Title

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Abstract: The streams and rivers of the Ozark Plateaus are an unrivaled natural resource for the region. They provide habitat to some of the North America's most abundant and rich biodiversity, while also serving as water sources for human drinking, agricultural, and recreational needs. The Nature Conservancy (TNC) has identified several priority watersheds through its Ozarks Ecoregional Conservation Assessment of 2003, where it focuses its on-the ground conservation planning and implementation efforts.

Sedimentation from unpaved roads is a primary threat to water quality in Ozark streams. TNC has partnered with various organizations including the US Forest Service (USFS), the Watershed Conservation Resource Center (WCRC), and others to develop a multi-phased approach to address the impacts of unpaved roads on these priority watersheds.

The first step in the approach utilizes advanced GIS/GPS technologies to develop a detailed vehicle-based road inventory of the target watershed or subwatershed. Sub-meter differential GPS with customized data dictionaries are used to characterize the location and function of sediment-producing and conveying features of the road infrastructure, including the road surface, prism and slope, ditches, bars, lead-offs, culverts, crossings, and outlets. The road inventory yields a comprehensive geodatabase and map series of the mapped features.

A stratified random sample of the inventoried road network is then measured to generate sediment yield predictions on ten percent of the road network. Detailed field measurements are collected with differential GPS and customized data dictionaries. The data are entered into the Water Erosion Prediction Project (WEPP) model, a process-based erosion prediction model developed by multiple federal agencies over the past 20 years. With sediment yields predicted for sample sites, erosion predictions are then extrapolated for the entire study watershed using the road inventory geodatabase.

Once sedimentation yields are predicted for each road segment in the entire study area, priority sub-watersheds are identified in the GIS using watershed sediment accumulation tools. These sub-watersheds with high potential for sediment yield may be compared to species inventory data, stream bank erosion surveys, and other land use information to set priorities for conservation planning and prioritization efforts. Priority infrastructure maintenance improvements are also identified through features that were flagged in the road inventory geodatabase as needing repair or replacement.

Road maintenance workshops are held with USFS engineers, county road crews, and other partners to transfer the inventory information, present the findings of the study and to demonstrate best management practices for road maintenance.

Since 2004, TNC and its partners in the Arkansas have worked in three priority Ozark watersheds to inventory over 600 miles of unpaved roads and 3000 associated point features in an area greater than 900 square miles. The area comprises over thirty 6th level (12-digit) HUCs.

Introduction

The Ozarks ecoregion is one of 80 physiographic ecoregions in the US. This highland ecoregion occupies nearly 14 million hectares in Missouri, Arkansas, Oklahoma, Illinois, and Kansas. Along with the Ouachita ecoregion to the south, the Ozarks form the most significant highland region in mid-continental North America. Portions of the Ozarks have been exposed for over 230 million years, making it one of the longest-exposed land masses in North America. Because of its age, position in the middle of the continent, and other factors, the Ozarks ecoregion hosts a wide diversity of terrestrial and aquatic habitats, which has led to high species diversity and endemism (TNC 2003).

The rivers and streams of the Ozarks ecoregion harbors one of the greatest concentrations of freshwater fauna in North America, including over 160 fish species. Forty-three aquatic species are endemic to the Ozarks, including 21 crayfish, 16 fish, and 6 mussels. According to the Arkansas Wildlife Action Plan, about 55% of the state's fish, crayfish, and mussel species of greatest conservation need (SGCN) occur in the Ozarks portion of the state (AGFC 2006), while it comprises less than 25% of the State's total area.

Many Ozark streams and rivers have experienced significant impacts including hydrologic alteration, habitat destruction, nutrient loading, and sedimentation (TNC 2003). These impacts have led to many Ozarks streams being placed on the US EPA Impaired Waterbody List (303(d)) (ADEQ 2004, MO DNR 2002). They have also contributed to declines in the ranges and population of many of the Ozarks' aquatic species. Sedimentation of rivers and streams is particularly detrimental. Suspended sediment loads impact aquatic habitats by filling interstitial spaces of gravel stream beds, by clogging fish gills, and suffocating eggs and benthic insect larvae.

The primary sources of sediment into Ozark streams are eroding stream banks and unpaved roads. Unpaved roads have the potential to be a significant source of suspended sediment in rural watersheds, accounting for 25% or more of the sediment load (NRCS). Even during small rainfall events, storm water runoff from unpaved roads and ditches can contribute suspended sediment to streams and creeks resulting in elevated turbidity and total suspended solids concentrations.

The Nature Conservancy's Ozark Rivers Program is working to abate sedimentation from both stream banks and unpaved roads in priority watersheds. The project presented here focuses on methods for mapping and inventorying unpaved roads, modeling sediment yield from roads and delivery to streams, and implementation strategies for best management practices on unpaved roads. This project was initiated in 2004 and is ongoing at multiple sites.

Methods

The description of methods presented here characterizes all the types of work.

Study Area

The Nature Conservancy (TNC) has identified several priority watersheds through its Ozarks Ecoregional Conservation Assessment of 2003 (TNC 2003). The priority watersheds in Arkansas include eight HUC-08 lever watersheds, as shown in figure 1. TNC has conducted road sedimentation work in portions of three of these priority watersheds, including the Mulberry, Kings, and Strawberry River watersheds. In the Mulberry watershed, the study area included four HUC-12 catchments in the upper watershed. In the Kings watershed, work was completed in two HUC-12 catchments that comprise the Dry Fork subwatershed. For the Strawberry River, the study area includes the entire watershed, which is comprised of 27 HUC-12 catchments.

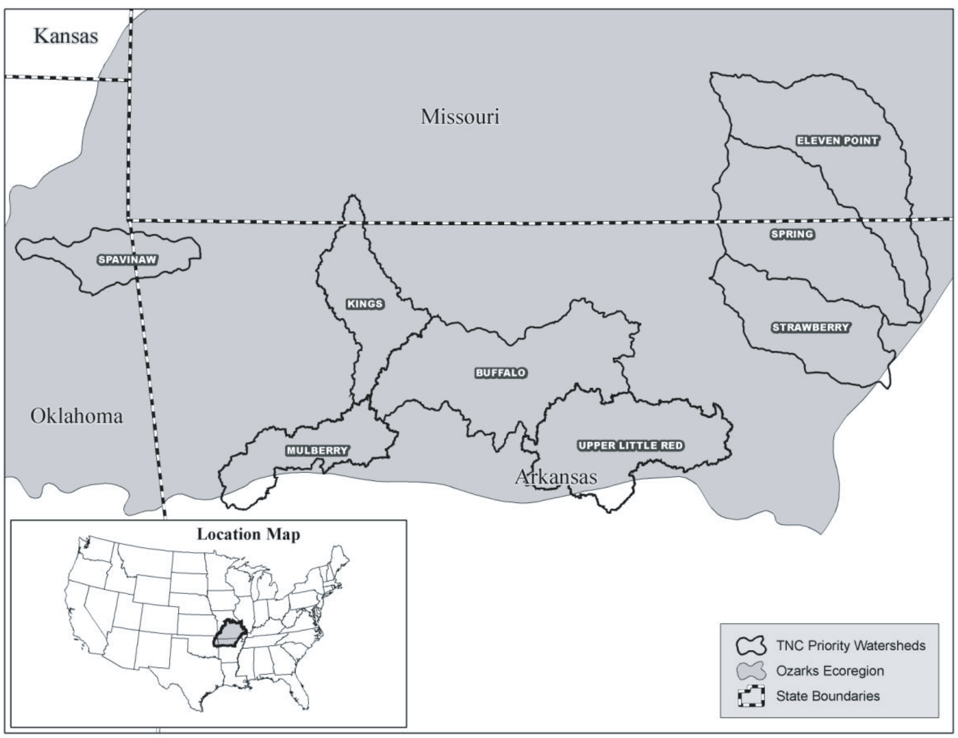

Figure 1. TNC priority watersheds in the Arkansas portion of the Ozarks ecoregion.

Partnerships

The Nature Conservancy has partnered with several agencies and organizations to address sedimentation of Ozark Rivers from unpaved roads including the US Forest Service (USFS), the Watershed Conservation Resource Center (WCRC), and several county agencies.

Road Inventory

The goal of an unpaved road inventory was to map the position and accessibility of roads, to document the sediment-related characteristics and conditions of the roads, and to document other road features such as stream crossings. Inventory generally occurred on all accessible, public unpaved roads outside of city limits. The road inventory methodology was initially developed by the USFS. TNC personnel were trained in the methodology by staff from the WCRC.

Equipment

The primary data collection tools for road inventory were Trimble GeoExplorer series units, which are Pocket PC Windows based field computers that are integrated with high-accuracy differential GPS receivers. Two models were used, including the GeoXT (sub-meter GPS accuracy) and the GeoXM (2 to 5 meter accuracy). These field computers have small color screens measuring about 6cm by 8cm (2” by 3in). Trimble TerraSync was the primary software used for mapping on the Trimble units. An external patch antenna was mounted to the top of the survey vehicle.

Recently, an advanced Vehicle Geographic Information System (VeGIS) setup was implemented for road inventory data collection. A Laptop PC was used to run TerraSync for data collection, with a GeoXT serving as an external GPS receiver. A 36cm (15”) touch screen LCD monitor was linked to the laptop and was mounted in the front passenger seat. See figure 2. This setup allowed for more efficient data collection and reduced mapper fatigue in comparison to using the small Trimble unit alone.

Figure 2. The VeGIS data collection system.

Ancillary GIS Database

The Inventory process was initiated by first developing a GIS database of relevant, existing, ancillary data layers such as road centerlines (from Arkansas Department of Highways and Transportation (AHTD) or USFS), stream channels (USGS NHD), jurisdictional boundaries (cities, counties, nation forest), topographic contours, and aerial photography background images. The database was used to identify total road miles and estimate the time it would take to complete the inventory. Plotted large-format maps were developed from the GIS database to aid in inventory planning and field navigation. Road layers were exported and placed into TerraSync as background files for aid in navigation.

GPS Data Dictionary

A data dictionary is a form within the Trimble TerraSync GPS software that allowed the mapper to enter descriptive attributes about a feature that is being mapped with the GPS. Custom data dictionaries were adopted from the USFS road inventory methodology, and were modified to incorporate new findings and techniques. The dictionaries were modified in the office using Trimble Pathfinder Office software, or in the field using TerraSync.

The data dictionary used for road inventory allows the user to collect a variety of features including line features representing road segments, and point features representing stream crossings, crossdrains, dips, wing ditches (lead-off ditches), road barriers, and others. See figure 3 below. Road segments were collected while the vehicle was moving at a logging interval of 15 meters (50’). Point features were collected with the vehicle stopped, the location of the point was averaged from at least five GPS positions.

Type	Feature Name
	Road Segment
	Wing ditch
	Crossdrains
	Bridge (Box) Xing
	Culvert Stream Xing
	Slab Stream Xing
	Ford Stream Xing
	Road Barrier
	Untraveled Rd Inters
	Surface Deformation
	Location of Concern
	Photograph
	Point_generic
	Line_generic
	Area_generic

Figure 3. Data dictionary feature types.

Road Segments. GPS line features representing road segments were usually collected at a speed of 8 to 30 km per hour (5 to 20 mph). Attributes of the road segment entered into the data dictionary include characteristics of the road surface, material, condition, ditch erosion and protection, and maintenance needs. The attributes collected and their default values are shown in figure 4. Attributes such as prism slope and ditch erosion depth were used in later sediment modeling efforts. If the mapper observed a change in the attributes of a road, the road feature was segmented in the GPS, and changes were applied to the new road segment in the attribute values of the data form. Road features with obvious sediment or maintenance issues were attributed with a moderate or high priority for later focus.

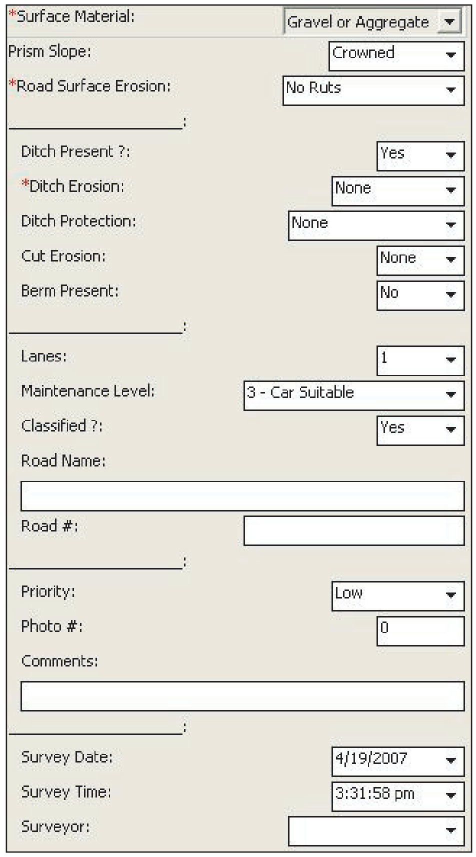
*Surface Material: Gravel or Aggregate
Prism Slope: Crowned
*Road Surface Erosion: No Ruts
Ditch Present ?: Yes
*Ditch Erosion: None
Ditch Protection: None
Cut Erosion: None
Berm Present: No
Lanes: 1
Maintenance Level: 3 - Car Suitable
Classified ?: Yes
Road Name:
Road #:
Priority: Low
Photo #: 0
Comments:
Survey Date: 4/19/2007
Survey Time: 3:31:58 pm
Surveyor:

Figure 4. Data form for road segments.

Water-Routing Features. Water-routing features of the road infrastructure were inventoried and represented as points. These features were characterized with the vehicle stopped, but the mapper did not generally exit the vehicle to collect these features. These features include wing ditches (also known as lead-off ditches), dips, bars, and crossdrains. These features route water off of the road surface, out of the road ditches, or from one side of the road to the other. The position function, and maintenance requirements of these features was attributed. See figures 5a and 5b below.

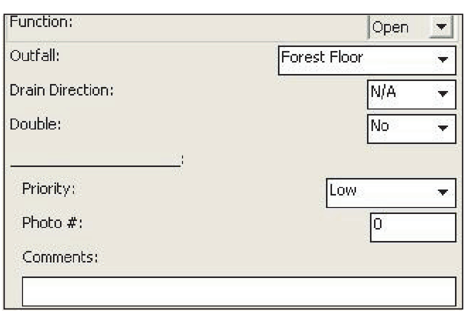
Function: Open
Outfall: Forest Floor
Drain Direction: N/A
Double: No
Priority: Low
Photo #: 0
Comments:

Figure 5a. Data form for wing ditches.

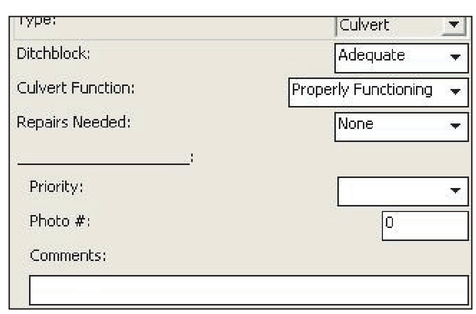
Type: Culvert
Ditchblock: Adequate
Culvert Function: Properly Functioning
Repairs Needed: None
Priority:
Photo #: 0
Comments:

Figure 5b. Data form for crossdrains.

Stream Crossings. All stream crossings that were encountered were inventoried by storing a point feature with appropriate attributes. Generally, the driver would exit the vehicle to inspect the crossing characteristics, and convey them verbally to the mapper, who would enter them into the GPS. Stream crossings were categorized into five major types: bridge, box culvert, pipe culvert, slab, and native ford. All five point types had similar attributes, and the data form for bridge (box) crossing is shown below in figure 6. The attributes included the general structural dimensions, the function and maintenance needs, and simple fish passage characteristics.

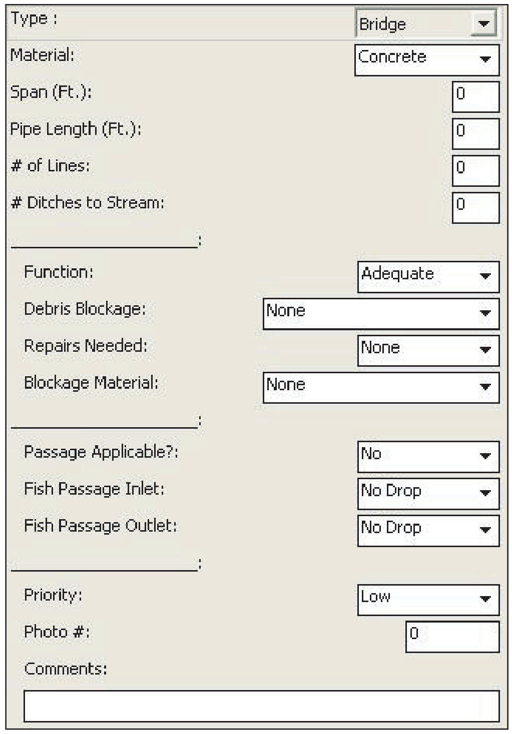
Type : Bridge
Material: Concrete
Span (Ft.): 0
Pipe Length (Ft.): 0
# of Lines: 0
Ditches to Stream: 0
Function: Adequate
Debris Blockage: None
Repairs Needed: None
Blockage Material: None
Passage Applicable?: No
Fish Passage Inlet: No Drop
Fish Passage Outlet: No Drop
Priority: Low
Photo #: 0
Comments:

Figure 6. Data form for bridge (box) crossings.

Surface Deformations. Areas with significant surface deformations such as potholes and washboard were characterized when encountered. These were documented from within the vehicle. Other problem areas, such as locations that needed improved road infrastructure were documented. Figure 7 shows a location which was documented because sediment production might be reduced if a crossdrain were installed.

Figure 7. A location where a cross drain is needed to reduce sediment production.

Road Barriers. Road barriers and untravelled road intersections were documented as point features. Road barriers included gates, cables, and other intentional barriers, as well as impassible roads such as ATV/OHV trails and dangerous stream crossings. Untravelled road intersections were stored at locations such as private road entrances. The purpose of storing these features was to document reasons for not traveling roads that were shown maps and GIS datasets.

GPS Data Processing

Once the field effort for a road inventory was completed, GPS data files were differentially corrected in Trimble Pathfinder Office software. Pathfinder searches the internet to find the closest available base station for differential correction of files. This process generally improves the spatial accuracy of the collected data to reduce errors to less that one meter on GeoXT units and two to five meters on the GeoXM units.

Because data were stored in many files (usually two files per day per mapper, with multiple mappers working at a time) the differentially corrected data files were merged into single files when possible in Pathfinder. The merged files were then exported to ESRI shapefile format in Pathfinder. A shapefile was created for each feature type. These shapefiles were then converted to feature classes in an ESRI geodatabase.

Various edits were made to the feature classes in ArcMap. Many errors occurred in the road feature representations when GPS signals were temporarily lost or weakened. Such disruptions would cause "zig-zagging" and other errors in the line representations. The lines representing two roads at a road intersection were often not snapped to each other. Point features collected in the field were often collected slightly away from the road line. Manual editing and topological rules were implemented to straighten erroneous road lines, snap roads at intersections, and snap point features to the road network. The edited geodatabase represented the completion of the road inventory process. Maps and spreadsheets of the various inventoried features were also generated.

Sediment Modeling

Sediment modeling tools were implemented to estimate the sediment production from inventoried roads reaching streams. A sub-set of the inventoried roads were randomly selected for sediment modeling. Field measurements were taken on these roads for input into the sediment model. The sediment model was run for sample road segment. Sediment model results were then extrapolated to all inventoried roads.

WEPP: Road

The Watershed Erosion Prediction Project Road (WEPP:Road) model (Elliot et al 1999) is a USFS internet-based interface to the Agricultural Research Service's (ARS) Water Erosion Prediction Project (WEPP) soil erosion model (Flanagan and Livingston 1995). The WEPP:Road model allows the user to predict runoff and sediment yield from a road segment into a nearby stream.

The data inputs for WEPP: Road include weather characteristics, soil texture, road design, road surface, traffic level, and dimensions of the road, fill and buffer. Data are entered into the interface and a report is produced that shows the estimated sediment yield from the road in units of tons/mile/year. It also estimates how much of that sediment will actually reach the stream. The data inputs for WEPP:Road are shown in the internet interface in figure 8. A WEPP: Road Batch tool is also available to run multiple road segments at a time.

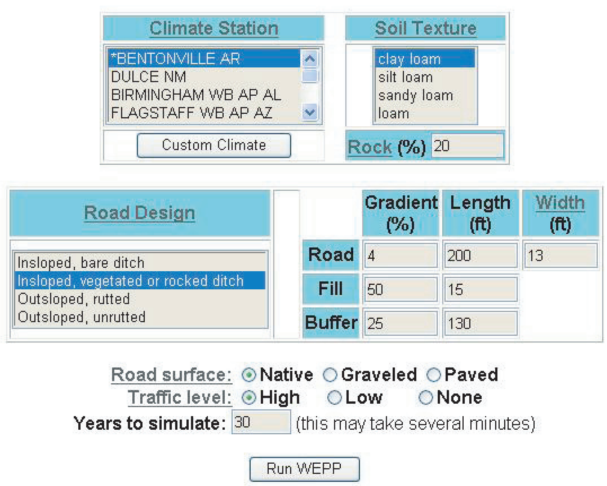

Figure 8. WEPP: Road Internet Interface

Sampling Design

In each of the three project areas, about 10% of the inventoried road segments were selected for WEPP: Road modeling. A stratified random sampling design was implemented that would capture the range of inventoried road types. USGS 10-meter and 30-meter digital elevation models (DEM) were used in ArcGIS to assign slope values to all inventoried road segments. SSURGO soils data were incorporated to account for the variations in soil texture across the study areas. Microsoft Excel was used to select random segments across a stratification of slope classes, soil types, road designs and road surface characteristics. The road segments selected for WEPP:Road modeling were plotted on large-format maps and loaded into the Trimble GPS units as background files for navigation to the sites.

Equipment

Field measurements of length, width, and slope were made on each road segment. Length was generally collected with a laser range finder. Width was generally collected with a logger's tape measure. Gradient was made with a clinometer. During early efforts, collected data were entered onto a paper data sheet. In 2006, a Trimble data dictionary was developed to collect and store WEPP:Road field data. The dictionary is shown in figure 9.

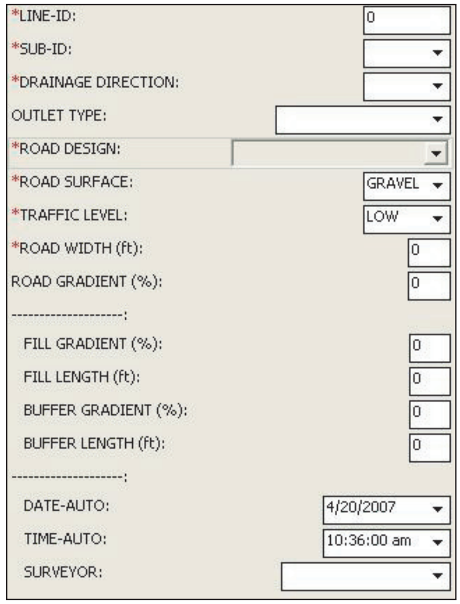
*LINE-ID: 0
*SUB-ID:
*DRAINAGE DIRECTION:
OUTLET TYPE:
*ROAD DESIGN:
*ROAD SURFACE: GRAVEL
*TRAFFIC LEVEL: LOW
*ROAD WIDTH (ft): 0
ROAD GRADIENT (%): 0
--------------------:
FILL GRADIENT (%): 0
FILL LENGTH (ft): 0
BUFFER GRADIENT (%): 0
BUFFER LENGTH (ft): 0
--------------------:
DATE-AUTO: 4/20/2007
TIME-AUTO: 10:36:00 am
SURVEYOR:

Figure 9. Data form for collecting WEPP: Road field data.

WEPP: Road Field Data Collection

WEPP: Road data were generally collected with teams of two or three people. Maps and GPS background files were used to navigate to the selected road segments for field measurements. For WEPP:Road modeling, a road segment was subdivided into individual hydrologic draining surfaces. For example, a sub-segment of a road might include the road from a local ridge down to a creek crossing where water is leaving the road. Another example would be a road sub-segment extending from a local topographic high to a wing ditch that routes water off the road. A third example is a crowned road. Each half of the road is measured as a distinct sub-segment because the water is exiting the road surface in different directions. See Figure 10 for a schematic example of road sub-segments.Measurements were taken for the road surface itself, and the fill material. Buffer characteristics of distance and gradient from the road to the stream were measured in ArcGIS using air photos, NHD streams, topographic streams, and roads data.

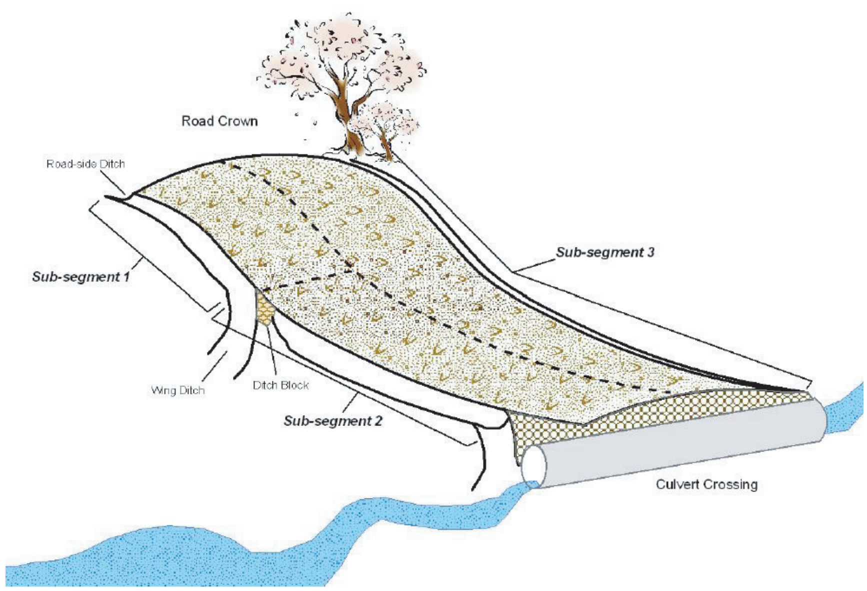

Figure 10. Schematic of road-sub-segments for WEPP: Road modeling.

WEPP: Road Data Processing and Modeling

Field data were transferred from paper datasheets or GPS files into Excel spreadsheets in the appropriate format for WEPP: Road Batch. As stated above, buffer characteristics were interpreted in GIS, and added to the Excel spreadsheet. The data were then run through the WEPP: Road Batch internet interface. WEPP: Road sediment yield results from modeled roads were extrapolated to all inventoried roads within the study areas, based on the road characteristics.

Implementation

Road Maintenance Workshops

The primary mechanism for implementing road maintenance improvements to date has been to hold training and demonstration workshops. USFS road engineers, County officials and road crews, other agency personnel, and private landowners were invited to attend these two-day workshops. The first day of the workshop typically included an introduction to unpaved roads as sediments sources, river hydrology and ecology. A presentation of the road inventory and sediment modeling process was also shown. This was fallowed by a discussion of best management practices (BMP) for road construction and maintenance for reducing sediment yields to streams. The second day of workshops generally involved field demonstrations for installing BMP structures and materials at priority sites that were identified through the road inventory process. Recently TNC has received grants to implement road maintenance BMPs in several locations in Arkansas.

Results

Road Inventory

From October 2004 to present (April 2007), over 1,200 kilometers of unpaved road and over 5,000 point features have been inventoried in three Ozark watersheds in Arkansas. Table 1 shows the total length of road and the total number of point features inventoried as of December 2006.

Table 1: Summary of Road Inventory through 2006

Watershed:	Strawberry		Kings	Mulberry	
Year:	2004	2006	2005	2006	Total
Road Segment					
Km Mapped	128	667	98	211	**1104**
Features					
Wing Ditch	379	1099	679	467	**2624**
Crossdrain	55	291	40	703	**1089**
Bridge (Box) Crossing	8	65	10	13	**96**
Culvert Crossing	60	223	42	161	**486**
Ford Crossing	14	106	17	50	**187**
Slab Crossing	13	94	8	3	**118**
Road Barrier		395		344	**739**
Untraveled Intersection		14		190	**204**
Total	**529**	**2287**	**796**	**1931**	**5543**

The geodatabase of edited features for the upper Mulberry River watershed was delivered to the USFS and is being used to update their enterprise road infrastructure database.

Sediment Modeling

WEPP: Road Analysis was completed for portions of the Strawberry River and Kings River watershed in 2005 (WCRC 2005a, WCRC 2005b). In the Strawberry study, which covered about 10% of the watershed, WEPP: Road data were collected on 18 km of roads. Sediment coefficients were generated for single and double lane roads with various ditch erosion depths. Table 2 shows the results of that study. Results are in tons/mile/year.

Table 2. WEPP: Road Results in the Strawberry Watershed Study Area.

Road Group (Road Width, Ditch Erosion)	Count	Length Surveyed (mi)	Erosion Coefficient (ton/mi/yr)	Sediment Export Coefficient leaving buffer (ton/mi/yr)	Sediment Export Coefficient entering stream (ton/mi/yr)
Double, >12"	2	0.8	48.5	6.9	2.4
Double, 1-12"	6	1.8	31.1	6	4.4
Double, none	1	0.1	12.2	0.6	0.6
Double Average	**9**		**32.8**	**5.6**	**3.5**
Single, >12"	6	1.2	83.6	35.1	35.1
Single, 1-12"	25	5.6	48.1	28.8	24.0
Single, none	11	1.9	26.2	11.6	10.5
Single Average	**42**		**47.4**	**25.2**	**22.1**
Average All Roads			**44.9**	**21.8**	**18.8**
Total	**51**	**11.4**			

The sediment coefficients were applied out to all unpaved roads in the inventory area.

Table 3: Estimated Yield from all Inventoried Roads Strawberry Watershed Study Area

Road Group (Road Width, Ditch Erosion)	Sediment Export Coefficient (ton/mi/yr)	Chandler Creek Watershed		Lick Branch Watershed		North Big Creek Watershed		Total Sediment Load (ton/yr)
		Miles	Sediment Load (ton/yr)	Miles	Sediment Load (ton/yr)	Miles	Sediment Load (ton/yr)	
Double, >12"	2.4	0.1	0.2	--	--	2.3	6	8
Double, 1-12"	4.4	1.7	7	0.5	2	10.3	45	67
Double, None	0.6	--	--	--	--	2.1	1	3
Single, >12"	35.1	0.5	18	0.2	6	5.6	196	227
Single, 1-12"	24	4.8	116	3.8	91	31.2	748	995
Single, none	10.5	0.2	3	0.1	1	17.0	179	199
Public Unpaved Total		**7**	**145**	**5**	**100**	**68**	**1175**	**1500**
Private Roads	22.1	5.3	117	1.7	38	56.9	1257	1412
Total		**13**	**262**	**6**	**137**	**125**	**2433**	**2912**

In the Strawberry River watershed, the remaining portion of the watershed has been inventoried. The WEPP:Road results shown above will be applied to all roads in the watershed in 2007.

In the Dry Fork sub-watershed of the Kings River, WEPP:Road data were collected on about 12 km of roads. The modeling and extrapolation results are presented in tables 4 and 5.

Table 4: WEPP: Road Results in the Kings Watershed Study Area

Road Group (Road Width, Ditch Erosion)	Count	Length Surveyed (mi)	Erosion Coefficient (ton/mi/yr)	Sediment Export Coefficient leaving buffer (ton/mi/yr)	Sediment Export Coefficient entering stream (ton/mi/yr)
Double Lane	2	1.2	25.1	9.2	9.2
Single Lane, No Ditch	6	0.4	19.5	14.6	14.6
Single Lane, Ditch Erosion > 12"	10	1.7	52.9	27.7	27.3
Single Lane, Ditch Erosion 1-12"	17	4.0	41.8	20.7	19.4
Single Lane, Ditch Erosion < 1"	4	0.5	17.7	4.7	4.7
Average All Roads			**37.8**	**19.6**	**18.9**
Total	**39**	**7.7**			

Table 5: Estimated Yield from all Inventoried Roads Kings Watershed Study Area

Road Group (Road Width, Ditch Erosion)	Sediment Export Coefficient (ton/mi/yr)	Miles	Total Sediment Load (ton/yr)
Double Lane	9.2	3.7	34
Single Lane, No Ditch	14.6	8.2	119
Single Lane, Ditch Erosion > 12"	27.3	11.5	314
Single Lane, Ditch Erosion 1-12"	19.4	30.5	590
Single Lane, Ditch Erosion < 1"	4.7	6.7	32
Public Unpaved Total			**1089**
Private Roads	16.5	43	710
Total			**1799**

WEPP: Road data were collected on about 19 km in the upper Mulberry River watershed. These data have been formatted for the WEPP:Road Batch, but have not yet been run.

Implementation

Two workshops have been held to date.

<u>Discussion</u>

The project presented here is a work in progress. The project has been a success to date, with a large volume of data collected. Large volumes of these data are currently being processed and analyzed. When completed, we will be able to compare results from all three mapped watersheds. The results above show similar erosion coefficients between the Mulberry and Kings watershed.

In current analysis, we are developing WEPP: Road coefficients that are specific to road gradients and soil types, as well as number of lanes and ditch characteristics. This will allow for more accurate estimates in applying coefficients to all inventoried roads.

We are currently mapping stream bank erosion on the upper Mulberry River using the Bank Erosion Hazard Index (BEHI). Once BEHI data are collected and analyzed, we will be able to identify sediment from roads and stream bank, which will account for the majority of sediment sources in the study area. We will then be able to prioritize sub-watersheds for sediment-reducing actions. Further prioritization can be accomplished by comparing species records and habitat iformation and focusing on critical areas for species of concern. Road maintenance priorities are already identified through inventory. Stream bank priorities will be identified through BEHI surveys.

Bigraphical Sketch: Ethan Inlander has been applying geospatial technologies and physical sciences to conservation issues for over 12 years. He received his undergraduate and master's degrees from the Department of Geography at University of California Santa Barbara, the #1 graduate geography program in the US (NRC, phds.org). His thesis topic was "An Integrated Methodology for the Mapping and Inventory of Riparian Areas in the Upper Santa Ynez Watershed, California ". Before joining The Nature Conservancy, Ethan applied geographical information systems technology to address multiple scale conservation problems in riparian and costal habitats of California. Since joining The Nature Conservancy, Ethan has applied these same techniques to identify and reduce impacts and habitat degradation to freshwater stream ecosystems, conduct local, watershed, and regional threat assessments of subterranean environments, and prioritize and implement karst, terrestrial, and riverine conservation actions at multiple scales.