure 3: An example of the use of the RIVERMorph program to classify a riffle on Little Elm Creek.

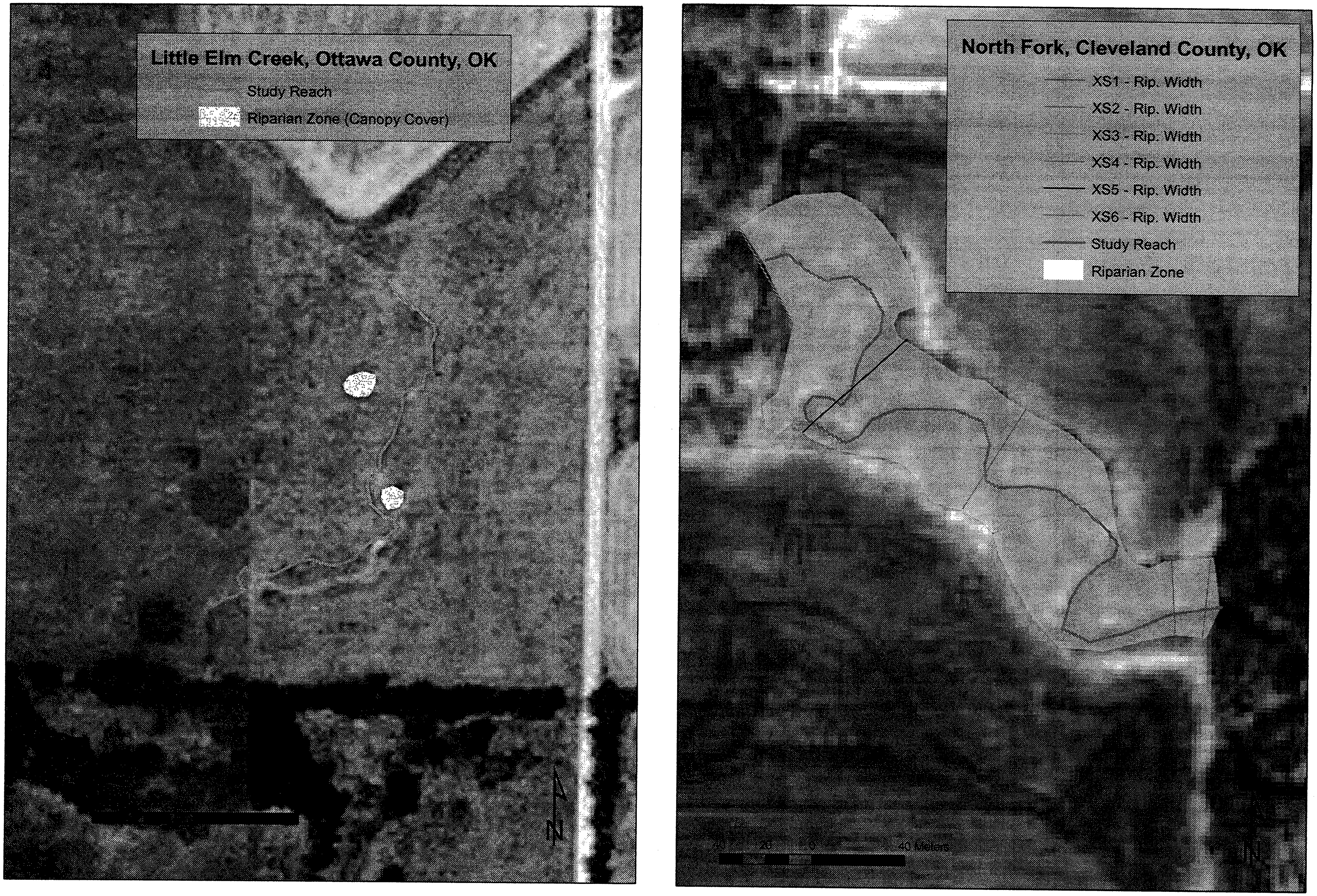


Figure 4: Little Elm Creek Reach (L) and North Fork Reach (R) showing the manner in which riparian area was calculated, and the riparian corridor width

Particle	Description	Size (mm)	Riffle	Particle Count Pool	Reach-Wide	%	Cum %
Silt/Clay	Silt/Clay	<0.062	9	12	21	21	21
Sand	Very Fine	0.062-0.125	0	0	0	0	21
	Fine	0.125-0.25	0	0	0	0	21
	Medium	0.25-0.5	0	0	0	0	21
	Coarse	0.5-1.0	0	2	2	2	23
	Very Coarse	1.0-2.0	4	7	11	11	34
Gravel	Very Fine	2.0-4.0	6	5	11	11	45
	Fine	4.0-5.7	2	2	4	4	49
	Fine	5.7-8.0	4	5	9	9	58
	Medium	8.0-11.3	4	7	11	11	69
	Medium	11.3-16.0	2	2	4	4	73
	Coarse	16.0-22.6	4	8	12	12	85
	Coarse	22.6-32	3	5	8	8	93
	Very Coarse	32-45	1	2	3	3	96
	Very Coarse	45-64	0	2	2	2	98
Cobble	Small	64-90	1	1	2	2	100
	Small	90-128	0	0	0	0	100
	Large	128-180	0	0	0	0	100
	Large	180-256	0	0	0	0	100
Boulder	Small	256-362	0	0	0	0	100
	Small	362-512	0	0	0	0	100
	Medium	512-1024	0	0	0	0	100
	Large	1024-2048	0	0	0	0	100
Bedrock	Bedrock	>2048	0	0	0	0	100
Total			40	60	100	100	100

Figure 1a: Pebble Count – Little Elm Creek

Particle	Description	Size (mm)	Riffle	Particle Count Pool	Reach-Wide	%	Cum %
Silt/Clay	Silt/Clay	<0.062	6	28	34	34	34
Sand	Very Fine	0.062-0.125	0	0	0	0	34
	Fine	0.125-0.25	0	1	1	1	35
	Medium	0.25-0.5	3	3	6	6	41
	Coarse	0.5-1.0	4	0	4	4	45
	Very Coarse	1.0-2.0	0	0	0	0	45
Gravel	Very Fine	2.0-4.0	3	7	10	10	55
	Fine	4.0-5.7	5	4	9	9	64
	Fine	5.7-8.0	4	3	7	7	71
	Medium	8.0-11.3	6	2	8	8	79
	Medium	11.3-16.0	6	1	7	7	86
	Coarse	16.0-22.6	3	0	3	3	89
	Coarse	22.6-32	5	1	6	6	95
	Very Coarse	32-45	2	0	2	2	97
	Very Coarse	45-64	2	0	2	2	99
Cobble	Small	64-90	1	0	1	1	100
	Small	90-128	0	0	0	0	100
	Large	128-180	0	0	0	0	100
	Large	180-256	0	0	0	0	100
Boulder	Small	256-362	0	0	0	0	100
	Small	362-512	0	0	0	0	100
	Medium	512-1024	0	0	0	0	100
	Large	1024-2048	0	0	0	0	100
Bedrock	Bedrock	>2048	0	0	0	0	100
Total			50	50	100	100	100

Figure 1b: Pebble Count – North Fork Creek

Parameter	**Pearson Correlation Constant**	**p**
Entrenchment Ratio	-0.008	0.99
Width to Depth Ratio	0.554	0.333
Average BEHI	0.992	0.083

Figure 2a: Statistical analysis of "Parameter" vs. longitudinal distance from downstream riffle in upstream direction (Little Elm Creek)

Parameter	Pearson Correlation Constant	p
Entrenchment Ratio	0.348	0.499
Width to Depth Ratio	-0.364	0.478
Average BEHI	-0.936	0.228

Figure 2b: Statistical analysis of "Parameter" vs. longitudinal distance from downstream riffle in upstream direction (North Fork Creek)

Cross Section	L/R	Bank height (ft)	Bankfull height (ft)	Root depth (ft)	Root density (%)	Bank angle (°)	Surface protection (%)	BEHI Rating
1	L	3.79	0.34	3.79	20	49.75	40	26.7
1	R	5.09	0.45	5.09	20	74.68	40	28.7
6	L	4.16	0.61	4.16	20	90	50	30.4
6	R	2.7	0.29	0	0	16.45	0	41.7
10	L	4.39	0.35	0.75	20	26.34	20	37.1
10	R	4.69	0.54	0.75	10	90	15	43.6

Figure 3a: BEHI of Little Elm Creek

Cross Section	L/R	Bank height (ft)	Bankfull height (ft)	Root depth (ft)	Root density (%)	Bank angle (°)	Surface protection (%)	BEHI Rating
1	L	6.09	0.67	6.09	20	41.14	5	31.2
1	R	7.45	0.86	7.45	20	45.14	15	29.3
4	L	11.82	1.01	11.82	10	41.51	40	27.6
4	R	13.64	0.69	13.64	10	61.51	20	30.7
6	L	12.05	1.11	12.05	20	21.64	5	30.3
6	R	9.42	0.84	6.5	50	53.85	40	27.2

Figure 3b: BEHI of North Fork Creek

Cross Section	L/R	Predicted Erosion (yd3/yr)	Predicted Erosion (ton/yr)
1	L	0.01	0.01
1	R	0.02	0.03
6	L	0.05	0.07
6	R	0.03	0.04
10	L	0.08	0.1
10	R	0.09	0.12

Figure 4a: Predicted Erosion Rates for Little Elm Creek

Cross Section	L/R	Predicted Erosion (yd3/yr)	Predicted Erosion (ton/yr)
1	L	0.05	0.07
1	R	0.07	0.09
4	L	0.15	0.2
4	R	0.08	0.1
6	L	0.03	0.04
6	R	0.08	0.1

Figure 4b: Predicted Erosion Rates for North Fork Creek

Cross Section	Average Pred. Erosion (yd3/yr)	Average Pred. Erosion (ton/yr)	Difference (yd3/yr	Difference (ton/yr)	Normalized average (vol.)	Normalized average (mass)	Normalized difference (vol.)	Normalized difference (mass)
1	0.015	0.02	0.01	0.02	0.006	0.008	1.244	2.488
6	0.04	0.055	0.02	0.03	0.016	0.022	0.905	1.357
10	0.085	0.11	0.01	0.02	0.034	0.044	0.226	0.452

Figure 5a: Predicted Erosion Rate analysis of Little Elm Creek

Cross Section	Average Pred. Erosion (yd3/yr)	Average Pred. Erosion (ton/yr)	Difference (yd3/yr	Difference (ton/yr)	Normalized average (vol.)	Normalized average (mass)	Normalized difference (vol.)	Normalized difference (mass)
1	0.06	0.08	0.02	0.02	0.004	0.005	5.119	5.119
4	0.115	0.15	0.07	0.1	0.007	0.010	9.348	13.355
6	0.055	0.07	0.05	0.06	0.004	0.005	13.962	16.754

Figure 5b: Predicted Erosion Rate analysis of North Fork Creek

Cross Section	Longitudinal Distance (ft)	Riparian Width (m)
1	0	0
5	431.133	15.075
6	503.219	0
7	681.323	0
10	922.71	0

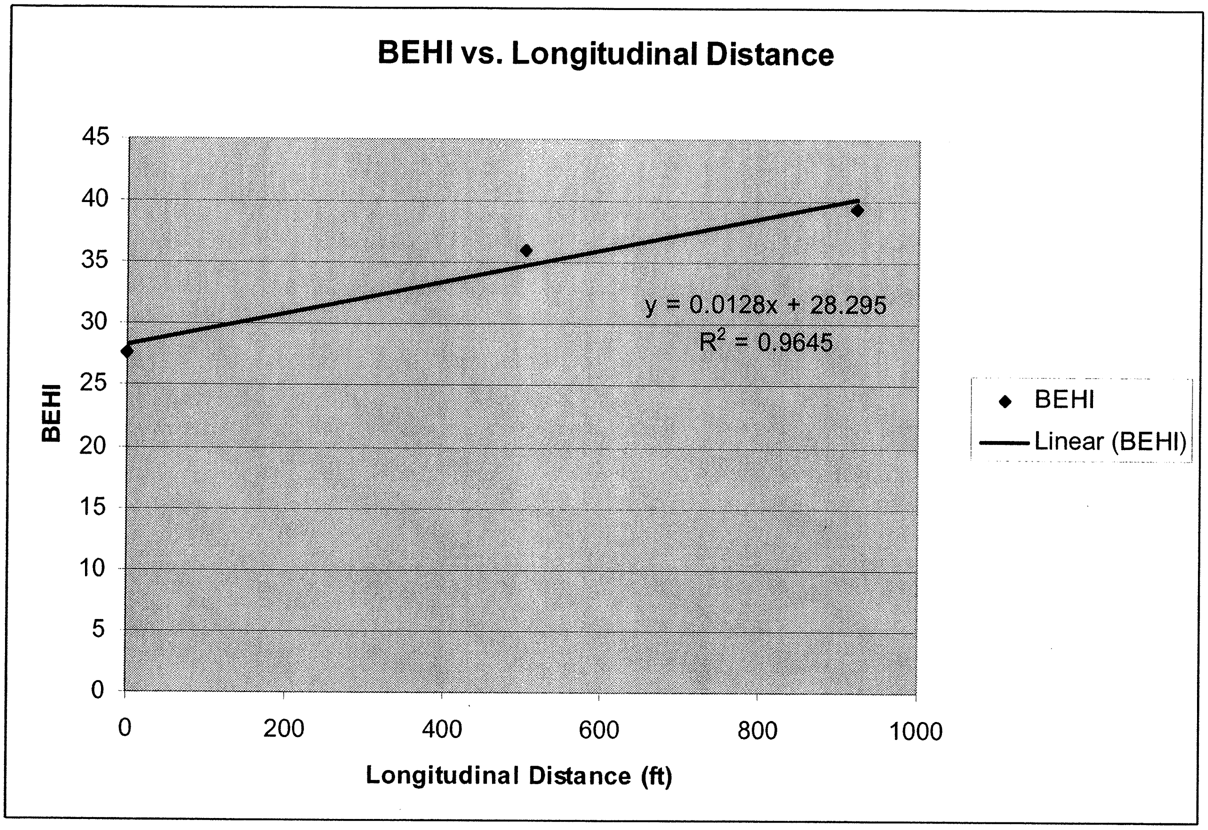
Figure 6a: Width of Riparian Corridor corresponding with cross-sections along Little Elm Creek

Cross Section	Longitudinal Distance (ft)	Riparian Width (m)
1	0	35.239
2	42.815	31.867
3	443.892	52.814
4	569.737	51.672
5	973.209	60.609
6	1365.532	45.899

Figure 6b: Widith of Riparian Corridor corresponding with cross-section along North Fork Creek

	BEHI	Entrenchment	WDR	Drainage Basin (sq. mi.)	Riparian Veg. (m^2)	Normalized Area
North Fork	29.38333333	1.271666667	21.31166667	15.358	14275	929.4830056
Little Elm	34.7	1.486	21.726	2.488	249.24	100.1768489

Figure 7: Averages of BEHI Rating, Entrenchment Ratio and the Width to Depth Ratio (WDR) as compared to the normalized Riparian vegetation area



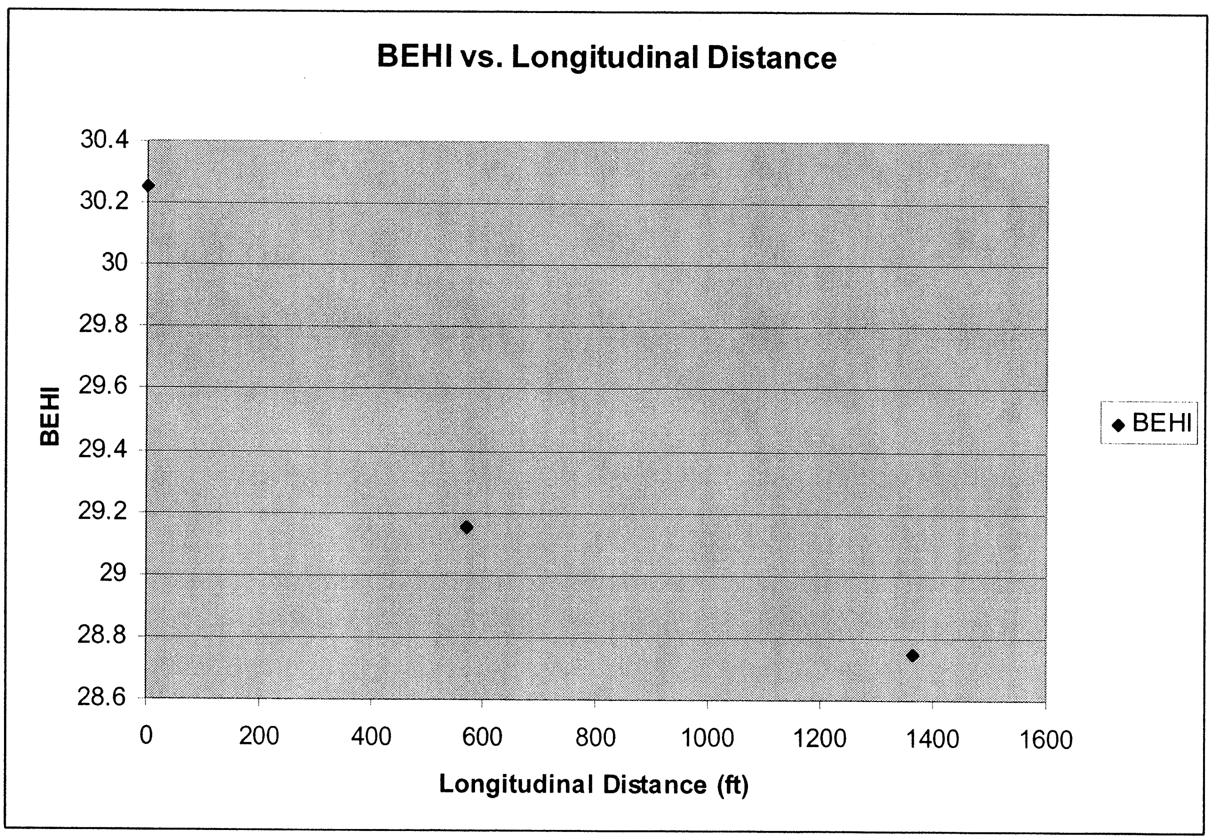


Figure 1: Plot of BEHI vs. Longitudinal Distance along Little Elm Creek (top) and North Fork Creek (bottom)

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